IDENTIFICATION OF AGRICULTURALLY IMPORTANT MOLLUSCS TO THE U.S. AND OBSERVATIONS ON SELECT FLORIDA SPECIES

By

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To my wonderful husband Steve whose love and support helped me to complete this work. I also dedicate this work to my beautiful daughter Sidni who remains the sunshine in my life.

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UF	University of Florida: Florida Museum of Natural History
FMNH	Field Museum of Natural History
LMNA	Land Mollusca of North America
UMMZ	University of Michigan Museum of Zoology

Abstract of Dissertation Presented to the Graduate School
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IDENTIFICATION OF AGRICULTURALLY IMPORTANT MOLLUSCS TO THE U.S. AND OBSERVATIONS ON SELECT FLORIDA SPECIES

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Many terrestrial molluscs have been documented as important plant pests and contaminants. The Terrestrial Mollusc Tool consists of a non-dichotomous pictorial key, fact sheets and dissection tutorials to help the user to distinguish between closely related species, to aid in the rapid identification of terrestrial gastropods of agricultural, trade and ecological concern.

Laboratory evaluation of the consumption potential and life history traits for *Deroceras reticulatum* and *D. laeve* were conducted at two constant temperatures and two population densities. There was no significant difference in the mean quantity of lettuce consumed by *D. reticulatum* and *D. laeve*; but, *D. laeve* consumed more at 21°C than at 14°C. The mean quantity of lettuce consumed by solitary individuals of both species was significantly greater when compared to respective individuals held in groups of five at both temperatures.

Thirty-seven plants commonly grown in Florida were evaluated for susceptibility to herbivory from four mollusc species using choice and no-choice tests. *Zachrysia provisoria* was the most polyphagous species consuming 84% of test plants, *Deroceras*

reticulatum consumed 11%, *Deroceras laeve* and *Bradybaena similaris* consumed 8%. Annuals were generally more susceptible to herbivory than perennials.

Laboratory evaluation of the feeding behavior and life history traits of *Philomycus carolinianus* indicated that weight gain followed a sigmoidal curve. The mean time to first oviposition was used to separate individuals into four statistically significant groups, indicating possible genetic polymorphism. This species is capable of self-fertilization. Paired individuals produced larger clutches of eggs and oviposited less frequently than solitary individuals. *Philomycus carolinianus* eggs developed at 14, 17, 21 and 25°C ; however, no hatching occurred at 10 and 29°C. Synthetic (gypsy moth, spruce budworm, rabbit pellet) diets and natural (white mushroom, lettuce, carrot) materials were evaluated as potential diets for rearing *P. carolinianus*. The gypsy moth diet produced the best combination of favorable attributes. *Philomycus carolinianus* displayed clear feeding preference for select mushroom species but did not consume higher plants, except lettuce.

Revision of the genus *Philomycus* indicated that the genus is monophyletic and consists of at least five species: *P. carolinianus, P. togatus, P. venustus, P. flexuolaris* and *P. sellatus*.

CHAPTER 1
OVERVIEW

Many terrestrial snails and slugs (Mollusca: Gastropoda) are considered significant agricultural and ecological pests worldwide (Iglesias and Speiser 2001; South 1992). Pestiferous terrestrial gastropods are of concern globally as they are capable of inflicting considerable economic damage to field crops (e.g., sugar beet, maize, soybean and cereals), vegetables (e.g., lettuce, cabbage), ornamentals (e.g., hosta, impatiens, gardenias and marigold), fruits (e.g., strawberries, banana, and grapes), and forestry plants (Hata et al. 1997). Damage is mainly caused by direct consumption of plant material (leaves, fruits and flowers); however, the quality of the produce may also be affected by the feces and slime often left behind by the animal or from contamination by the animal itself (Iglesias et al. 2001).

The global trade in agricultural produce is guided by several conventional practices formulated to minimize the potential dispersal of pest molluscs and other regulated species (McCullough et al. 2006). As a general rule, many countries that import agricultural produce frequently require phyto-sanitary certificates from their trade counterparts indicating that shipments are free of molluscs and their eggs (Hata et al. 1997). Contaminated shipments are frequently rejected, destroyed or subjected to costly treatments (Cowie et al. 2008). These stringent but necessary screening measures are often effective, and are integral to protecting the United States of America’s agricultural trade industry valued at approximate $34 billion (2010) (USDA-ERS 2011). Unfortunately, the inherent time-delays often associated with the implementation of these measures may be perceived as an impediment to trade, and research to investigate novel preclusion and treatment options continues (McCullough et al. 2006).

Many snails and slugs are highly adaptable and may rapidly achieve pest status in many cropping systems. Several biological and chemical control measures have been developed for the management of pestiferous molluscs but the efficacy of available control options is often highly variable (Iglesias and Speiser 2001). Molluscicides are most often formulated in the form of pellets, and typically, the active ingredient is metaldehyde, carbamate or iron phosphate (Speiser and Kistler 2002; Thompson et al. 2005). Metaldehyde and carbamate-based molluscicides are potentially toxic to non-target animals (wildlife, pets and beneficial invertebrates) and degrade quickly, (Thompson et al. 2005) whereas iron phosphate is very costly to use because it is required at higher rates per area to achieve similar control as the former chemicals (Speiser and Kistler 2002).

The most effective strategies for the management of pestiferous molluscs often employ a combination of measures aimed at preventing introductions or re-introductions into new areas. Preventative measures include early detection of eggs or live specimens in cargo, quarantine and treatments to eradicate the pest species. The Terrestrial Mollusc Tool was developed to facilitate the early detection of terrestrial gastropods of regulatory concern at US ports of entry. This tool provides background information on the biology and ecology of terrestrial snails and slugs and includes a pictorial key for the identification of both native and exotic pest species.

Terrestrial snails and slugs have consistently been recorded as agricultural pests worldwide (Nash et al. 2007); however, the information reported in the literature for this group primarily addresses the monetary loss or the qualitative impact of feeding damage. One of the primary goals of this work is to quantify the potential feeding damage of *Deroceras reticulatum* and *D. laeve* under laboratory conditions.

Historically, terrestrial snails and slugs have been of little agricultural significance in Florida as compared to insect pests. Hence, the host range of several common snails and slugs (native and non-native) in Florida is poorly addressed in the literature. This work evaluated the potential host range of the pest species, *Bradybaena similaris*, *Zachrysia provisoria*, *Deroceras reticulatum* and *D. laeve,* under laboratory conditions. Several fruit, vegetable and ornamental species commonly grown in Florida were evaluated in choice and no-choice tests and an acceptability index calculated.

The reputation and profile of pestiferous gastropods often overshadow the ecological importance of less conspicuous non-pest species. It is, however, important to gain an understanding of the biology and provide insight into the ecological role of native snail and slug species in the environment. This work investigated the biology and ecology of the native species *Philomycus carolinianus* under laboratory conditions. Additionally, the taxonomy of the genus *Philomycus* was evaluated using morphological and molecular techniques to clarify inconsistencies in the nomenclature of the species classified into this genus.

CHAPTER 2
TERRESTRIAL MOLLUSC TOOL

Introduction

Lucid tools are computer-based systems designed to facilitate rapid and accurate visual identification of entities. This tool always includes an interactive key and may also include additional features such as fact sheets and external links to other resources that complement the key and may be useful to the user for making appropriate selections.

In recent years, biologists have been incorporating more computer-based technologies into species identification tools (Zhang et al. 2009; Edwards and Morse 1995). Computer-based interactive keys are an especially useful tool for identification work, as they allow users to select multiple character options at any point, as opposed to dichotomous keys that only allow for a single character selection to proceed systematically through the key (Zhang et al. 2008; Shayler and Siver 2006). This feature of interactive keys alleviates the need to select characters that are ambiguous or cannot be seen by the observer hence reducing potential misidentifications (Bell, 2002). Interactive keys also allow the incorporation of images such as photographs and drawings that emphasize characteristics and distinguishing features. Within these, the user selects appropriate representative images that match features of the specimen in question. Prior decisions in the key, including image selection by the user determines the next suite of characters and/or image options presented to the user. Images not appropriately representative of the specimen in question are sequentially eliminated until a final selection is made.

The Lucid software package is the most popular interactive key available. It was developed by the Center for Biological Information Technology, University of

Queensland. The lucid software is written in Java code, thus enabling it to function on any modern operating system (e.g., Windows ®, Macintosh ®, Unix ®, Linux ®, etc.). The lucid 3.4 system has two major components: a builder and a player (Shayler and Siver 2006). The builder component of the system allows the author to construct a lucid key matrix based on character states and features deemed useful by the author. This key matrix is then exported (deployed) into the player format, so that it can be viewed and used by an end-user. Any modifications made to the builder must be saved and deployed into the player format. The key can be deployed either in a CD format or it can be accessed via the World Wide Web (Shayler and Siver 2006).

The Terrestrial Molluscs Tool was specifically developed to assist in the identification of adult terrestrial slugs and snails of agricultural importance. The tool includes species of quarantine significance as well as invasive and contaminant mollusc species commonly intercepted at U.S. ports of entry. This lucid-based identification tool specifically targets federal, state and other agencies or organizations within the U.S. that are concerned with the detection and identification of terrestrial molluscs of agricultural, ecological and trade significance. This tool includes 33 families and 128 species. This resource includes an interactive identification key, comparison chart, fact sheets, biological and ecological notes, a dissection tutorial, a glossary of commonly used terms, and a list of useful links and references.

Materials and Methods

In order to initiate the construction of the lucid tool, the scope of the tool was first defined. This included determining the potential end-users and deciphering what information would be most useful to them.

A list of taxa (snails and slugs) was generated based on pest species reported in Barker 2002, Cowie et al. 2009, and Godan 1983 as well as port of entry interception data provided by the United States Department of Agriculture's Animal and Plant Health Inspection Service's Plant Protection and Quarantine (USDA-APHIS-PPQ) and the Florida Department of Agriculture and Consumer Service's Division of Plant Industry (FDACS-DPI). Species were selected for inclusion in the tool using the following criteria: (a) all species documented as significant agricultural and ecological pest, (b) all contaminant species documented to materially affect the value and quality of produce, and (c) occasional contaminants or hitchhiker species intercepted at U.S.A. ports of entry a minimum of 7 times per year. Given the recognized time and resource constraints of the project approximately 200 species were considered a reasonable number for inclusion in the tool. Consequently, numerous occasional contaminant species that were intercepted fewer than 7 times per year were excluded.

General information was then gathered on the targeted taxa from different media and literature sources. This included biology, ecology, and parameters needed for the identification of members of this group.

Supporting Materials

The following pages were created as supporting materials for the lucid key. Each page was generated in an html format to be hosted on the lucid tool website.

Home page: This page displays a listing of the components of the lucid tool and provides a link to each component. The format of the home page serves as a template for the general outline of subsequent pages.

About the lucid tool: This page gives a general introduction to the lucid tool. It provides the rationale behind the construction of the tool, clearly defines the tool's scope and gives a general outline of the tool's components. The source of funding and collaborators are also acknowledged in this section.

How to use the lucid key: The "how to use the lucid key" section of the lucid tool provides an in-depth review of the components of the lucid key. This section uses screen shots of various windows of the lucid player to provide a step-by-step guide through the navigation process. Important distinguishing features available to the end-user as selection options are highlighted in each screen shot. Also included in this section of the tool is a list of the equipment that may be useful in optimizing the utility of the key. Additionally, the scope and limitations of the key are addressed in this section of the tool, and the system requirements are briefly mentioned.

Terrestrial gastropods: biology and ecology: The biology and ecology section of the lucid tool gives a brief overview of the morphological, behavioral, biological, and ecological characteristics of terrestrial molluscs.

How to identify terrestrial gastropods: This section of the tool is geared toward explaining and demonstrating the characteristic features of snails and slugs, and how they can be used for identification purposes, because terrestrial gastropods are difficult to identify, particularly without an understanding of the morphology of this group.

Fact sheets: This section of the tool is comprised an alphabetical listing of the taxa included in the tool. Each taxon is linked to its own fact sheet, which gives a brief description of the taxon, its nomenclature, ecological significance, synonyms and any diagnostic feature (s) that may be useful in its identification.

Snail and slug dissection tutorial: Many terrestrial gastropods cannot be positively identified without dissection and identification of specific features of the genitalia. A dissection tutorial is included in the tool and consists of written instructions and step-by-step annotated pictorial slide shows for both snails and slugs.

Glossary: This section includes an alphabetical list of terms that are unique to malacology or are not commonly used. Each definition was uniquely created with the assistance of multiple malacological references.

References: The references include a list of resources used as references for the construction of the tool.

Acknowledgments: This includes a list of all the parties involved either directly or indirectly in the successful completion of the lucid tool.

Information and links: This is a compilation of additional reference material that may be useful to the end-user.

Copyright, citation and disclaimers: This section of the tool is a requirement of the USDA-APHIS-PPQ. It explains the legal ramifications of any re-use, misuse or modifications of the content of the lucid tool.

Lucid 3.4 system requirements: This portion of the lucid tool informs the end-user of the computer software and hardware requirements that are essential for proper functioning of the lucid key.

Key Construction

The author compiled a list of discriminatory characters and character states for each taxon included in the lucid key. Each taxon was then scored based on the state of each characteristic used. The computer program (lucid builder) then generated a matrix based on this input. The end-user interacts with the matrix through an interface in the form of a selection window containing important characteristic features for each taxon. The end-user is able to successfully identify a particular snail or slug, through a process of sequential elimination of characters that are not pertinent to the specimen in question.

Results

The website hosting the material is as follows: http://idtools.org/id/mollusc/

Object 1-1. The Terrestrial Mollusc Tool website

A flow chart of the identification process using a lucid key can be seen in Figure 2-1. A list of species the species included in the Terrestrial Mollusc Tool is included in Appendix A. The factsheets, and supporting materials that were created as a part of the lucid tool are included in Appendix B.

Discussion

The Terrestrial Mollusc Tool was developed primarily to increase the efficiency of identification of terrestrial molluscs of regulatory significance by USDA-APHIS-PPQ. Terrestrial molluscs intercepted during routine cargo inspections would typically be sent offsite for official identification by an identifier appointed by the USDA-APHIS-PPQ-National Identification Service. The “turn around time” associated with this process often impedes the timely movement of cargo through the ports as consignments of perishable items may be held for extended periods pending official identification. The Terrestrial Mollusc Tool was developed to expedite preliminary identification of terrestrial molluscs at the ports of entry and to improve the efficiency of the current decision-making process.

The construction of the pictorial key component of the Terrestrial Mollusc Tool required the procurement of high quality photographs and diagrams that adequately illustrate diagnostic characters of the taxa included in the key. The author sought and received permission from the copyright holders to use several of the photographs included in the key. However, in many cases photographs of species were nonexistent or those that were available were either of poor quality or did not display diagnostic characters of interest. Photographs of unacceptable quality were substituted with appropriate drawings.

The limited number of diagnostic morphological characters available in terrestrial molluscs proved to be a significant impediment to the development of the lucid key. The pictorial key is comprised of both quantitative (e.g., length, number of whorls) and qualitative (e.g., color and texture) characters. The author attempted to score a greater number of quantitative characters for each taxon in order to reduce errors due to end-user perception of qualitative characters.

The fact sheet component of the Terrestrial Mollusc Tool was included to inform the end-user of the agricultural significance or potential pest status of each taxon included in the key. There is however, a dearth of information in the literature concerning the ecology and life history traits of several species included in the Terrestrial Mollusc Tool. Additionally, several species are listed in the literature by numerous synonyms due to repeated taxonomic reclassification. The process of resolving the currently accepted classification with older synonyms proved to be very time consuming and was a major impediment in the construction of this tool. For clarity and consistency, the taxonomic nomenclature utilized by the USDA-APHIS-PPQ-NIS's malacology representative was adopted in the construction of the Terrestrial Mollusc Tool. A list of synonyms was recorded for each species in their respective fact sheets to assist the end-user.

The Terrestrial Mollusc Tool was constructed to include the terrestrial mollusc species that are commonly intercepted and of current regulatory concern to the U.S.A. and is not comprehensive for species that may be encountered in the U.S.A.

The pictorial key component of the Terrestrial Mollusc Tool requires a suite of diagnostic characters that may only be present in adults. Additionally, adult albino morphs (white body and shells) and the weathered shells of snails may lack adequate morphological characters for an accurate diagnosis. The Terrestrial Mollusc Tool will therefore be of limited utility to the end-user when juveniles and albino morphs are in question.

A few taxa will not be able to be identified below the family level when using the pictorial key in the Terrestrial Mollusc Tool. This is true especially for the families Veronicellidae and Succineidae. The major reason for this is the lack of diagnostic morphological characters and the variability of members of these groups. Molecular techniques provide useful alternative for the identification of members of these families (Holland and Cowie 2007; Gomes et al. 2010). This inadequacy of the key is, however, mitigated by the fact that most if not all the members of these problematic groups are pestiferous and as such are regulated at the family level. The same is true for several species complexes (e.g., *Arion hortensis* group, *A. ater* group) included in the tool.

There are a number of malacological terms that were not included in the Terrestrial Mollusc Tool because the targeted end-users are non-experts. The author attempted to use commonly used language as opposed to technical jargon where possible. Additionally, several diagnostic but subjective and/or inconspicuous characters traditionally emphasized in published dichotomous keys were excluded from the Terrestrial Mollusc Tool in an attempt to reduce subjectivity.

The utility of the Terrestrial Mollusc Tool can be improved over time as it offers the flexibility for continuous modifications and the addition of new taxa of interest.

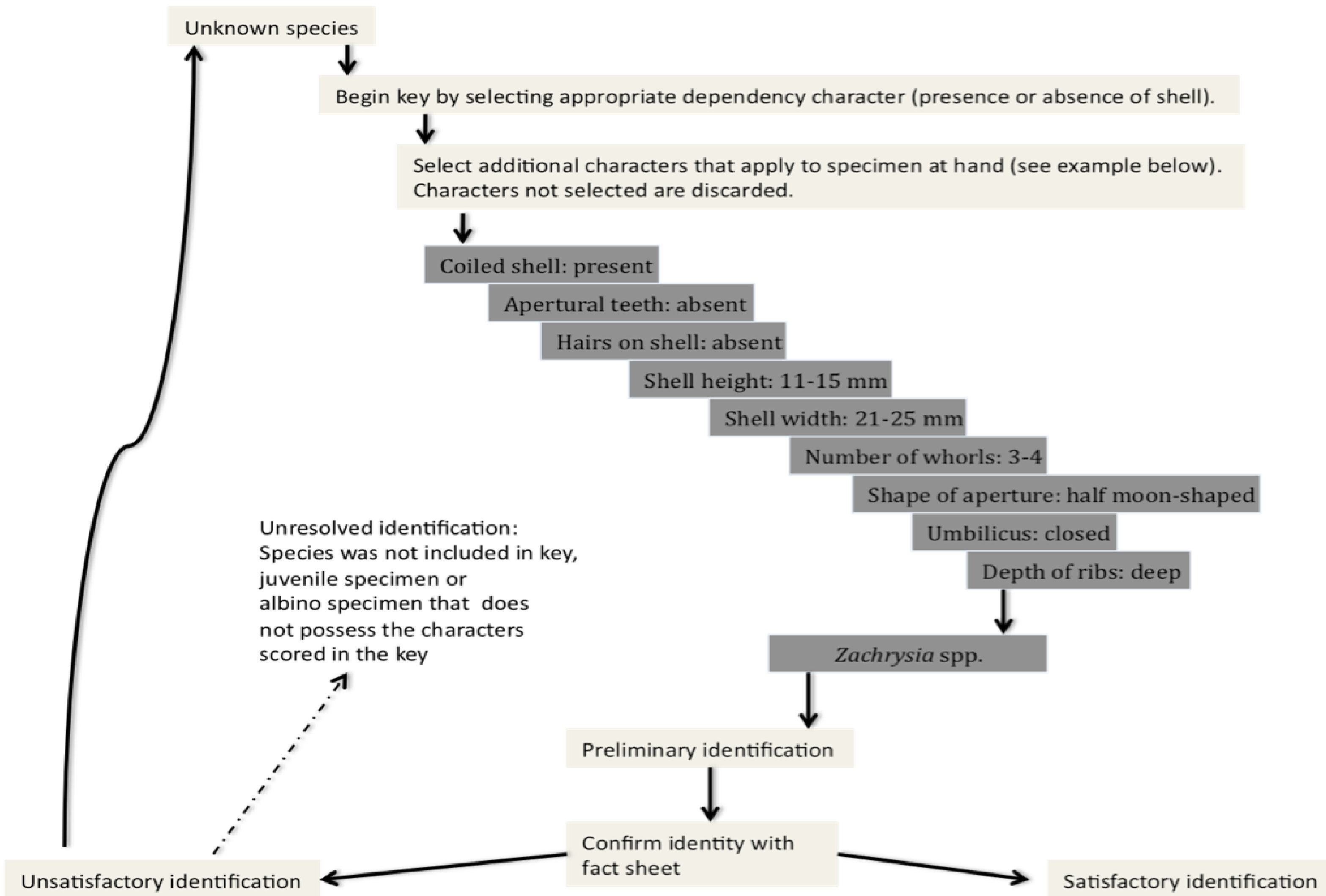

Figure 2-1. Lucid key identification process using *Zachrysia* sp. as an example.

CHAPTER 3
THE CONSUMPTION PATTERN OF *DEROCERAS RETICULATUM* AND *D. LAEVE* (AGRIOLIMACIDAE) AT TWO TEMPERATURES AND TWO DENSITIES

Introduction

Terrestrial slugs consistently have been reported as agricultural and horticultural pests (Gebauer 2002; Mair and Port 2002; Pickett and Stephenson 1980; Schley and Bees 2003) in temperate regions worldwide (Brooks et al. 2006; Cook et al. 1996; Glen et al. 1993; Kozłowski and Kozłowska 2008; Moens and Glen 2002; Port and Port 1986; South 1992). Slugs in the genus *Deroceras* (Family: Agriolimacidae) are plant pests globally (Grimm et al. 2009).

Deroceras reticulatum (Müller, 1774), the grey field slug, is thought to have originated in the Palearctic ecozone (Speiser et al. 2001), but has been inadvertently introduced to other continents, aided primarily by trade (Howlett et al. 2008) and the movement of humans across the world (Speiser et al. 2001). *Deroceras reticulatum* is now considered among the most cosmopolitan slug species recorded to date (Nash et al. 2007; Speiser et al. 2001), occurring in temperate regions (Barker 1991) of Europe, Asia, Australia, New Zealand and North and South America (South 1992; Willis et al. 2006; Yildirim and Kebapçi 2004). Over the years, repeated introductions of this species have not lead to established populations in Florida. *D. reticulatum* flourishes in disturbed habitats such as gardens, grasslands, hedgerows, greenhouses and agricultural fields (Barker 1991; Godan 1983; Howlett et al. 2008; Lipa and Smits 1999; Willis et al. 2006). *D. reticulatum* is an important agricultural pest (Barratt et al. 1994; Ester and Nijenstein 1995; Frank 1998; Hammond et al. 1996; Keller et al. 1999; Pilsbry 1948). According to Speiser et al. (2001), this slug is considered the most economically damaging slug pest species, and as such, the biology and behavior of this species is well documented in the literature (Faberi et al. 2006).

Deroceras laeve (Müller, 1774), the marsh slug, is native to North America (Getz 1959), and other areas of the holarctic ecozone, including Europe and Asia. This slug species has colonized a wide range of climatic zones in the Americas, occurring from Alaska to central Florida in the U.S. and throughout Central America (Faberi et al. 2006; Hubricht 1985; Jordaens et al. 2006; Pilsbry 1948; Wiktor 2000). *D. laeve* has been introduced into South America and successfully coexists with *Deroceras reticulatum* in temperate zones (Getz 1959). According to Barker (2002), *Deroceras laeve* is a recognized pest of pastures in North America and Faberi et al. (2006) also reports it to be a crop pest wherever conservation tillage is practiced in southeastern regions of Buenos Aires Province, Argentina. However, very little has been documented on the comparative pest status of *D. laeve* (Faberi et al. 2006).

This study was undertaken to assess the influence of two constant temperatures and two slug densities on the time to reproductive maturity and consumption pattern of *Deroceras reticulatum* and *Deroceras laeve*.

Materials and Methods

Field-collected slugs were used to establish laboratory populations of *Deroceras reticulatum* and *Deroceras laeve*. *D. reticulatum*, an invasive agricultural pest, was collected from Rockland, Maine. The native *D. laeve* was collected in Gainesville, Florida.

Two-week-old juveniles of each species were obtained from these colonies for use in this experiment. Twenty-five slugs of each species were individually placed into plastic cylindrical containers (9.5 cm diam. X 4.5 cm high) that were partially lined with moistened, crumpled paper towel, and vented to allow for air circulation while maintaining high humidity levels. The slugs were fed leaf discs of Romaine lettuce (*Lactuca sativa* L. var. longifolia), measuring approximately 11.4 cm^2. The weight of each leaf disc and the slug were recorded using an analytical balance (Mettler Toledo-AL104, Fisher Scientific, Denver, CO) prior to being placed inside the plastic container. The plastic containers were then placed into an incubator (Percival, Boone, IA) at 14 or 21 ± 1°C, with a 12h light and dark period (LD: 12/12 h) for the duration of the experiment. Thereafter, at 3-day intervals, each slug was weighed and the remaining lettuce weighed and replaced with fresh lettuce.

In addition, 20 replicate groups of 5 two-week-old juveniles were treated similarly. As the experiment progressed, the numbers of leaf discs were adjusted so that adequate food was always available to the slugs. Twenty leaf discs were maintained in the same manner but without slugs (control) thereby allowing for assessing lettuce weight change, and accurate estimation of consumption. The experiment was terminated when there was a decline in the amount of lettuce consumed by the slugs, as this likely indicated senescence.

Three-way analyses of variance (ANOVA) were used to determine if there were any significant differences in development and consumption for *Deroceras reticulatum* and *D. laeve* at reproductive maturity. The following variables were evaluated: species, temperature, density and any possible interactions. Any resulting significant differences were further investigated using two-sample t-tests. All statistical analyses were done using Statistical Analysis System software® (SAS Institute, Inc. 2008). Means ± SE are presented where applicable.

The statistical relationship between the area of lettuce (cm^2) and the corresponding weight in milligrams was established using a regression analysis. This should provide a visual estimate of the quantity of leaf tissue consumed. This was assessed by using fifteen cork borers of different sizes (number: 1 (0.13 cm^2) to 15 (4.15 cm^2)) to randomly excise 20 leaf discs each from fresh lettuce leaf. The 20 leaf discs from each respective cork borer were immediately weighed and mean values calculated. A regression analysis was conducted to determine the relationship between leaf area and weight and to facilitate accurate conversion of data.

Results

Both *Deroceras reticulatum* and *D. laeve* gained weight as they matured; however, *D. reticulatum* weighed (29.4 ± 2.6 mg) twice (F = 14.92; df = 86; P = 0.0002) as much as *D. laeve* (12.2 ± 2.2 mg) at first oviposition. Temperature (14°C and 21°C) influenced weight gain in each slug species (F = 4.09; df = 86; P = 0.0462). *D. laeve* gained approximately five times as much weight when reared at 21°C than at 14°C (t = -4.47; df = 43; P <0.0001) whereas, *D. reticulatum* gained weight similarly at both temperatures. For both slug species, there were no difference between the weight of animals reared as solitary individuals and those reared in groups (F = 0.17; df = 86; P = 0.6789) (Figure 3-1 and Figure 3-2).

Despite their larger size, *Deroceras reticulatum* did not consume significantly (F = 0.13; df = 85; P = 0.7181) more plant material than *D. laeve*. However, temperature (F = 16.49; df = 85; P = 0.0001) significantly influenced the amount of lettuce consumed by at least one species. The quantity of lettuce consumed by *D. reticulatum* at both temperatures [21°C (26.3 ± 5.5 mg) and 14°C (25.7 ± 3.1 mg)] was not different from each other (*t* = -0.11; df = 46; *P* = 0.9162), whereas *D. laeve* consumed more lettuce (*t* = -4.47; df = 43; *P* < 0.0001) at 21°C (37.5 ± 8 mg) than at 14°C (7.6 ± 1.1 mg).

Density (*F* = 27.77; df = 85; *P* < 0.0001) influenced the amount of lettuce consumed by at least one species. *D. reticulatum* consumed similar quantities (*t* = -0.88; df = 46; *P* = 0.3827) of lettuce when reared as solitary (27.6 ± 3.5 mg) individuals and as groups of five (22.6 ± 4.1 mg). *D. laeve* consumed more lettuce per slug (*t* = -2.46; df = 43; *P* = 0.0179), when reared as individuals (26.3 ± 5.7 mg) than in groups of five (7.3 ± 1.4 mg) (Figure 3-3 and Figure 3-4).

There was a strong correlation (Pearson correlation coefficient = 0.99088) (*F* = 702.62, df = 13; *P* < 0.0001) between lettuce leaf discs weight and area (Y= 46.217 X – 6.6718; R^2 = 0.9818), allowing for accurate estimation of leaf area consumed based on weight loss.

Discussion

The primary goal of this study was to assess the comparative damage potential of *Deroceras reticulatum* and *D. laeve.* Secondly, the effects of density and temperature on the consumption pattern and weight gain of *D. laeve* and *D. reticulatum* from juveniles to the adult stage also were investigated. Temperature had minimal effects and density did not directly affect the overall weight of each slug species.

The quantity of host material (lettuce) consumed by both species to achieve maturity was also compared to assess the relative damage potential for each species. As expected, groups of slugs consumed more lettuce than solitary individuals. However, the mean quantity of lettuce consumed by solitary specimens of *D. reticulatum* and *D. laeve* was significantly greater than that consumed by individuals reared in groups of five, at both temperatures. There was not a simple additive relationship between the quantity of host material consumed by a solitary individuals and groups, suggesting competitive interference in groups of slugs. This is a common result of group feeding.

Evaluation of lettuce consumption between species showed that there was no significant difference between the quantity of host material consumed by *Deroceras reticulatum* and *Deroceras laeve.* This is surprising considering the larger size attained by *D. reticulatum.* This raises the question of why *D. reticulatum* has consistently been reported to be an agricultural pest (Airey 1987; Brooks et al. 2003; Brooks et al. 2006; Cook et al. 1996; Cook et al. 2000; Frank and Barone 1999; Howlett et al. 2008; Keller et al. 1999; Mair and Port 2002; Pakarinen 1992; Pickett and Stephenson 1980; Schley and Bees 2003; Speiser et al. 2001; Wareing 1993; Wiktor 2000; Willis et al. 2006), whereas *D. laeve* is only reported as an occasional pest, usually where reduced tillage is practiced, or in small gardens or in greenhouses (Dankowska 1996; Faberi et al. 2006; Fox and Landis 1973; Wiktor 2000). One such explanation could be the disparity between the reproductive potential of each species.

While conducting this study it was observed that laboratory colonies of *D. reticulatum* produced larger clutch sizes, and laid eggs more frequent than *D. laeve*. These laboratory populations of *D. reticulatum* produced clutches ranging in size from 35-72 eggs per clutch. Similar observations were noted by Baur (1994) where a clutch size of 100 eggs was reported, whereas Karlin and Bacon (1961) reported 73 eggs per clutch. On the other hand, *D. laeve* reared under the same laboratory conditions laid five to six eggs per clutch. Faberi et al. (2006) reported that on average, five eggs were produced at 12°C and approximately seven eggs at 20°C. However, in another study conducted by Karlin and Bacon (1961), it was reported that the clutch size of *D. laeve* ranges from one to 33 eggs per clutch and Dankowska (1996) reported 2-16 eggs per clutch. The potential ten-fold difference in the number of eggs per clutch for *D. reticulatum* when compared to *D. laeve* suggests that the population of the former could attain higher levels and cause greater damage to plants. Hence, it is likely that reproductive output would explain why *D. reticulatum* is reported more frequently as an economically damaging species.

Additionally, the differences in the treatment of both species in the literature could be attributed to cannibalism by *Deroceras laeve*. The occurrence of cannibalism is not rare among herbivores. Immobile stages are often preyed upon, and unhatched eggs are especially easy prey. Shen (1995) demonstrated that cannibalism occurs commonly in *D. laeve*, where the primary means of such an occurrence was through the consumption of unhatched eggs by juveniles. Shen (1995) also observed cannibalism in all life stages, wherein adults and juvenile of *D. laeve* consumed adults and juveniles of conspecifics. Cannibalism in *D. laeve* could play a role in restricting the growth of populations and as such could help to explain the lowered incidence of field damaged documented for this species.

Fox and Landis (1973) demonstrated experimentally that *Deroceras laeve* has an omnivorous feeding behavior. The predatory nature of this *D. laeve* was documented, wherein this species was noted to consume an average of 8.5 green peach aphids [*Myzus persicae* (Sulzer)] per slug per day. The authors were able to demonstrate that the aphids were not consumed accidentally, and further demonstrated that *D. laeve* consumed the eggs of lepidopterans, including: zebra caterpillar [*Ceramica picta* (Harris)], alfalfa looper [*Autographa californica* (Speyer)] and the celery looper

[*Anagrapha falcifera* (Kirby)]. The results of Fox and Landis' (1973) experiment suggest that *D. laeve* may persist at high numbers in the field but not necessarily consume agriculturally important crops as their diet may be supplemented by non-plant sources.

Several authors have reported *Deroceras reticulatum* to be a pest in disturbed habitats (Barker 1991; Rathcke 1985), while *D. laeve* is a pest of areas where conservation tillage is commonly practiced. Disturbed sites are often not able to support slug populations due to the inability of the area to maintain enough humidity to support slug activity. It appears that *D. reticulatum* has been able to adapt to this type of area by reproducing more frequently and producing larger numbers of eggs. Also, we observed that *D. reticulatum* developed significantly faster than *D. laeve* at cooler temperatures. Assuming that the observation made under experimental conditions hold true in field settings, the combination of characters displayed by *D. reticulatum* could account for this species' ability to respond more quickly and take advantage of changing conditions in disturbed habitats.

Faberi et al. (2006) conducted an experiment in Argentina wherein *Deroceras laeve* collected locally from Buenos Aires Province was reared at 12 and 20°C. The results indicated that slugs held at the lower temperature (12°C) weighed twice as much as slugs held at 20°C at the end of the study. Those results are inconsistent with results obtained from this study. In this study it was observed that *D. laeve* developed at a significantly slower rate at the lower temperature (14°C) than at 21°C. One possible explanation could be that the geographic locality of each population could influence the biology of this species. The population of *D. laeve* used in this experiment was collected in Florida, where subtropical conditions exist, whereas the slug population used by

Faberi et al. (2006) was collected in Buenos Aires Province, Argentina, where temperate conditions prevail.

Karlin and Bacon (1961) suggest that there may be varietal differences between the native populations of *Deroceras laeve* in the Americas and populations in Europe. For example, Karlin and Bacon (1961) noted that *D. laeve* eggs collected from populations in Ohio, U.S.A. had a range of 10-15 days for incubation whereas eggs of European origin had a range of 17-20 days, when held at 21.6 – 22.8^{o}C. Jordaens et al. (2006) alluded to the fact that there is considerable variation in the life-history traits of *D. laeve*. Specifically, there exists a three to eight fold difference between the minimum and maximum mean values for adult size, the length of the reproductive phase, egg weight and incubation period. It is therefore suggested that future studies be conducted to determine if varietal differences exist among populations of *D. laeve*, or if *D. laeve* represents an unrecognized species complex.

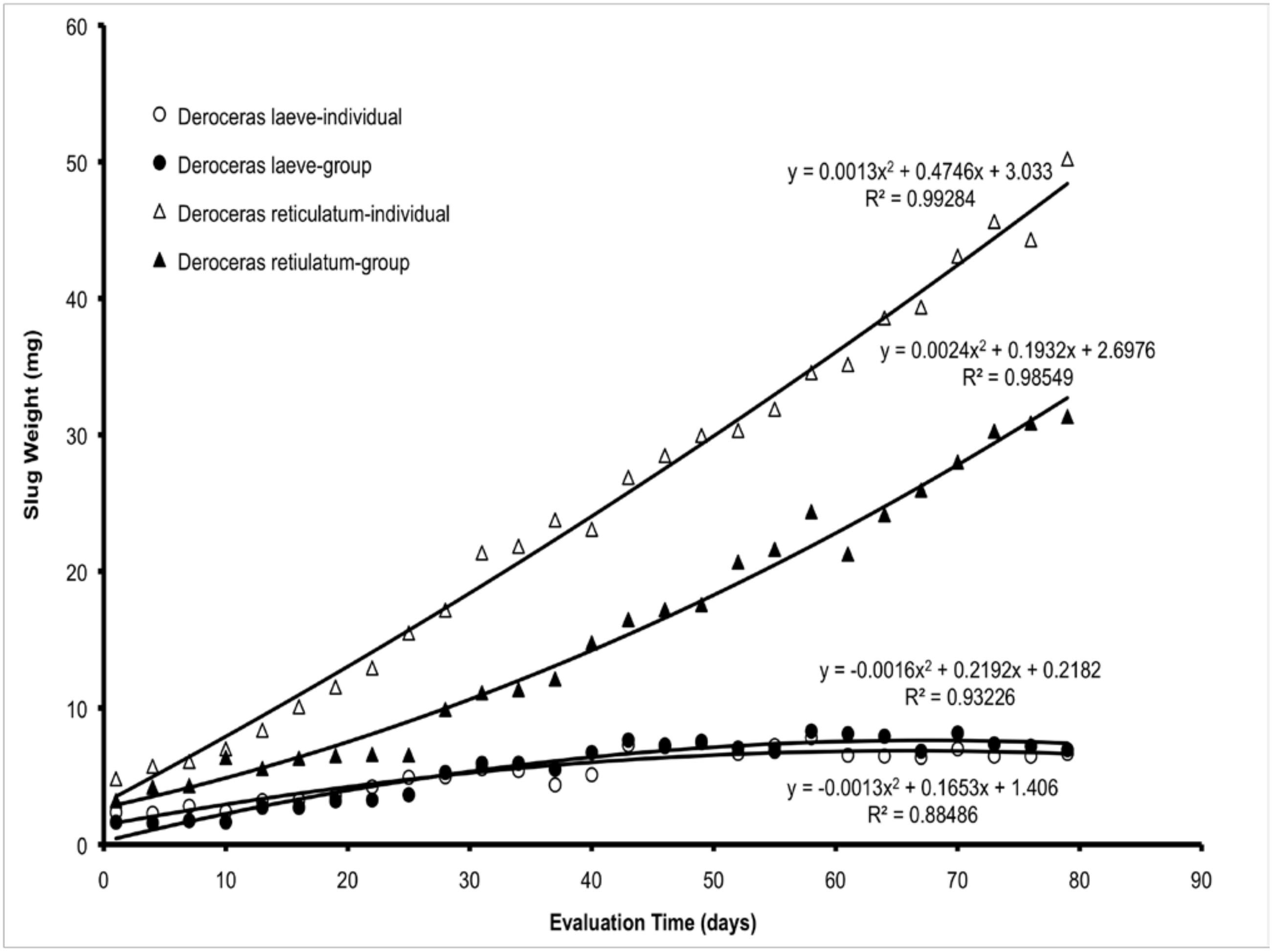

Figure 3-1. Mean weight gain of *Deroceras laeve* and *D. reticulatum* beginning with 14-day old juveniles and held at 14°C until reproductive maturity. Slugs from both species were assayed singly and in groups of five.

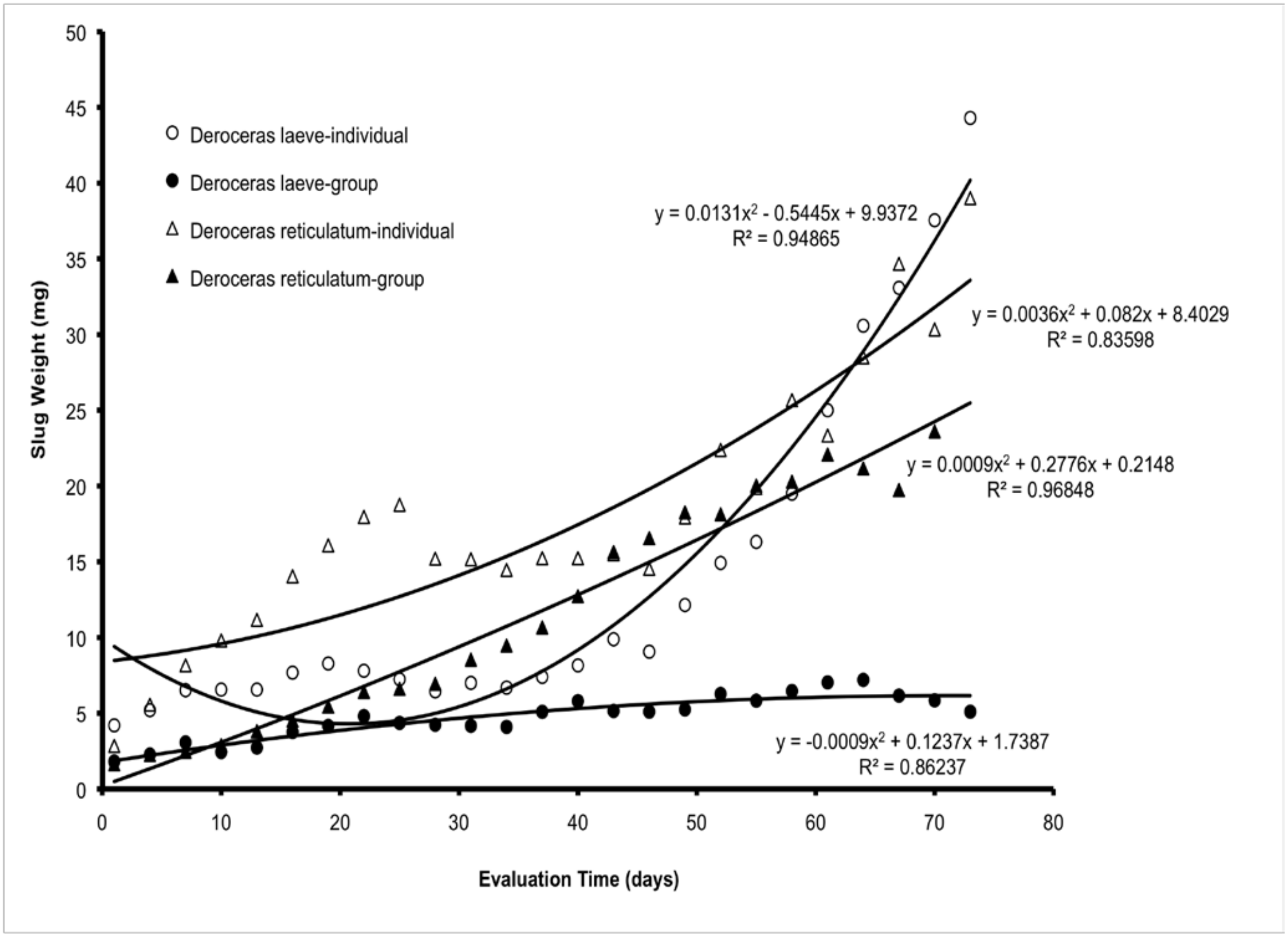

Figure 3-2. Mean weight gain of *Deroceras laeve* and *D. reticulatum* beginning with 14-day old juveniles and held at 21°C until reproductive maturity. Slugs from both species were assayed singly and in groups of five.

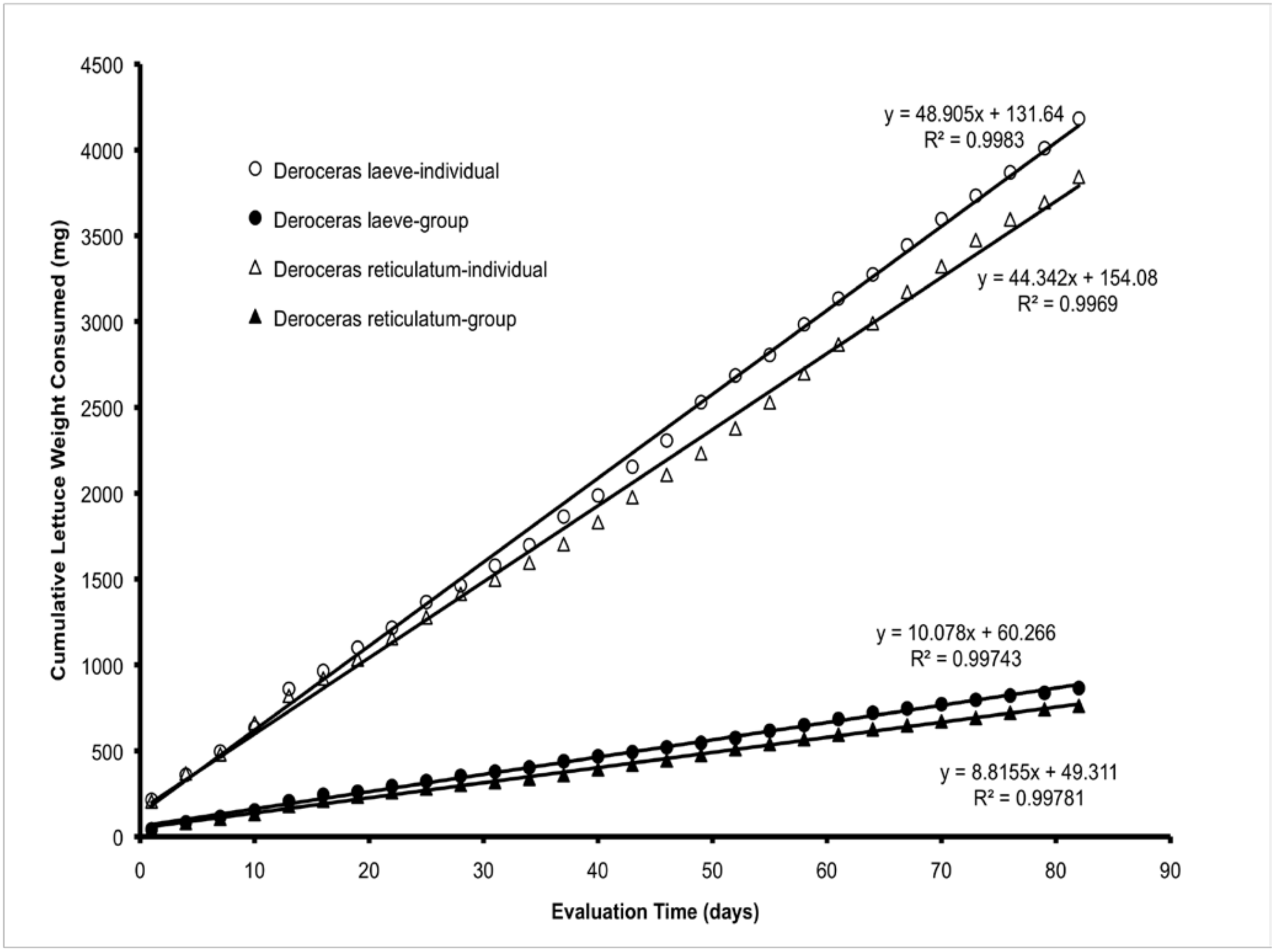

Figure 3-3. Mean cumulative consumption of lettuce by *Deroceras laeve* and *D. reticulatum* per individual beginning with 14-day old juveniles and held at 14°C until reproductive maturity. Slugs of each species were assayed singly and in groups of five.

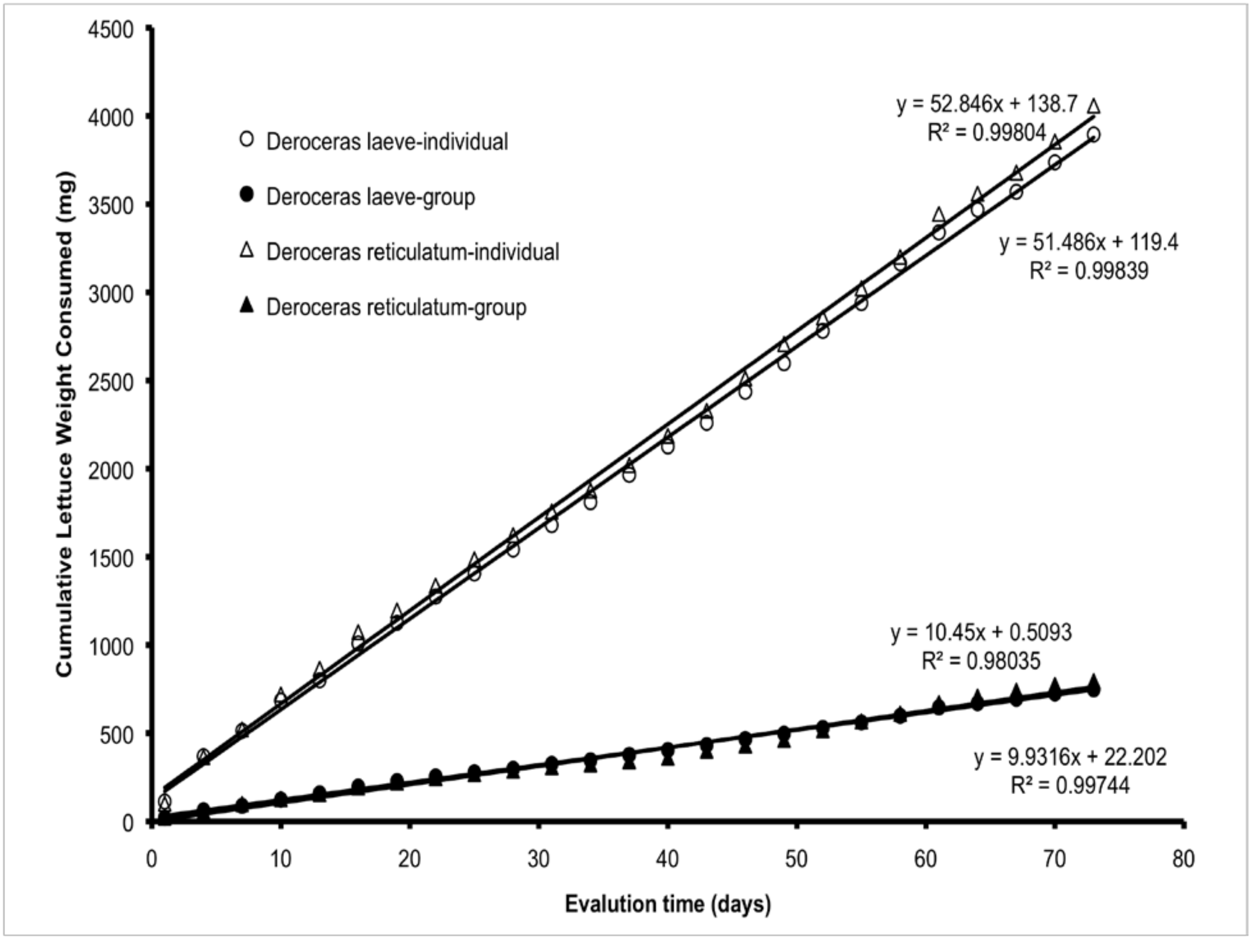

Figure 3-4. Mean cumulative consumption of lettuce by *Deroceras laeve* and *D. reticulatum* per individual beginning with 14-day old juveniles and held at 21°C until reproductive maturity. Slugs of each species were assayed singly and in groups of five.

CHAPTER 4
HOST PLANT PREFERENCE OF AGRICULTURALLY IMPORTANT MOLLUSC SPECIES

Introduction

Terrestrial snails and slugs are generalist herbivores that feed on both living and dead plant material (Briner and Frank 1998; Chatfield 1976; Godan 1983; Joe and Daehler 2008; Keller et al. 1999; Pickett and Stephenson 1980; Rueda et al. 1991; Schüder et al. 2004; South 1992). Analysis of fecal samples from field-collected terrestrial molluscs indicates that higher plants are preferentially consumed (Dirzo 1980; Jennings and Barkham 1975; Pallant 1969) with fungi, mosses and liverworts being a minor component of the diet (Dirzo 1980). Pestiferous gastropods will consume many higher plants valued as important agricultural species, including cereals, ornamentals (Briner and Frank 1998; Kozłowska and Kozłowski 2004b; Peters et al. 2000) and vegetable crops (Pickett and Stephenson 1980).

The palatability of plants to generalist herbivores is highly variable (Buschmann et al. 2005; Williamson and Cameron 1976). This variability is often attributed to physical structures such as hairs, thorns and spines (Dirzo 1980) and secondary defensive compounds produced by plants (Aguiar and Wink 2005; Gelperin 1975; Mølgaard 1986; Rueda et al. 1991). These compounds include terpenes (Aguiar and Wink 2005; Chevalier et al. 2003; Frank et al. 2002; Gouyon et al. 1983; Linhart and Thompson 1995; Mølgaard 1986), cyanogenic glucosides (Dirzo and Harper 1982; Raffaelli and Mordue 1990), glucosinolates (Chevalier et al. 2003; Dirzo 1980; Mølgaard 1986), tannins, alkaloids (Chevalier et al. 2003; Frank et al. 2002; Dirzo 1980; Mølgaard 1986; Speiser et al. 1992) and carvone (Frank et al. 2002). Notwithstanding the considerable array of natural defenses employed, higher plants continue to be susceptible to varying degrees of herbivory. In an attempt to mitigate the damage caused by generalist herbivores, the application of pesticides has been incorporated into routine conventional agricultural production (Bengtsson et al. 2005).

The application of molluscicides is the primary means of control for pestiferous terrestrial molluscs (Kozłowski and Kozłowska 2008; Rae et al. 2007; Speiser 1999). Molluscicides are largely formulated as edible baits (Bailey 2002; Rae et al. 2007; Speiser 1999), often in the form of pellets, with either methiocarb or metaldehyde as the active ingredient (Frank et al. 2002; Speiser 1999). The efficacy of molluscicides has remained relatively unsatisfactory (Bailey and Wedgewood 1991; Kozłowski and Kozłowska 2008), especially in wet conditions, where the pesticide may be rendered ineffective (Cook et al. 1997; Rae et al. 2007; Oberholzer et al. 2003), allowing for the recovery of poisoned slugs (Bourne et al. 1990; Cook et al. 1997). Additionally, pelletized molluscicides that contain metaldehyde are very toxic and pose a threat to non-target organisms, including invertebrates, mammals and birds (Brooks et al. 2003; Cook et al. 1997; Frank et al. 2002; Hagin and Bobnick 1991; Oberholzer et al. 2003; Purvis and Bannon 1992; Rae et al. 2007; South 1992).

Biological control continues to be evaluated as a feasible alternative or accompaniment to chemical control of terrestrial slugs. The use of the nematode *Phasmarhabditis hermaphrodita* (Schneider) (Speiser et al. 2001; Rae et al. 2007; Tan and Grewal 2001a), though effective, is very costly (Brooks et al. 2003; Speiser and Kistler 2002). The commercial formulation of this nematode (Nemaslug®) has variable pathogenicity between batches (Tan and Grewal 2001b), has a short shelf life, is thermo-sensitive (Speiser and Kistler 2002) and is not permitted for use within the

United States of America (Becker Underwood 2011). There are also several species within the beetle family Carabidae that are predominantly mollusc feeders (Hatteland et al. 2010; Oberholzer et al. 2003)) and have been suggested as a management option. Carabid beetles (*Carabus nemoralis*, *Pterostichus niger* and *P. melanarius)* have been documented to prey upon the eggs and juveniles of pestiferous slugs (Hatteland et al. 2010). Also, cultural control of terrestrial gastropods includes soil cultivation, deep seed placement, and soil compaction (Cook et al. 1997; Davis 1989; Glen et al. 1989, 1990). These strategies have shown some efficacy in agricultural settings, but must be used in conjunction with a molluscicide (Cook et al. 1997; Glen et al. 1989).

As the market for crops grown with little or reduced pesticide input continues to expand (Schüder et al. 2004), there is increased demand for alternatives (Burrows 1983; Kozłowska and Kozłowski 2004b; Starbird 1994). One such approach is the use of crop plants that are unattractive to snails and slugs. It is important to gain an understanding of host plant selection by herbivores (Mølgaard 1986) in order to be able to recommend ornamental and food crop plants that are resistant to mollusc attack.

Snails and slugs have been reported to cause damage to legumes (Byers 2002), soybean (Hammond 1985; Speiser et al. 2001), corn (Byers and Calvin 1994; Speiser et al. 2001), wheat (Cook et al. 1996), strawberry (Prystupa et al. 1987), barley, oilseed rape, sugar beet, potato, Brussels sprouts and other Brassicaceae, green asparagus, lettuce (Speiser et al. 2001) and ornamental plants (Briner and Frank 1998; Kozłowska and Kozłowski 2004b; Peters et al. 2000). Several mollusc species occur throughout Florida, and some of these are considered to be serious agricultural pests (Klassen et al. 2002; Rawlings et al. 2007).

The goal of this study was to generate an acceptability index to determine which species of plants commonly grown in Florida would most likely be consumed by each of four species of terrestrial molluscs commonly found in Florida, or potentially found here. This was achieved through a series of choice and no-choice tests, which are traditionally conducted to test for host plant selectivity in terrestrial gastropods (Kozłowska and Kozłowski 2004a; Richardson and Whittaker 1982). In choice tests, Richardson and Whittaker (1982) noted that the degree of separation of plants based on acceptability indices depends heavily on the choice of the reference/control material. Hence, in this experiment, lettuce will be used as the primary reference plant and cabbage used as the reference plant for a subsample of the plants tested to determine whether the plants would be classified similarly for each reference plant.

Materials and Methods

Molluscs and Plants

Two invasive, established snails [*Bradybaena similaris* (Bradybaenidae) and *Zachrysia provisoria* (Pleurodontidae)] were used in this study. Both species were collected from Homestead, Florida. Also, two species of slugs were included, *Deroceras laeve* and *Deroceras reticulatum* (Agriolimacide). The native species *D. laeve* was collected in Gainesville, Florida and *D. reticulatum,* a potentially invasive slug that is not established in Florida, but which has been intercepted on multiple occasions (Stange et al. 1999), was collected in Rockland, Maine. Field collected, adults of each species were used to determine food acceptability of agronomic and ornamental crop plants, as juveniles usually are more sensitive to toxicants than adults (Speiser et al. 1992). This was done in an effort to minimize variability that may be induced by age-dependent sensitivity to plant defense compounds. Between trials, the slugs were maintained at a constant temperature of 21°C and with a 12h dark and light period (LD: 12/12 h). The mollusc species were fed gypsy month diet (Bio-Serv, Frenchtown, NJ), prior to, and between, studies.

A total of 37 plant species in 28 families were evaluated as possible host plants for each of the four mollusc species. Ornamental and food crop plants that are of economic importance and commonly grown in Florida, U.S.A. were selected for evaluation in this study.

Palatability Tests

Choice Test: In the laboratory, a single adult specimen was placed in a cylindrical, transparent plastic container (18.5 cm diam. x 7.5 cm high) that had been lined with a single moistened coffee filter paper to maintain high humidity. Cylindrical containers were employed to minimize potential corner effect caused by a square container. Molluscs were starved for 24 hours before the experiment to ensure they were hungry.

Mature, fresh non-senescent leaves were provided at each test. Each test included a control plant [commercially available romaine lettuce *(Lactuca sativa* L. var. longifolia)] and a test plant. The leaves (lettuce and test) were cut into discs measuring approximately 4.15 cm^2 using a number 15-cork borer, weighed, and arranged such that three lettuce and three test discs were arranged equidistant in a circle, along the edges of each test chamber. This ensured that the molluscs had an equal chance of intercepting each individual leaf disc. For each trial, a total of twenty slugs of each mollusc species were tested.

In addition, a total of twenty control containers were set up similarly with three test plant discs and three control plant discs, except that the mollusc was not included. These control containers were included to account for any weight loss or gain by the plant material due to humidity within the containers. The test was initiated in the afternoon in an incubator (Percival, Boone, IA) set at 21°C. The containers were examined the following morning (approximately 18 hours) to determine if at least 50% of either the test plant or control disc had been consumed, and continued until this level of consumption was attained. The leaf discs were weighed after each feeding event to determine the fresh weight consumed by the molluscs.

The following acceptability index was used to evaluate the selective preference of each mollusc species:

Acceptability Index:

$$A.I. = \frac{\text{Quantity of Test Plant Eaten (g)}}{\text{Quantity of Both Plants Eaten (g)}}$$

Where,

A.I.: 0-Test plant unacceptable

A.I.: 0.01-0.07-Test plant slightly acceptable

A.I.: 0.08-0.17-Test plant moderately acceptable

A.I.: 0.18-0.5-Test plant highly acceptable

The mean change in weight of leaf discs in the control containers was used to correct for fluctuations in the weight of leaf discs presented to the molluscs:

A) The weight change in lettuce and test discs in the control containers were calculated by subtracting the initial weight of each disc from the final weight. Positive (>0) indicated weight gain, negative values (<0) indicated weight loss and a value of zero indicated no weight change. The mean weight change for the lettuce discs and the test plant in question were then calculated.

B) Positive mean values for the leaf discs (lettuce and test plant) in the control containers were then subtracted from corresponding mean weight values in containers being evaluated. Conversely, negative mean control values were added to corresponding values in the test containers. The A.I. values were then calculated using the adjusted values.

Nine plants previously presented to *Zachrysia provisoria* with lettuce as the control in the previous choice tests were re-evaluated with cabbage as the control. Three plants were randomly selected from each of the three major A.I. groups (highly, moderately or slightly acceptable) for testing (Table 4-4).

No-choice Test: For those plants that were unacceptable to the molluscs (i.e., A.I.=0), an additional no-choice test was conducted. For this test, 3 leaf discs of the test plant were presented alone (i.e., without lettuce), under otherwise identical conditions to that of the choice test described above. The goal of the no-choice test was to determine whether these plants would be consumed in the absence of an alternative palatable plant. After 24 hours the experiment was terminated as the molluscs species evaluated would have been starved for 48 hours (24hrs prior to experiment and 24hrs evaluated) and would have voided their guts.

Statistical Analysis

All statistical analyses were done using SAS® statistical software (SAS Institute, Inc. 2008). The non-parametric Friedman's test (Lockwood III 1998) was used to determine if there were any significant differences between the A.I. of the test plants evaluated in the choice test. Acceptability indices were compared using a Tukey's post hoc multiple comparison test.

Results

In all four mollusc species evaluated, annuals were more preferred than perennials: *Zachrysia provisoria* (F=34.05; df= 738; P< 0.0001);

The majority, 31 (84%) of the food and ornamental plants evaluated, were found to be acceptable to at least one of the four mollusc species when presented with lettuce as an option in the choice test (Table 4-1). Of the six unacceptable plants, five were perennials and one was an annual: four were ornamentals, one was a fruit and the other was a vegetable (Table 4-1). Only three (8%) plant species (*Petunia* sp., *Impatiens walleriana* and *Tagetes patula*) of the 37 plants that were tested were found acceptable by all four mollusc species in the choice test.

Zachrysia provisoria was the most polyphagous mollusc species evaluated in this experiment. This snail consumed 31 (84%) of the tested plants, 25 (68%) of these were only acceptable to this species among the four tested in the choice test (Table 4-2). Of the plants acceptable to *Z. provisoria*, ten test plants were highly acceptable, 11 were moderately acceptable, ten were slightly acceptable, and six were significantly (F=12.78; df= 36, 684; P< 0.001) unacceptable (Table 4-2).

Bradybaena similaris was more selective, consuming six of the plants presented in the choice test, with one plant being highly acceptable (*Phaseolus vulgaris*) and significantly more so (F=25.24; df= 36, 684; P< 0.0001) than the other four plants eaten, which were moderately acceptable and one slightly acceptable (Table 4-2).

The *Deroceras* spp. also were rather selective in their feedings. Three of four test plants consumed by *Deroceras laeve* were highly acceptable and one was moderately acceptable (Table 4-2). *Impatiens walleriana*, *Petunia* sp. and *Tagetes patula* were highly acceptable; but, their palatability differed significantly (F=55.91; df = 36, 684; P<0.0001) from each other as well as from *Cordyline terminalis*, the fourth plant, which was moderately acceptable. Four of the five test plants consumed by *Deroceras reticulatum* were highly acceptable and one moderately acceptable (Table 4-2). *Solenostemon* sp. and *Impatiens walleriana* was found to be significantly more palatable (F=59.45; df = 36, 684; P<0.0001) when compared to *Petunia* sp. and *Tagetes patula,* and *Cordyline terminalis*.

The percent consumption values for no-choice tests are presented in Table 4-3. *Zachrysia provisoria* consumed six of the seven test plants presented under these conditions, with percent consumption ranging from <5 - 61%. *Bradybaena similaris* consumed 17 of the thirty-one plants presented in the no-choice tests and consumption ranged from <5 - 50%. *Deroceras laeve* consumed 19 of the 33 plants presented, and consumption ranged from <5 - 24%. *Deroceras reticulatum* consumed 16 of the 32 plants presented, and consumption ranged from <5 - 22% (Table 4-3). *Stromanthe* *sanguinea* var. *tricolor* was the only plant species not consumed by any of the molluscs tested in either the choice or the no-choice tests (Table 4-2 and 4-3).

Analysis of the data from the choice test conducted with cabbage as the control plant, showed that there were significant (F=31.78; df = 8, 72; $P < 0.0001$) differences in the acceptability values obtained for the list of plants tested (Table 4-4). The A.I. values and categories obtained from the choice tests where lettuce was used as the control plant were different when the experiment was repeated using cabbage as the control.

Discussion

All the test plants evaluated in this study are commonly grown in Florida and many are commercially produced. Thus, these tests provide broad assessment of damage potential by these molluscs in Florida. Note that several tropical perennial species are typically grown as annuals in the predominantly subtropical climate of Florida.

The most broadly favored plants across the four mollusc species included in this study (*Zachrysia provisoria*, *Bradybaena similaris*, *Deroceras laeve* and *Deroceras reticulatum*) were *Impatiens walleriana*, *Petunia* sp. and *Tagetes patula*, which were either moderately or highly acceptable to each mollusc. Only one plant tested (*Stromanthe sanguinea* var. *tricolor*) was shown to be unacceptable to all four mollusc species.

Zachrysia provisoria was the most polyphagous herbivore of the four mollusc species. *Zachrysia provisoria* consumed a large proportion (84%) of the plants provided to it in the choice test, whereas *Deroceras reticulatum* consumed only five (14%), *Deroceras laeve* 4 (11%) and *Bradybaena similaris* 6 (16%) of the 37 plants presented (Table 4-2).

Under the no-choice testing regime, *Zachrysia provisoria* consumed all the plants initially rejected in the choice test, with the exception of *Stromanthe sanguinea* var. *tricolor* (Marantaceae) (Table 4-3). Eleven plants were not consumed by the remaining three species (*Bradybaena similaris*, *Deroceras laeve* and *D. reticulatum*) when each was presented in the no-choice test: *Curcurbita moschata*, *Fragaria ananassa*, *Lycopersicon esculentum*, *Musa* sp., *Canna generalis*, *Lantana montevidensis*, *Mirabilis jalapa*, *Odontonema strictum*, *Pilea cadieri* and *Philodendron monster*. In addition, neither *Deroceras* species consumed *Citrus* sp., *Canna indica* and *Hypoestes phyllostachya*. Whereas, *Deroceras reticulatum* also did not consume *Arachis hypogaea* and *Rudbeckia fulgida* var. *sullivantii*, but *Deroceras laeve* did consume small portions of these plants. *Bradybaena similaris* did not consume three additional plant species in the no-choice test: *Cordyline terminalis*, *Hosta* sp. var. *pilgrim* and *Torenia asiatica*

No visible feeding damage was observed on the leaf discs of plants not consumed in the no-choice test. Pickett and Stephenson (1980), suggest that the ocular tentacles of molluscs may be involved in the detection of volatile compounds produced by potential food sources. It is possible that the plants not consumed are unacceptable because they produce volatile compounds that are perceived as deterrents. If so, these mollusc species could determine an acceptable host plant without exploratory grazing.

Lactuca sativa (Lettuce) is a very attractive plant to slugs and snails, as this plant has relative thin, soft leaves and produces only small quantities of secondary compounds (Frank et al. 2002). Pickett and Stephenson (1980) were able to demonstrate that *Deroceras reticulatum* is attracted to extracts of lettuce. It is likely that this is the case for the other mollusc species included in this study. When the highly acceptable lettuce was paired with the test plants, the resultant acceptability indices (A.I.) generated were always skewed towards the lettuce and the breadth of the mean A.I. generated for each plant species was very narrow as none of the test plants were consumed in greater quantity than the lettuce (Table 4-2).

Richardson and Whittaker (1982) noted that the degree of separation of plants based on acceptability indices depends heavily on the choice of the reference /control material. In these tests, the separation was much narrower than observed by Brooks et al. (2003). A second choice test was conducted to determine how the control plant affected host selection by using cabbage (*Brassica oleracea*) as the control plant. Cabbage was selected for use as the control plant because it was found to be highly acceptable in the previous choice test (Table 4-2).

Cabbage proved to be a better plant at separating the prospective hosts into broader levels of acceptability than lettuce. Mean A.I. ranged from 0.03 - 0.44 (Table 4-2), compared with 0.2 - 0.93 for cabbage (Table 4-4). The greater separation achieved in the second choice test was as a result of cabbage not being the most preferred plant among those offered. Cabbage produces a variety of glucosinolate compounds. A number of these compounds have been reported as feeding deterrents to slugs (Buschmann et al. 2005). This may provide the basis for greater separation of the test plants' computed A.I.

Although cabbage has the advantage of providing better separation for use as the check plant in choice tests studies, lettuce has its advantages as well. Lettuce, in comparison to most plants is an attractive host, thus it serves well to identify species that would be especially at risk. Any plant consumed in the presence of the highly palatable host plant, lettuce would likely be consumed readily under field conditions.

Generally, plants grown as annuals are at greater risk of herbivory by all four species, compared to plants grown as perennials. In areas where the snail *Bradybaena similaris* and the slugs *Deroceras laeve* and *D. reticulatum* occur with some regularity, it may be appropriate to incorporate the following plants into landscape or cropping systems (as it is highly unlikely for these plants to be as risk of herbivory by these three species): *Curcurbita moschata*, *Fragaria ananassa*, *Lycopersicon esculentum*, *Musa* sp., *Canna generalis*, *Lantana montevidensis*, *Mirabilis jalapa*, *Odontonema strictum*, *Pilea cadieri* and *Philodendron monster*. *Stromanthe sanguinea* var. *tricolor* was not acceptable to any of the mollusc species in the choice and no-choice tests and could be considered an appropriate plant for use in landscapes where any of the molluscs tested in the study are of concern. Overall, considering both choice and no-choice studies, it is clear that nearly all the plants tested are at risk of herbivory by *Zachrysia provisoria.*

This study has identified ornamental and food crop plants that can be useful to agriculturalists and homeowners for use in landscape and cropping systems. If the intended planting area is infested with any of the molluscs species included in this study, the results presented herein should provide a guide as to the degree to which the plants would be at risk of herbivory.

Table 4-1. List of test plants included in the palatability study. In the life cycle column: P-perennial, A-annual and P/A-plant that can be grown as an annual or perennial depending on the climate.

Plants	Common name	Family	Life cycle	Acceptable
Fruits and vegetables				
Abelmoschus esculentus	Okra	Malvaceae	P/A	yes
Arachis hypogaea	Peanut	Fabaceae	A	yes
Brassica oleracea	Cabbage	Brassicaceae	A	yes
Capsicum sp.	Pepper	Solanaceae	P/A	yes
Carica papaya	Papaya	Caricaceae	P	yes
Citrus sp. var pineapple	Orange	Rutaceae	P	yes
Cucurbita moschata	Squash	Cucurbitaceae	A	no
Fragaria ananassa	Strawberry	Rosaceae	P/A	no
Lycopersicon esculentum	Tomato	Solanaceae	P/A	yes
Musa sp.	Banana	Musaceae	P	yes
Phaseolus vulgaris	Bean	Fabaceae	A	yes
Solanum melongena	Eggplant	Solanaceae	P/A	yes
Spinacea oleracea	Spinach	Amaranthaceae	A	yes
Ornamentals				
Begonia semperflorens	Begonia	Begoniaceae	A	yes
Canna indica	Canna lily	Cannaceae	P	yes
Canna generalis	Canna lily var. Tropicana Gold	Cannaceae	P	yes
Catharanthus roseus	Vinca	Apocynaceae	A	yes
Colocasia esculenta	Variegated taro	Araceae	P	yes
Cordyline terminalis	Red sister cordyline	Agavaceae	P	yes
Hosta sp. var pilgrim	Hosta var. pilgrim	Liliaceae	P	yes
Hypoestes phyllostachya	Pink splash	Acanthaceae	P	yes
Impatiens walleriana	Double impatiens	Balsaminaceae	A	yes
Ipomoea batatas	Sweet potato	Convolvulaceae	P	yes
Lantana montevidensis	Lantana	Verbenaceae	P	no
Mirabilis jalapa	4 o'clock	Nyctaginaceae	P/A	yes
Odontonema strictum	Firespike	Acanthaceae	P	yes
Petunia sp.	Petunia	Solanaceae	P/A	yes
Philodendron monster	Philodendron	Araceae	P	yes
Pilea cadieri	Aluminum plant	Urticaceae	P	yes
Rhododendron sp.	Azalea	Ericaceae	P	no

Table 4-1. Continued

Plants	Common name	Family	Life cycle	Acceptable
Rudbeckia fulgida var. *sullivantii*	Black-eyed Susan	Asteraceae	P	no
Solenostemon sp.	Coleus	Lamiaceae	P/A	yes
Stromanthe sanguinea var. *tricolor*	Stromanthe	Marantaceae	P	no
Tagetes patula	Marigold-French	Asteraceae	A	yes
Torenia asiatica	Wishbone flower	Scrophulariaceae	A	yes
Tradescantia pallida	Purple queen	Commelinaceae	A	yes
Zinnia elegans	Zinnia	Asteraceae	A	yes

Acceptable column indicates plant that was consumed by at least one of the four mollusc species tested in the choice test where lettuce was used as the control plant.

Table 4-2. Choice test: comsumption (A.I.) of selected ornamental and food plants in Florida, by four pestiferous mollusc species.

Plants	*Zachrysia provisoria*	*Bradybaena similaris*	*Deroceras laeve*	*Deroceras reticulatum*
Fruits and vegetables				
Abelmoschus esculentus	0.41 a	0.11 b	0 d	0 d
Arachis hypogaea	0.14 defghijk	0 c	0 d	0 d
Brassica oleracea	0.27 abcd	0 c	0 d	0 d
Capsicum sp.	0.15 cdefghijk	0 c	0 d	0 d
Carica papaya	0.17 bcdefghij	0 c	0 d	0 d
Citrus sp. var pineapple	0.21 bcdefg	0 c	0 d	0 d
Cucurbita moschata	0 k	0 c	0 d	0 d
Fragaria ananassa	0 k	0 c	0 d	0 d
Lycopersicon esculentum	0.3 abc	0 c	0 d	0 d
Musa sp.	0.05 ghijk	0 c	0 d	0 d
Phaseolus vulgaris	0.05 ghijk	0.21 a	0 d	0 d
Solanum melongena	0.11 efghijk	0 c	0 d	0 d
Spinacea oleracea	0.14 defghijk	0 c	0 d	0 d
Ornamentals				
Begonia semperflorens	0.19 bcdefghi	0 c	0 d	0 d
Canna indica	0.08 fghijk	0.02 c	0 d	0 d
Canna generalis	0.11 efghijk	0 c	0 d	0 d
Catharanthus roseus	0.19 bcdefghi	0 c	0 d	0 d
Colocasia esculenta	0.04 ijk	0 c	0 d	0 d
Cordyline terminalis	0.04 hijk	0 c	0.1 c	0.13 c
Hosta sp. var pilgrim	0.07 fghijk	0 c	0 d	0 d
Hypoestes phyllostachya	0.17 bcdefghij	0 c	0 d	0 d
Impatiens walleriana	0.06 ghijk	0.09 b	0.4 a	0.42 a
Ipomoea batatas	0.03 jk	0 c	0 d	0 d
Lantana montevidensis	0 k	0 c	0 d	0 d
Mirabilis jalapa	0.08 fghijk	0 c	0 d	0 d
Odontonema strictum	0.19 bcdefghij	0 c	0 d	0 d
Petunia sp.	0.25 abcde	0.14 b	0.27 b	0.24 b
Philodendron monster	0.13 defhhijk	0 c	0 d	0 d
Pilea cadieri	0.19 bcdefgh	0 c	0 d	0 d
Rhododendron sp.	0 k	0 c	0 d	0 d
Rudbeckia fulgida var. *sullivantii*	0 k	0 c	0 d	0 d
Solenostemon sp.	0.04 hijk	0 c	0 d	0.44 a

Table 4-2. Continued

Plants	*Zachrysia provisoria*	*Bradybaena similaris*	*Deroceras laeve*	*Deroceras reticulatum*
Stromanthe sanguinea var. *tricolor*	0 k	0 c	0 d	0 d
Tagetes patula	0.12 defhhijk	0.13 b	0.23 b	0.21 b
Torenia asiatica	0.06 ghijk	0 c	0 d	0 d
Tradescantia pallida	0.32 ab	0 c	0 d	0 d
Zinnia elegans	0.22 bcdef	0 c	0 d	0 d

Values shown are acceptability index (AI) of test plant consumed as compared to control (lettuce), where the test plant is: 0-unacceptable; 0.01-0.07: slightly acceptable; 0.08-0.17: moderately acceptable and 0.18-0.5: highly acceptable. Results of Tukey's test at α= 0.05 also presented in each column, where values followed by the same letter are not significantly different.

Table 4-3. No Choice: percent consumption of the foliage of ornamental, fruit and vegetable plants by four pestiferous mollusc species: *Zachrysia provisoria*, *Bradybaena similaris*, *Deroceras laeve* and *D. reticulatum*. Plants accepted by molluscs in the choice test were not included in the no-choice test.

Plants	*Zachrysia provisoria*	*Bradybaena similaris*	*Deroceras laeve*	*Deroceras reticulatum*
Fruits and vegetables				
Abelmoschus esculentus	*	*	6	5
Arachis hypogaea	*	20	8	0
Brassica oleracea	*	<5	13	<5
Capsicum sp.	*	<5	<5	<5
Carica papaya	*	12	10	<5
Citrus sp. "pineapple var."	*	<5	0	0
Cucurbita moschata	<5	0	0	0
Fragaria ananassa	58	0	0	0
Lycopersicon esculentum	30	0	0	0
Musa sp.	*	0	0	0
Phaseolus vugaris	*	*	38	22
Solanum melongena	*	33	<5	13
Spinacea oleracea	*	<5	<5	<5
Ornamentals				
Begonia semperflorens	*	26	<5	<5
Canna generalis	*	0	0	0
Canna indica	*	*	0	0
Catharanthus roseus	*	40	21	20
Colocasia esculenta	*	<5	<5	<5
Cordyline terminalis	*	0	*	*
Hosta sp. var pilgrim	*	0	15	<5
Hypoestes phyllostachya	*	<5	0	0
Impatiens walleriana	*	*	*	*
Ipomoea batatas	*	31	24	22
Lantana montevidensis	<5	0	0	0
Mirabilis jalapa	*	0	0	0
Odontonema strictum	*	0	0	0
Petunia sp.	*	*	*	*
Philodendron monster	*	5	<5	<5
Pilea cadieri	*	0	0	0
Rhododendron sp.	<5	0	0	0
Rudbeckia fulgida var. sullivantii	61	<5	<5	0

Table 4-3. Continued

Plants	*Zachrysia provisoria*	*Bradybaena similaris*	*Deroceras laeve*	*Deroceras reticulatum*
Solenostemon sp.	*	25	<5	*
Stromanthe sanguinea var. *tricolor*	0	0	0	0
Tagetes patula	*	*	*	*
Torenia asiatica	*	0	16	18
Tradescantia pallida	*	<5	<5	<5
Zinnia elegans	*	50	14	11

Table 4-4. Reassessment (cabbage used as control) of the acceptability index values (A.I.) for selected ornamental and food crops that are commonly grown in Florida, and consumed by *Zachrysia provisoria*.

Plants	A.I.
Abelmoschus esculentus	0.86
Canna indica	0.30
Capsicum sp.	0.87
Musa sp.	0.20
Phaseolus vulgaris	0.60
Philodendron monster	0.52
Solanum melongena	0.92
Solenostemon sp.	0.63
Tradescantia pallida	0.93

Values shown are derived from test plants consumed relative to cabbage (control), where the test plant is: 0-unacceptable; 0.1-0.44: slightly acceptable; 0.45-0.55: moderately acceptable and 0.56-1 highly acceptable. Results of Tukey's test at $\alpha = 0.05$ also presented, where values followed by the same letter are not significantly different.

CHAPTER 5
NOTES ON THE LIFE HISTORY TRAITS AND FEEDING BEHAVIOR OF *PHILOMYCUS CAROLINIANUS* (PULMONATA: STYLOMMATOPHORA: PHILOMYCIDAE)

Introduction

The genus *Philomycus* Rafinesque (Family: Philomycidae) is comprised of aulacopod slugs that characteristically possess a large empty shell sac and a mantle that extends over the entire back (Burch 1962). *Philomycus carolinianus* represents one species within this genus that is widely distributed across eastern North America ranging from Canada to Florida and west to Iowa and eastern Texas (Pilsbry 1948).

Philomycus carolinianus typically inhabit the loosened bark of decaying logs in humid undisturbed coniferous and deciduous forests (Pilsbry 1948; South 1992). Decayed beech, birch, basswood and other hardwood trees are typically preferred (Ingram 1949). However, on occasion, slugs may be observed foraging in the open, and *P. carolinianus* and other species in the genus *Philomycus* have been observed crawling down trees from as high as 20 feet (approx. 6 m) (Ingram 1949).

Mature slugs of this species may range from 75-100 mm in length, with the sole of the foot undivided. The genital opening is located on the right side of the animal's head, as typical of *Philomycus,* and the pneumostome (breathing pore) is located anteriorly, on the right margin of the mantle (Pilsbry 1948).

This slug has been documented to consume several genera of mushrooms (Ingram 1949) and in the laboratory, lettuce (Pilsbry 1948). This slug produces copious amount of slime even when not disturbed. Ingram (1949) considers *Philomycus carolinianus* an aggregating species.

The biology and life history traits of *Philomycus carolinianus* are poorly known. The goal of this study was to document the developmental and reproductive characters of *P. carolinianus* under laboratory conditions.

Materials and Methods

Life History Traits

Growth experiment: Six clutches of eggs were obtained from *Philomycus carolinianus* field-collected in Gainesville, FL. In this experiment. One replicate constituted a single clutch of eggs, averaging 60 eggs per clutch (N_{total} = 356 eggs). The clutches were incubated between moistened paper towels in a cylindrical plastic container (18.5 cm diam. x 7.5 cm high). Upon hatching, juveniles were promptly removed from the incubation chamber and placed individually into vented cylindrical plastic containers (9.5 cm diam. X 4.5 cm high). The slugs were fed gypsy moth diet (Bio-Serv, Frenchtown, NJ) from hatching to reproductive maturity (Time at first oviposition). A moistened paper towel was placed in each container to maintain humidity, and each juvenile was weighed every 3 days. The slugs were provided with fresh food and transferred to a clean container once a week, observed for nine months, and maintained at 21°C ± 1°C, with a photoperiod of 12:12 (L:D).

There was considerable variation in weight gain and the length of time to reproductive maturity among specimens within each replicate. The slugs that remained alive for the duration of the experiment could be visually separated into three distinct groups. A hierarchical clustering analysis was used to sort the time to reproductive maturity data into three natural groups using the Statistical Analysis System (SAS®), JMP – Version 8 software (SAS Institute, Inc. 2008). The separation was conducted based on the degree of similarity (i.e., the shortest distance between values).

Both sorting methods (visual and clustering analysis) were compared and the results were similar except for a few individuals that occurred in the upper and lower quartiles. These individuals were placed into groups based on the results of the clustering analysis.

A one-way analysis of variance (ANOVA) was used to determine if there were any significant differences among the times to reproductive maturity for each group discerned by the clustering analysis. All statistical analyses were done using SAS ® software (SAS Institute, Inc. 2008). The growth curves for each group were compared using Tukey's post hoc multiple comparison test.

Fecundity experiment: Oviposition date and clutch size of 124 clutches (N_{total} = 7266 eggs) collected from self-fertilizing specimens in the growth experiment were recorded. Each clutch was incubated in a separate cylindrical container (18.5 cm diam. x 7.5 cm high), between a folded, moistened paper towel. The eggs were held for 30 days in an incubator at 21°C in the dark. Eggs were considered to be not viable if no embryonic development was observed at the end of this period, but were included in pertinent calculations (e.g., percent hatch). Hatching date and the number of hatchlings per clutch were recorded. All hatchlings emerged successfully from the eggs within 5-8 hours.

A second experiment was conducted to evaluate changes in clutch size and hatching success in successive clutches. Thirty adults from the aforementioned growth experiment were randomly selected, and clutch size and hatching success determined for the first six successive clutches produced by each self-fertilizing animal.

A one-way analysis of variance (ANOVA) was used to determine if there were any significant differences among clutch sizes and hatching success in successive clutches. All statistical analyses were done using SAS ® (SAS Institute, Inc. 2008). Clutch sizes and hatching success for successive clutches were compared using Tukey's post hoc multiple comparison test.

Influence of pairing on reproductive parameters: The objective of this experiment was to evaluate reproductive parameters of *Philomycus carolinianus* when reared as solitary or paired specimens, under laboratory conditions. Clutches laid by three field-collected slugs were used. Upon hatching, 72 juveniles (F1 progeny) were randomly selected from three clutches to make 36 pairs. It was assumed that all three field-collected slugs deposited eggs, but it is not clear if the slugs mated prior to captivity. Each pair was placed into vented plastic containers (9.5 cm diam. X 4.5 cm high) lined with moistened paper towel and kept separate from other specimens for the duration of the experiment. The slugs were fed gypsy moth diet (Bio-Serv, Frenchtown, NJ) ad libitum, and held at 21°C with 12:12 (L:D). The eggs from all clutches produced by the paired slugs over nine-months were collected and incubated separately. The following parameters were recorded: number of eggs per clutch, percent hatching, and incubation period (days). In addition, the pre-oviposition period measured in days and the time between oviposition events of each of the paired slugs were also documented. These parameters were recorded for the pair, not individuals of the pair.

The same reproductive parameters were obtained for 82 randomly selected slugs selected from the same source but reared in isolation under otherwise identical conditions. These parameters were then compared with those of the paired specimens.

Two-sample t-tests were used to compare reproductive parameters between solitary and paired specimens, using SAS® (SAS Institute, Inc. 2008).

Influence of temperature on egg development: The objective of this experiment was to estimate upper and lower temperature thresholds for *Philomycus carolinianus* embryonic development. The eggs used in this experiment were collected from a laboratory colony of *Philomycus carolinianus* maintained at 21°C ± 1°C, with a photoperiod of 12:12 (L:D) and fed gypsy moth diet (Bio-Serv, Frenchtown, NJ) ad libitum.

Six constant temperatures (10, 14, 17, 21, 25 and 29°C ± 1°C) were evaluated using 30 clutches per temperature (1 clutch = 1 replication). The clutches were immediately removed from the adult rearing containers after deposition and incubated in a cylindrical plastic containers (15 cm diam. X 6.5 cm high) between sections of a folded, moistened paper towel and misted with tap water every 5-7 days to ensure that the eggs did not desiccate.

Six insect rearing chambers (Percival, Boone, IA) were used for incubation, each set at one of the experimental temperatures. Percent hatching and the time to hatching were documented. The percent of embryos that developed, as determined by visual inspection, but did not hatch during the course of the experiment were also recorded. The eggs were classified as developed if they met all of the following parameters: the un-hatched embryo responded to tactile stimuli; the embryo was strongly pigmented; and the tentacles were obvious and dark-colored. If at least one of these parameters was not met, the egg was considered dead, and was excluded from the pertinent calculations. The eggs evaluated in this experiment were incubated until eclosion or for a maximum of 180 days.

A one-way analysis of variance (ANOVA) was used to test for differences in the percent egg development, percent egg hatch and time to eclosion among temperature treatments. Differences between means were separated using Tukey's post hoc multiple comparison. All statistical analyses were done using SAS ®.

Evaluation of Artificial and Natural Diets for Short-term Rearing

The objective of this experiment was to determine an appropriate natural or artificial foods for short-term maintenance of laboratory colonies of *Philomycus carolinianus*. The diets selected were those reported in previous studies for short-term maintenance of slug colonies or were formulated for insects and mammals.

Diets selected were: (1) romaine lettuce (*Lactuca sativa* var. longifolia) (Brooks et al. 2003; Cook et al. 2000; Egonmwan 1992; Pickett and Stephenson 1980; Speiser et al. 1992), (2) carrot (*Daucus carota* L.) (Brooks et al. 2003; Cook et al. 2000; Egonmwan 1992; Grewal et al. 2003; Pickett and Stephenson 1980; Tan and Grewal 2001), (3) rabbit pellets (Faberi et al. 2006; Ireland 1988), (4) white mushroom (*Agaricus bisporus*) (Ingram 1949; Keller and Snell 2002; Pilsbry 1948), (5) gypsy moth diet (Bio-Serv, Frenchtown, NJ), and (6) spruce budworm diet (Bio-Serv, Frenchtown, NJ).

A seventh treatment group of unfed slugs were maintained under the same conditions except no food source was provided. This was included to evaluate the effect of a lack of a food source on the slug weight.

The slugs used in this experiment were selected from a laboratory colony reared on gypsy moth diet. There were 30 adult slugs per treatment. All were starved for 5 days prior to the experiment to void the gut. Slugs were determined to be adults based its production of at least one clutch of eggs prior to this experiment. Each slug was weighed and placed individually in a clear, vented plastic container (9.5 cm diam. X 7.5 cm high) with moistened paper towel for increased humidity.

The containers were arranged in a completely randomized design (7 rows and 30 columns) on a laboratory bench with an ambient temperature of 22°C ± 1°C. Slugs were weighed once every 7 days, at which time they were placed in a clean container with fresh food source.

A one-way analysis of variance (ANOVA) was used to test for significant differences among treatments for the following parameters: final weight of the slugs, number of clutches, and percent mortality. Differences between means were separated using a Tukey's post hoc multiple comparison test. All statistical analyses were done using SAS ® (SAS Institute, Inc. 2008).

Food Preference

Mushroom preference: The goal of this experiment was to determine the species or taxonomic groups of mushrooms that would most likely be consumed by *Philomycus carolinianus* in natural habitats. A total of 51 mushroom species in 18 families, and a single species of lichen, were collected from areas where natural populations of *P.*

carolinianus exist and were evaluated as possible host material. An acceptability index was established for each potential food source by comparing consumption of test mushrooms to a control.

Adults of *P. carolinianus* were used to conduct this experiment at a constant temperature of 22°C. Prior to the initiation of this experiment, the slugs were maintained on gypsy moth diet and had not been exposed to any other food source.

Slugs were placed individually in a cylindrical, plastic container (9 cm diam. X 4.5 cm high) with a single moistened paper towel to maintain humidity. Fresh mushrooms were provided for each test, with the commercially available white mushroom *(Agaricus bisporus*) as the control. Mushrooms were cut into similar dimensions, weighed and then arranged so one piece each of a test and control mushroom were available. Ten replicates (one slug/container) were used per treatment. No slug was used to evaluate more than one species of test mushroom.

Five control containers were set up similarly with a pair of mushrooms pieces but without a mollusc to calculate weight loss or gain of each mushroom. Tests were initiated in the afternoon, as slugs are more likely to feed during the evening, and examined the following morning (approximately 18 hours), and every hour after until at least 50% of either the test or control had been consumed. The mushroom pieces (control and test) were then weighed.

The following acceptability index was used to evaluate feeding preference:

Acceptability Index:

$$\text{A.I.} = \frac{\text{Quantity of test mushroom eaten (g)}}{\text{Quantity of both mushrooms eaten (g)}}$$

Where,

A.I.: 0 Test mushroom-unacceptable

A.I.: 0.01-0.44 Test mushroom-slightly acceptable

A.I.: 0.45-0.55 Test mushroom-moderately acceptable

A.I.: 0.56-1.0 Test mushroom-highly acceptable

The mean change in weight of each species of mushroom tested (test and control) in the control containers was used to correct for temporal change in the weight of the pieces of mushrooms presented to the molluscs. The procedure used is as follows:

A) The weight change in white mushroom and test mushroom in the control containers was calculated by subtracting the initial weight from the final weight.

B) Weight gain in the control containers were subtracted from corresponding mean weight values in containers being evaluated. Conversely, weight loss in the controls were added to corresponding values in the test containers. The A.I. values were then calculated using the adjusted values.

Suitability of green plants: The objective of this experiment was to determine whether select plant species would be consumed by *Philomycus carolinianus* when their preferred host species was not available.

No-choice tests were conducted for a selected number of understory plant species that co-occur with *P. carolinianus* (Table 5-3). Each slug was starved for 24 h prior to the initiation of the experiment and placed in a cylindrical, plastic container (9 cm diam. X 4.5 cm high), lined with a single moistened paper towel. A single intact leaf of the test plant was presented to each slug with no alternative food source for a period of 24 h. If no obvious feeding damage was observed after this period, the test plant was considered to be an unacceptable host.

Statistical analysis: All statistical analyses were done using SAS ® statistical software (SAS Institute, Inc. 2008). The non-parametric Friedman's test (Lockwood III 1998) was used to determine if there were any significant differences among the A.I. of the mushrooms evaluated in the choice test. Acceptability indices were compared using Tukey's post hoc multiple comparison test.

Results

Life History Traits

Growth experiment: *Philomycus carolinianus* gained weight along a sigmoid curve (Figure 5-1), although with dramatic variation. Time to reproductive maturity also varied. This time to achieve reproductive maturity was used as the basis for the separation of the slugs from each of the six clutches into four statistically significant groups ($F = 2081.93$; df = 340; $P < 0.0001$) (Figure 5-2 and Figure 5-4).

A total of 84 slugs (24%) from the total population adhered to the growth pattern characteristic of group 1. These slugs achieved reproductive maturity in 129 ± 6 (± SD) days. The growth rate of group 1 was significantly faster than groups 2 and 3 ($F = 132.9$; df = 262; $P < 0.0001$). The slugs in group 2 achieved reproductive maturity in 173 ± 25 (± SD) days. The growth rate was slower than slugs in group 1, but faster than those in group 3. There were 79 slugs in group 2, representing 23% of the test population. Group 3 took 217 ± 26 (± SD) days to attain reproductive maturity, and was represented by 102 slugs, or 30% of the test population. The mean weight of individuals in groups 1, 2, and 3 continued to increase after first oviposition was achieved;

however, the rate of weight gain progressively declined thereafter (Figure 5-2). Summary data (minimum, maximum and mean) for groups 1, 2 and 3 are represented in Figure 5-3.

Group four was comprised of specimens that exhibited marginal mean weight gain within the first ten days, then established a trend of progressive mean weight decline until death, never achieving sexual maturity (Figure 5-4). Seventy-nine slugs exhibited this growth pattern, representing 23% of the test population. The mean longevity of individuals in group 4 was 64 days (range 12 - 64) and the highest percent mortality occurred between 30 and 40 days (Figure 5-5).

There were 12 individuals (of 356) that were not included in the results as they died prematurely and could not be separated into a distinct group with any level of confidence.

Longevity of *P. carolinianus* was not specifically addressed in this experiment, as the duration of evaluation was only nine months. However, upon termination of this experiment the slugs were re-introduced to the laboratory colony and were still alive and regularly producing eggs after 18 months of being alive.

Fecundity experiment and influence of pairing on reproductive parameters: There was no difference in the length of the pre-oviposition period (juvenile stage) between solitary and paired individuals (t = 0.98; df = 116; *P* = 0.3311) (Table 5-1). There also was no difference in the length of the incubation period for eggs produced by solitary versus paired slugs (t = 1.22; df = 205; *P* = 0.2251). Slugs reared in pairs produced significantly fewer eggs (t = 3.12; df = 228; *P* = 0.002) and had a greater number of days between each egg-laying event, than solitary individuals (t = 4.15; df = 109; *P* < 0.0001). A higher proportion of eggs hatched for individuals reared as pairs than as solitary individuals(t = 4.22; df = 228; *P* < 0.0001) (Table 5-1).

There was a significant increase in the mean number of eggs produced per clutch over successive clutches (*F* = 9.7; df = 5; *P* <0.0001) (Figure 5-6), from. A mean total of 58.8 ± 6.4 eggs were produced for the first clutch whereas 71.1 ± 11.1 eggs were produced for the sixth clutch. The first clutch produced the highest mean percent hatch at 74% (*F* = 2.64; df = 5; *P* = 0.0249), but generally decreased thereafter with some fluctuation (Figure 5-6).

Influence of temperature on egg development: Embryonic development within the egg capsules occurred across the entire temperature range (10 – 29°C) tested. Developmental success was higher at 10, 14, 17 and 21°C, than at 25 and 29°C (F = 10.72; df = 174; *P* < 0.0001) (Figure 5-7). However, the embryos that developed at 10 and 29°C did not hatch (Figure 5-9). Hatching success of clutches incubated at 14, 17 and 21°C were not statistically distinguishable, nor were those incubated at 10, 25 and 29°C (F = 25.76; df = 174; *P* < 0.0001) (Figure 5-9). Among clutches that hatched, incubation period decreased with increasing temperature, so that eggs incubated at 14°C had the longest pre-hatching period, whereas those held at 25°C the shortest (F = 57.85; df = 174; *P* < 0.0001) (Figure 5-8).

Evaluation of Artificial and Natural Diets for Short-term Rearing

Initial weights of slugs in different treatments did not differ (*F* = 0.49; df = 203; *P* = 0.8146) (Figure 5-10). The different food sources had both positive and negative effects on the weight of the slugs (*F* = 92.44; df = 153; *P* < 0.0001) (Figure 5-10). Unfed slugs had the lowest final weight (1.95 g). Spruce budworm diet resulted in the highest final slug weight (6.19 g), although not surprisingly higher than slugs fed gypsy moth diet, or white mushroom. Individuals fed rabbit pellets lost the most weigh over the eight-week period when compared to the other diets, and had a final mean weight of 3.31 g (Figure 5-10).

Slugs laid eggs throughout the duration of the experiment, regardless of food source. Food source significantly (*F* = 31.47; df = 203; *P* < 0.0001) affected the number of clutches produced. Slugs fed white mushroom and rabbit pellets produced on average less than one clutch and were no different from unfed slugs (Figure 5-11).

There was variation in mortality with diet, with slugs fed mushrooms and rabbit pellets having higher mortality than other groups, whereas those reared on the gypsy moth diet and carrot diet suffered no mortality (*F* = 40.81; df = 203; *P* < 0.0001) (Figure 5-12).

Food Preference

There was some degree of separation (*F* = 1839.61; df = 49; *P* < 0.0001) in the acceptability indexes obtained for the mushrooms and the lichen evaluated in this experiment, ranging from highly acceptable to unacceptable (Table 5-2). None of the mushrooms and lichen evaluated was found to be unacceptable to *Philomycus carolinianus*. There were 29 mushrooms and a lichen (60%) that were slightly acceptable, five mushrooms (10%) were moderately acceptable and 15 mushrooms (30%) were highly acceptable. There was no clear preference among the mushroom orders evaluated (Table 5-2).

Philomycus carolinianus did not feed on any of the forest understory or weedy plant species evaluated (Table 5-3).

Discussion

Life History Traits

Growth experiment: *Philomycus carolinianus* specimens held at 21°C generally displayed incremental growth for the first 50 days, followed by rapid mean weight gain, then gradual decline after approximately 200 days (Figure 5-1). There were large variation in rate of weight gain among slugs, both within and between clutches, that are not completely evident in the growth curve. According to Zotin (2007), generic growth curves derived from multiple specimens mask individual growth patterns. Because of this variation, the time to reproductive maturity was selected as the basis for separating individuals displaying disparate rates of weight gain into distinct groups. Four distinct growth patterns were exhibited by *P. carolinianus*: under laboratory conditions groups 1, 2, and 3 had dissimilar rates of weight gain to reproductive maturity (Figure 5-2), whereas group 4 had progressive reduction in weight until death (Figure 5-3).

There are several potential biological reasons for such variation in growth rate including genetically predetermined staggering of growth to reduce sibling competition. This could be a survival mechanism to increase the probability of survival for a cohort of eggs deposited under dissimilar environmental conditions. Hypotheses of adaptation are difficult to think of for the existence of group 4, as these represent developmental failures. It is possible that group 4 eggs are the last to be deposited from each clutch and are endowed with fewer biological resources for survival. Documenting the order in which the eggs are oviposited for each clutch, then statistically determining whether there is a correlation between the order in oviposition and growth rate could test this hypothesis.

There was a noticeable progressive change in the external pigmentation of *Philomycus carolinianus* as the slugs matured. The mantle and sole of juveniles were predominantly white or cream-white and changed to pale orange-brown as the slugs matured. The orange-brown pigmentation appeared darker and intensified with age.

Fecundity experiment and influence of pairing on reproductive parameters: This experiment showed that *Philomycus carolinianus* is capable of selfing or parthenogenesis, and that the reproductive output of selfed/parthenogenetic animal were comparable to paired ones. These data further suggest that there could be some reproductive benefit derived from being reared as solitary individuals because potentially greater numbers of juveniles could be produced from solitary slugs, when compared to paired slugs. Paired specimens did not oviposit as frequently as solitary slugs, nor did they produce clutch sizes as large as solitary specimens, although paired specimens produced clutches with a higher mean percent hatch. *P. carolinianus* was not previously known to be capable of reproducing by self-fertilization or parthenogenesis (Anderson and McCracken 1986; McCracken and Selander 1980). Anderson and McCracken (1986) concluded that there was overwhelming evidence to suggest that *P. carolinianus* reproduced primarily by out-crossing. They also noted that there was some level of genetic homogeneity with populations, which they attributed to sampling error and inbreeding. However, selfing or parthenogenesis will also lead to high genetic homogeneity.

It was not clear in this experiment whether paired specimens reproduced by reciprocal mating or cross-fertilization. However, observations of paired specimens revealed elaborate mating rituals where both parties exhibited trail-following, followed by the apparent fusion of both head regions, as also described by Webb (1968). However, this anecdotal evidence for reciprocal mating was not confirmed by dissection.

The first clutch of eggs produced by *Philomycus carolinianus* had the highest hatching success, compared to subsequent clutches. There was a trend of increasing number of eggs with successive clutches, although the clutches were not statistically different after the third oviposition (Figure 5-6).

Influence of temperature on egg development: Temperature influences biological parameters of all living organisms. The geographic distribution of *P. carolinianus* ranges from temperate to subtropical regions of North America (Hubricht 1985; Pilsbry 1948). The results of this experiment suggest that embryonic development (as here defined) of *P. carolinianus* eggs will occur across the entire temperature range tested, between 10 and 29°C. However, percent development declined above 21°C, with eggs held at 29°C (Figure 5-7).

Evaluation of hatching success indicated that the optimal temperature range for *P. carolinianus* was between 14 and 21°C. Low hatching success occurred in eggs held at 25°C, and eggs held at 10 and 29°C did not hatch. The 29°C constant temperature appeared to exceed the upper temperature development threshold for *P. carolinianus* eggs, as embryos that developed appeared to be viable only for a brief period and did not hatch. Similarly, although 57% of *P. carolinianus* eggs held at 10°C exhibited embryonic development, none hatched after 100 days of observation. On the 120th day of observation, a total of 5 clutches (267 eggs) that were held at the 10°C temperature were randomly selected and removed. These eggs were placed on a laboratory counter overnight (~ 18h) at an ambient temperature of approximately 22°C. The next morning, all (100%) the eggs that had previously displayed embryonic development hatched. The mean proportion of juveniles that hatchedd was calculated for all five clutches, yielding a mean value of 63%. None of the eggs that remained at the 10°C treatment temperature hatched during the prescribed period of evaluation (180 d). After 180 days, the eggs were placed on the laboratory counter at the ambient temperature described previously and held for two weeks. The eggs rapidly deteriorated and there was no eclosion.

This indicates that *Philomycus carolinianus* eggs can survive extended periods of low temperatures, suggesting that eggs could serve as an over-wintering stage. Supporting this, it is evident that embryonic development proceeds at low temperatures and viable embryos will persist for extended periods and emerge when environmental conditions improve. Although constant temperatures used in laboratory evaluations are not a feature of natural environments, the pre-and post eclosion development trends of *P. carolinianus* observed in this experiment could form a useful basis on which to make inferences about similar phenomena in natural populations.

Evaluation of Artificial and Natural Diets for Short-term Rearing

Suitability of the diets evaluated varied greatly, with white mushroom, gypsy moth and spruce budworm diets producing the greatest slug weights, demonstrating superior suitability. Slugs reared on these three diets consistently laid eggs throughout the duration of the experiment; however, mortality was very high for slugs fed white mushroom.

The quality of the white mushroom inside each container degraded rapidly and may have been responsible for the higher mortality. Post-experiment, when the mushroom was replaced and rearing containers changed with greater frequency, the mortality rate was substantially reduced. This suggests that low quality of white mushroom as a possible food source may be an artifact of the experiment. The gypsy moth and spruce budworm insect diets remained palatable to the slugs for the longest periods. This is most likely due to the antibiotic and antifungal compounds included in the formulations.

Carrot and lettuce could be considered reasonable alternatives to white mushroom and gypsy moth and spruce budworm insect diets. Weight of individuals reared on carrot and lettuce was lower, but these slugs produced large numbers of clutches with low percent mortality. The least suitable diets was the rabbit pellets. There was substantial weight loss of slugs reared on this diet, and these animals produced only a single clutch and experienced high mortality. This food source also was rapidly colonized by saprophytic fungi and bacteria.

Upon the termination of this trial all slugs surviving from the unfed treatment were re-integrated into the laboratory colony and maintained on gypsy moth diet. These slugs rapidly gained weight and in approximately three weeks had achieved mean weights comparable to specimens of similar age maintained continuously on gypsy moth diet. Also, these slugs produced clutches with similar frequency and of similar mean clutch size as slugs maintained in the colony. This would suggest that populations in natural habitats would most likely be able to endure prolonged adverse environmental conditions when food resources became limited and quickly recover when conditions improved, and this may be an important feature of *P. carolinianus* survival strategy.

Food Preference

The diet of *Philomycus carolinianus* has been reported to consist of a wide variety of mushrooms, with no noticeable species preference under natural conditions (Ingram 1949). The results of this experiment confirm that this species is, indeed, a fungus feeder. Although none of the mushroom species presented to this animal was rejected, it was clear that *P. carolinianus* displayed some preference.

While there was no detectable variation in preference among mushroom orders evaluated, there was among genera and species. This variability may be explained by chemical or structural (e.g., texture) difference among mushroom species.

Several species of understory plants were offered to *P. carolinianus*; however, none were consumed, suggesting this species will not consume much green plant material in natural habitats.

In summary, *Philomycus carolinianus* has demonstrated four distinct growth patterns under laboratory conditions. This slug has the ability to reproduce by both self-fertilization and cross-fertilization. Clutch sizes produced by this slug can be as large as 102 eggs with percent hatch approaching 100%. Eggs can develop and hatch over a wide temperature range. *P. carolinianus* will consume any mushroom species and can survive for at least eight weeks without food, with full recovery when favorable conditions return. *P. carolinianus* is irrefutably a successful species, and the attributes investigated in this study may contribute to the ability of this species to successfully colonize much of North America.

Table 5-1. Comparison of reproductive parameters of *Philomycus carolinianus* reared in pairs and alone.

Reproductive parameters	Density		Degrees of freedom	p-value
	Solitary	Pair		
Pre-oviposition period (days)	183 ± 2.7 a	189.7 ± 8.4 a	116	0.3311
Time between oviposition events (days)	18.3 ± 1.1 a	33.9 ± 2.8 b	109	< 0.0001
Number of eggs per clutch	58.6 ± 0.7 a	65.5 ± 2.3 b	228	0.002
Percent hatch	64.7 ± 3.8 a	84.6 ± 2.6 b	228	< 0.0001
Incubation period (days)	21.9 ± 0.1 a	21.6 ± 0.2 a	205	0.2251

Data are mean (±SE) for parameters listed. Means in rows followed by the same letter do not differ based on the two-sample t-test ($\alpha = 0.05$)

Table 5-2. Choice test evaluation of select mushroom species commonly found in Florida by *Philomycus carolinianus* for acceptability as food source.

Order	Family	Species	A.I.	Mean A.I.
Agaricales	Agaricaceae	*Agaricus bisporus*	-	0.42 a
		Agaricus blazei	0.3 op	
	Amanitaceae	*Amanita komarekensis*	0.16 uv	
		Amanita phalloides	0.43 kl	
		Amanita rubescens	0.87 c	
		Amanita sp.	0.23 rs	
		Amanita vaginata	0.13 v	
		Amanita verna	0.25 r	
		Amanita virosa	0.43 kl	
	Auriculariaceae	*Auricularia* sp.	0.14 v	
	Lepiotaceae	*Chlorophyllum molybdites*	0.62 e	
		Leucoagaricus sp.	0.19 tu	
		Leucocoprinus luteus	0.2 st	
	Marasmiaceae	*Lentinula edodes*	0.56 gh	
	Pluteaceae	*Pluteus* sp.	0.41 l	
	Strophariaceae	*Naematoloma* sp.	0.22 rst	
	Tricholomataceae	*Armillaria mellea*	0.93 b	
		Armillaria tabescens	0.45 k	
		Lepista sp.	0.94 b	
		Collybia iocephala	0.57 fg	
		Macrocybe titans	0.33 no	
	Clavariaceae		0.35 mn	
Phallales	Phallaceae	*Clathrus columnatus*	0.06 w	0.06 b
Lecanorales	Cladoniaceae	*Cladina evansii*	0.04 w	0.04 b
Boletales	Strobilomycetaceae	*Tylopilus felleus*	0.15 v	0.46 a
		Tylopilus rhoadsiae	0.04 w	
	Xerocomaceae	*Phylloporus boletinoides*	0.99 a	
	Sclerodermataceae	*Scleroderma* sp.	0.53 hi	
	Suillaceae	*Suillus cothurnatus*	0.6 ef	
	Boletaceae	*Boletus edulis*	0.05 w	

Table 5-2. Continued

Order	Family	Species	A.I.	Mean A.I.
		Boletus granulosiceps	0.29 pq	
		Boletus luridiceps	0.99 a	
		Boletus oliveisporus	0.92 b	
		Boletus ornatipes	0.57 fg	
		Boletus rubellus	0.42 kl	
		Boletus underwoodii	0.33 no	
		Leccinum albellum	0.14 v	
Cantharellales	Hydnaceae	*Hydnum* sp.	0.13 v	0.47 a
	Cantharellaceae	*Cantharellus cibarius*	0.82 d	
Polyporales	Ganodermataceae	*Ganoderma applanatum*	0.51 ij	0.47 a
		Ganoderma lucidum	0.55 gh	
		Ganoderma sp.	0.26 qr	
	Polyporaceae	*Lentinus crinitus*	0.37 m	
		Lentinus sp.	0.83 d	
		Panus rudis	0.49 j	
		Trametes sp.	0.44 kl	
		Tyromyces sp.	0.32 nop	
	Pleurotaceae	*Pleurotus ostreatus*	0.42 kl	
Russulales	Russulaceae	*Lactarius hygrophoroides*	0.63 e	0.56 a
		Lactarius luteolus	0.25 r	
		Russula emetica	0.8 d	

Values shown are acceptability index (A.I.) of test mushrooms consumed as compared to the control (white mushroom). Values within each column with the same letters are not significant different (Tukey's test α = 0.05).

Table 5-3. Plants used to conduct a no-choice test: none were consumed.

Weedy plants	Understory plants
Monocotyledons	Monocotyledons
Commelina diffusa	Panicum dichotomiflorum
Cyperus brevifolius	Microstegium vimineum
Cyperus globulosus	Digitaria ciliaris
Cyperus rotundatus	
Andropogon virginicus	
Digitaria sanguinalis	
Eleusine indica	
Dicotyledons	Dicotyledons
Alternanthera pungens	Lespedeza striata
Bidens alba	Callicarpa americana
Drymaria cordata	Vitis sp. (Muscadine)
Ambrosia artemisiifolia	Smilax bona-nox
Eupatorium capillifolium	Smilax rotundifolia
Wedelia trilobata	Smilax glauca
Dichondra carolinensis	Diospyros sp.
Chamaesyce hirta	Galium aparine
Phyllanthus urinaria	Desmodium tortuosum
Portulaca amilis	Hedyotis corymbosa
Portulaca oleracea	Rubus cuneifolius
Richardia brasiliensis	Acalypha sp.
Hydrocotyle sp.	Nephrolepis sp.
Arachis glabrata	

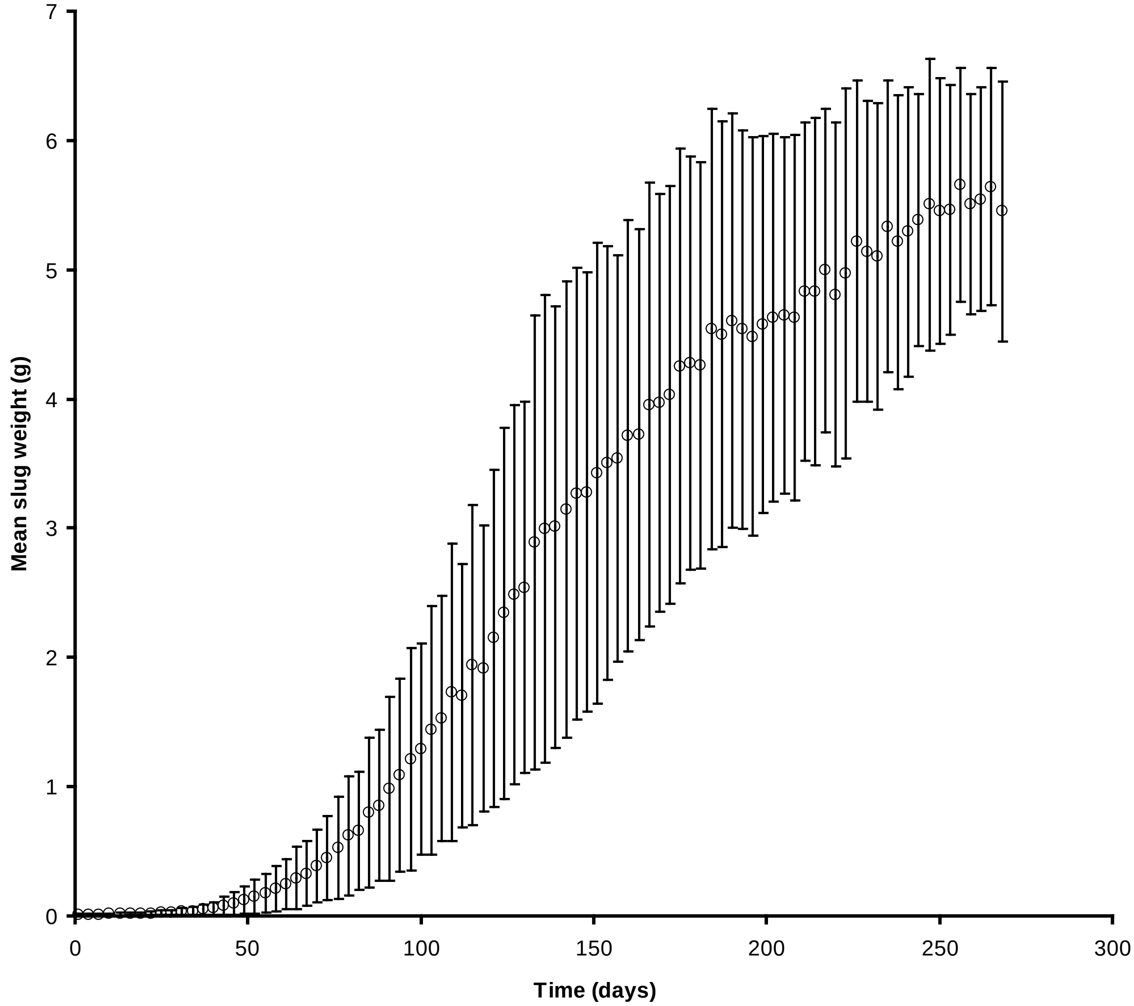

Figure 5-1. Mean (± SD) weight of 356 *Philomycus carolinianus* slugs reared on gypsy moth diet (Bio-Serv, Frenchtown, NJ) from hatchlings to reproductive maturity at 21°C.

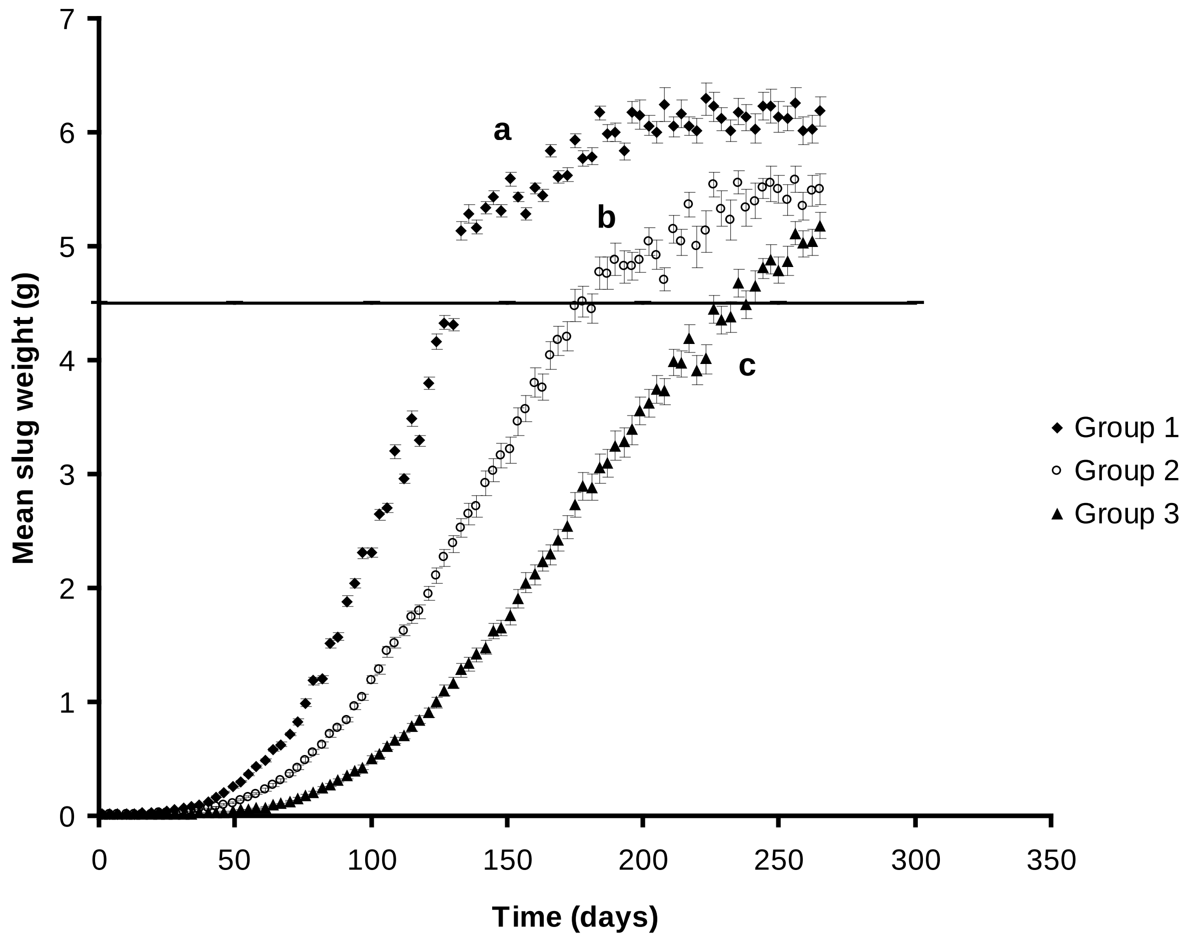

Figure 5-2. Mean weight (± SE) slugs in three of four cohorts exhibited by *Philomycus carolinianus* individuals reared on synthetic gypsy moth diet from egg-eclosion to sexual maturity at 21°C. Horizontal line denotes mean weight at first oviposition (reproductive maturity). Curves followed by the same letter are not significantly different from each other (Tukey's test α = 0.05).

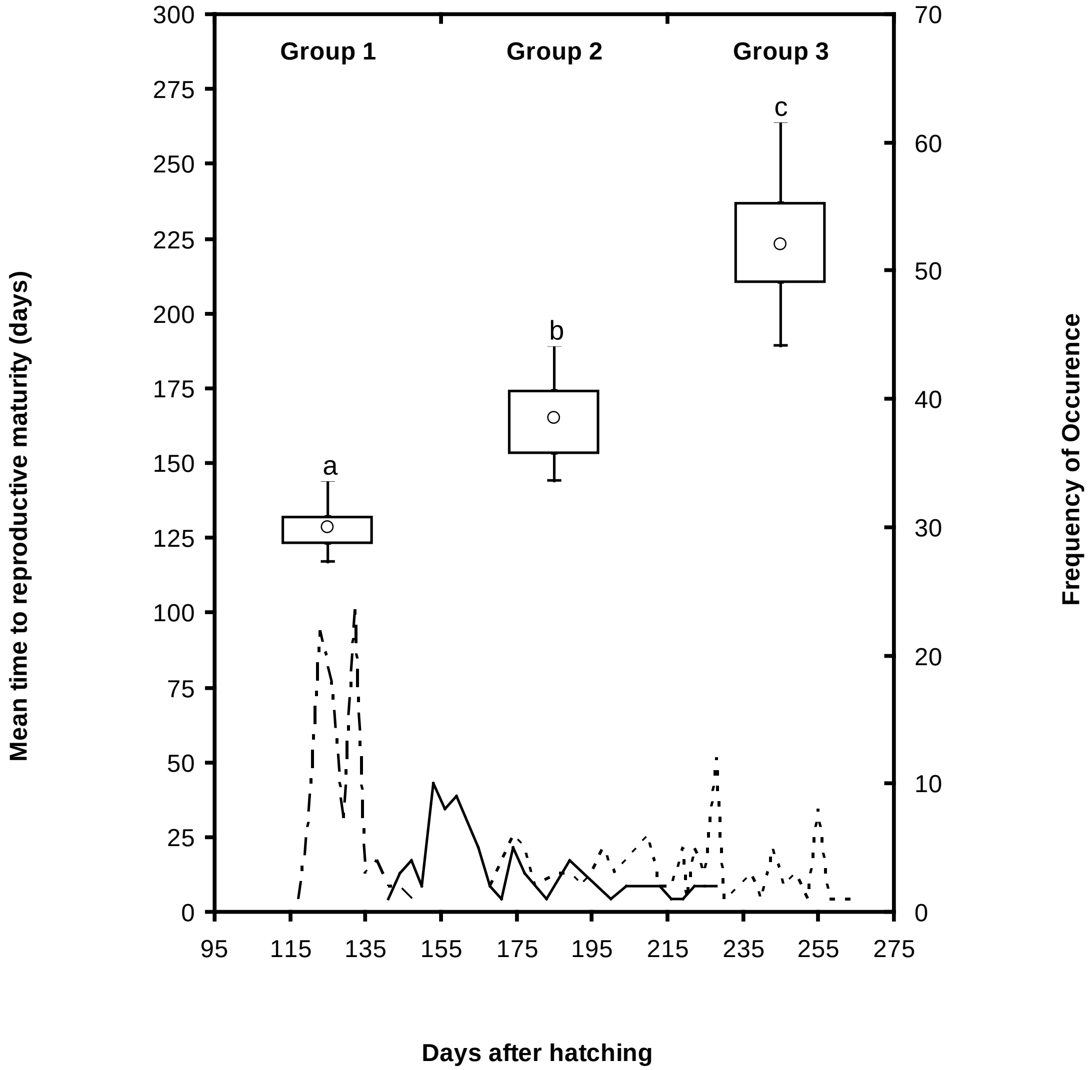

Figure 5-3. Mean time to reproductive maturity of slugs exhibiting three of four growths patterns displayed by *Philomycus carolinianus* slugs reared on synthetic gypsy moth diet from egg-eclosion to sexual maturity at 21°C. Box plots indicate the mean, minimum, maximum, upper and lower quartiles of each group. Curves indicate the time to maturity of individuals in each group and the corresponding frequency. Box plots followed by the same letter are not significantly different (α = 0.05; Tukey's test).

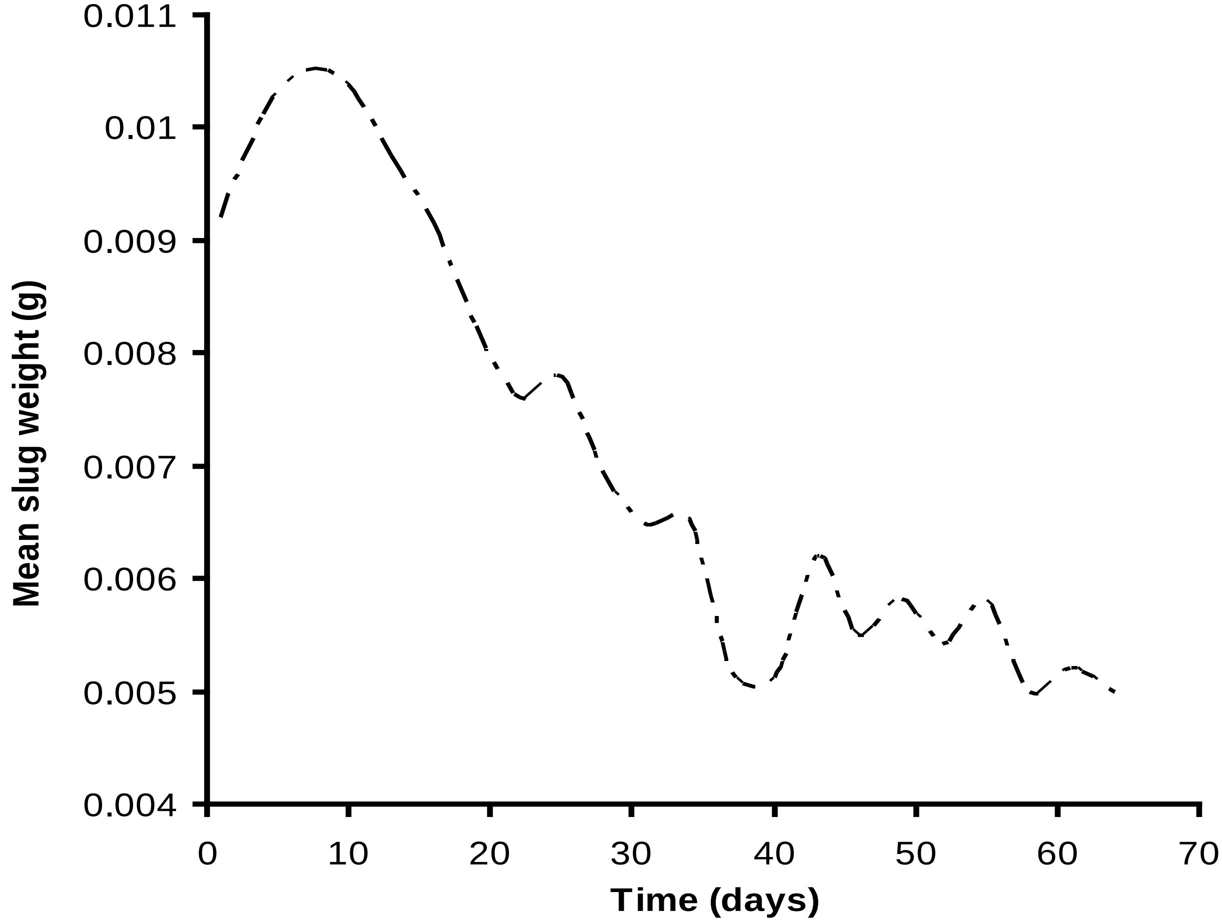

Figure 5-4. Mean weight of *Philomycus carolinianus* slugs that in the fourth growth pattern, reared on gypsy moth diet (Bio-Serv, Frenchtown, NJ) from hatchlings until death at 21°C. This growth pattern is characterized by progressive mean weight decline. Specimens following this growth pattern never achieved sexual maturity.

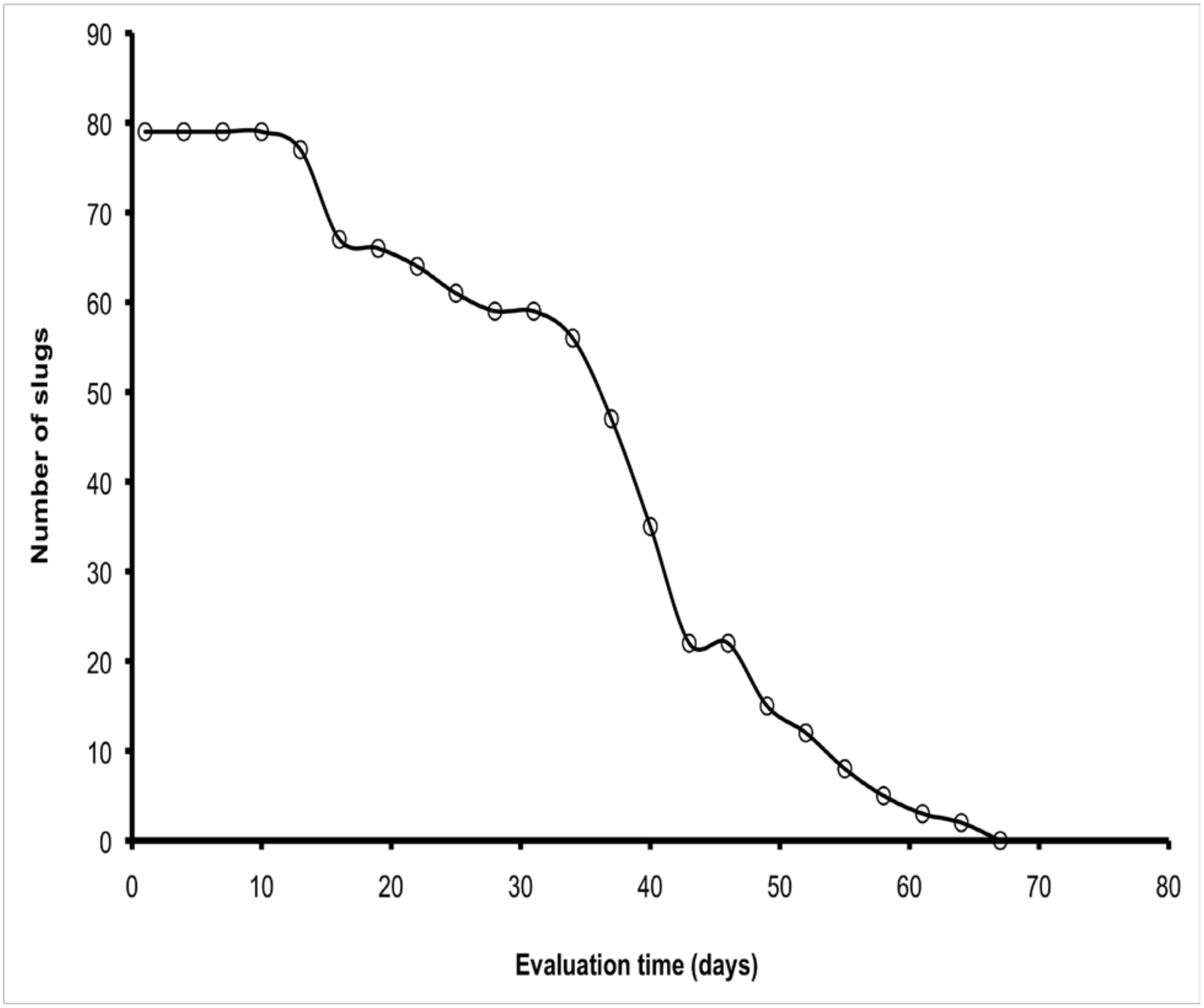

Figure 5-5. Temporal trend in survivorship of the 79 *Philomycus carolinianus* slugs that exhibited the fourth growth pattern when held at 21°C and reared on gypsy moth diet (Bio-Serv, Frenchtown, NJ).

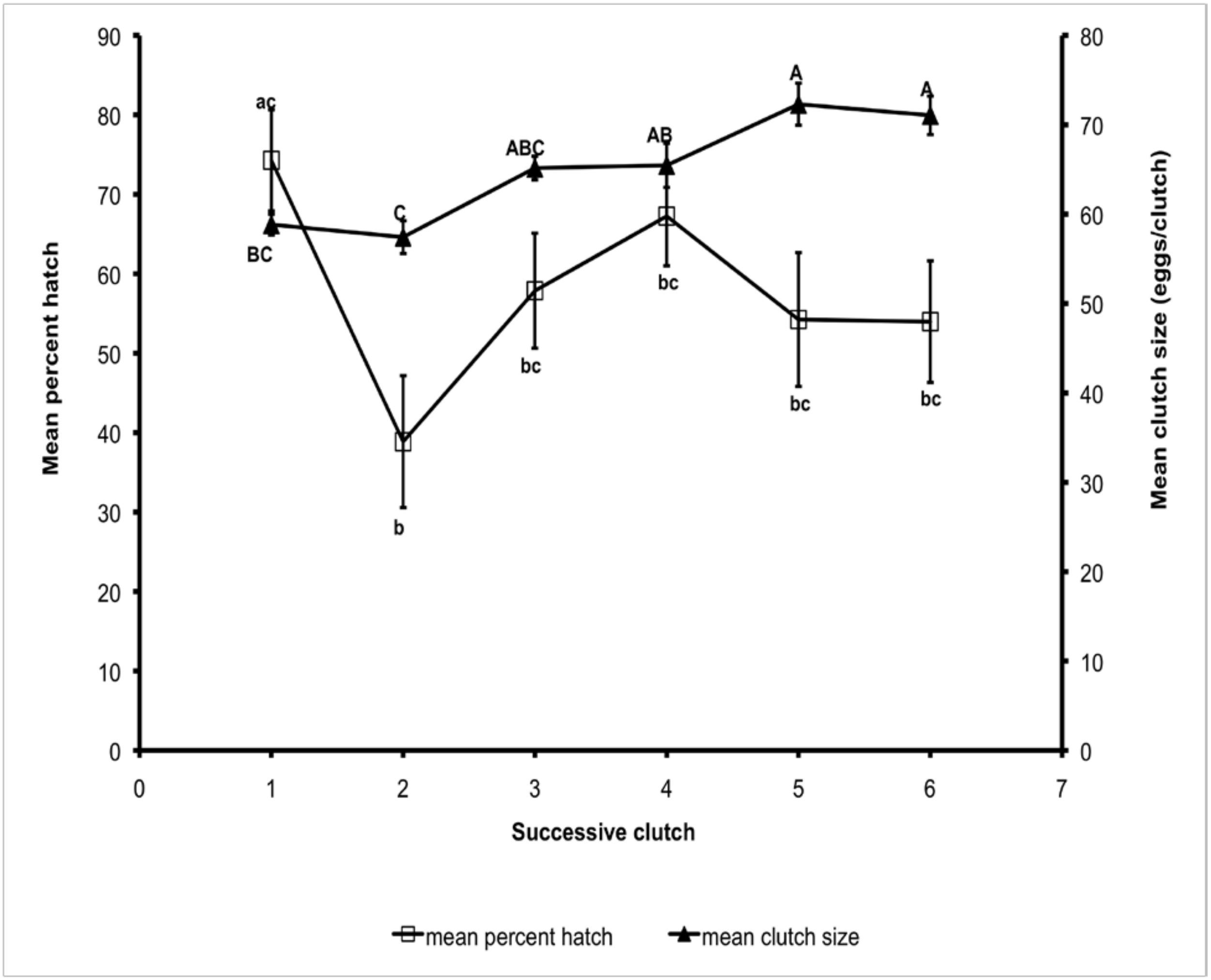

Figure 5-6. Mean percent hatch and mean clutch size for the first six consecutive clutches produced by *Philomycus carolinianus* slugs held at 21°C when reared on gypsy moth diet (Bio-Serv, Frenchtown, NJ). Graphs followed by the same case letters are not significantly different (Tukey's test α = 0.05).

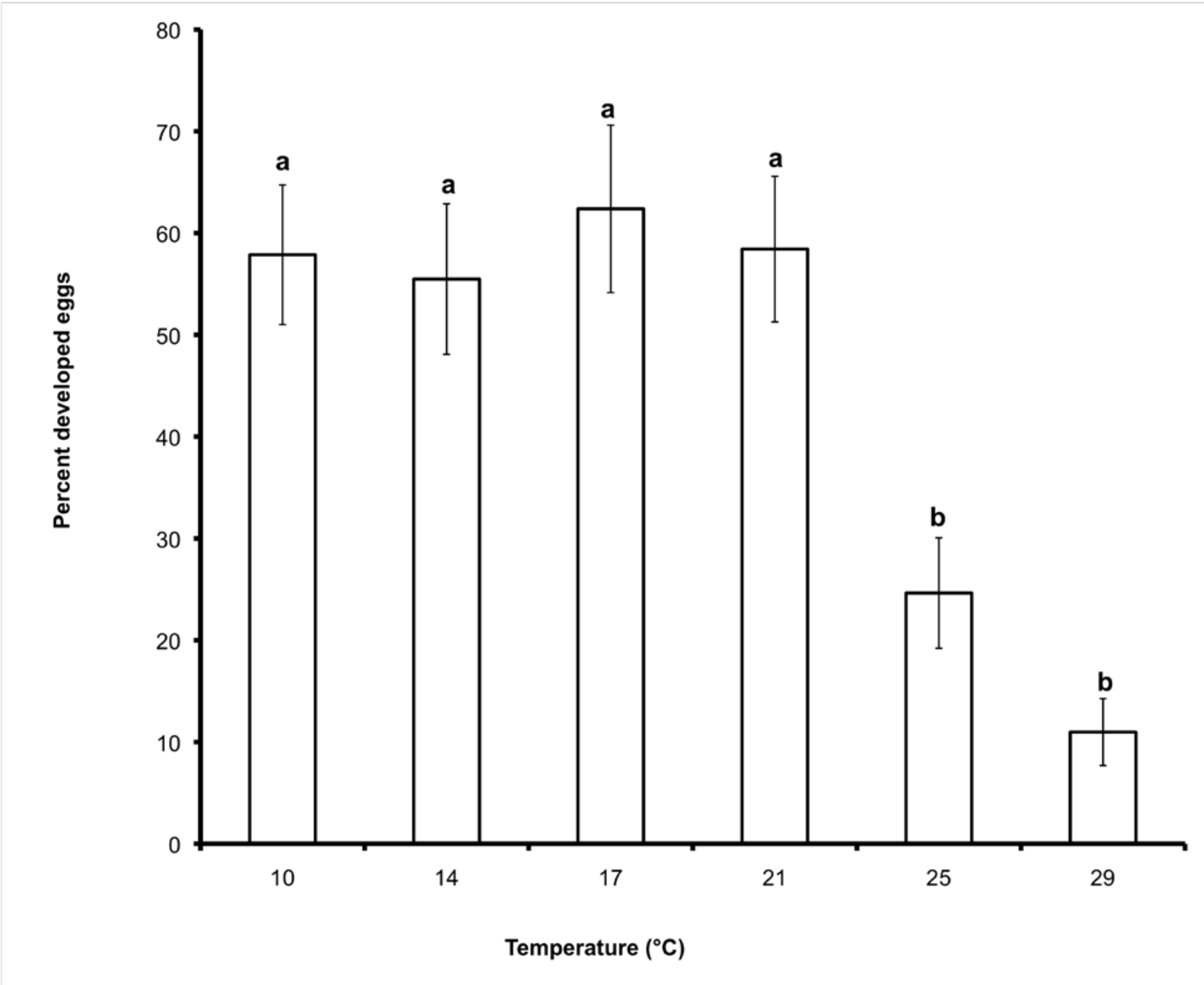

Figure 5-7. Mean (± SE) percent successful embryonic development of *Philomycus carolinianus* eggs held at six constant temperatures. Bars with same letter are not significantly different (α = 0.05; Tukey's test).

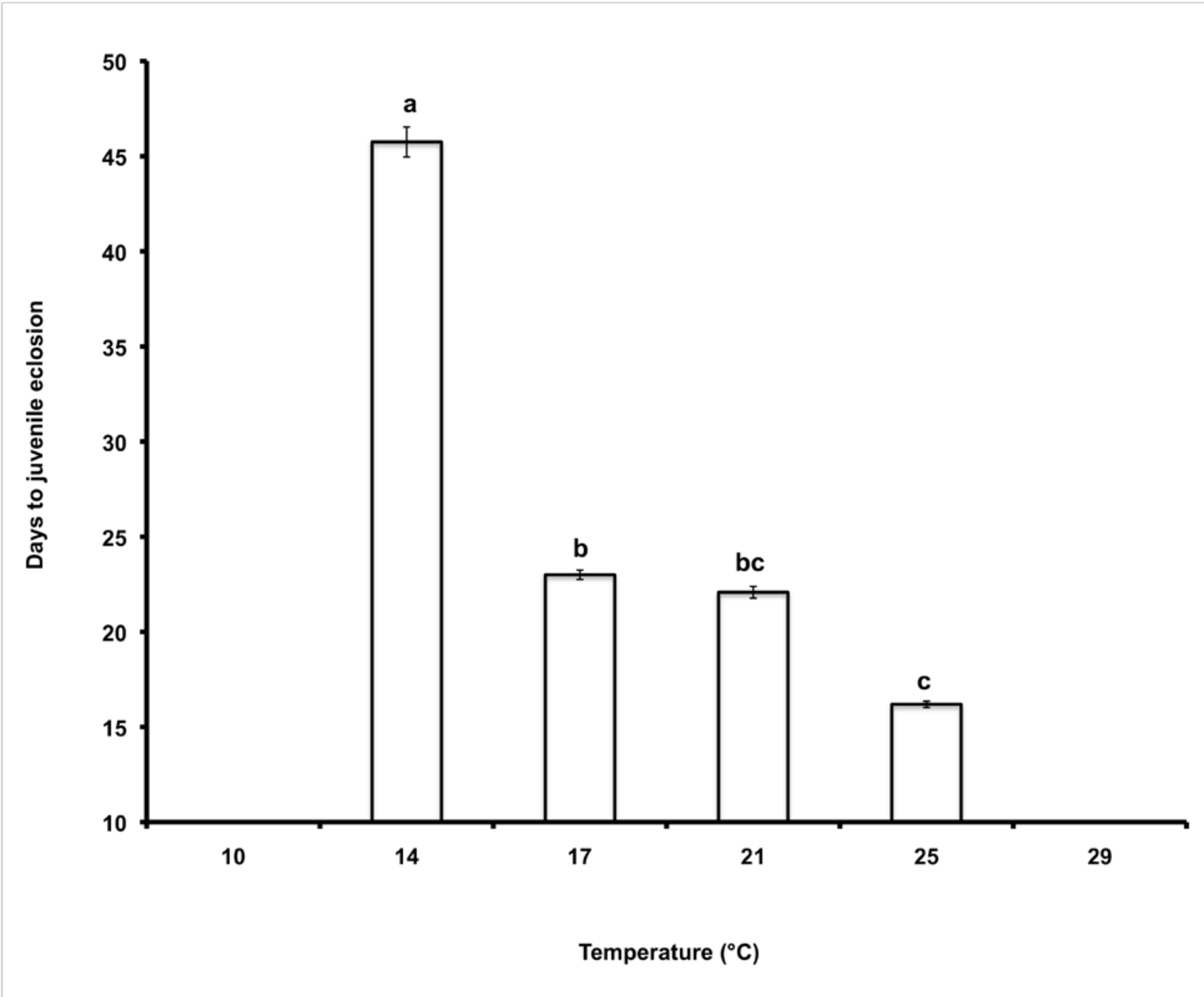

Figure 5-8. Mean (± SE) days to juvenile eclosion of *Philomycus carolinianus* eggs held at six constant temperatures. Bars with the same letter label are not significantly different (α = 0.05; Tukey's test).

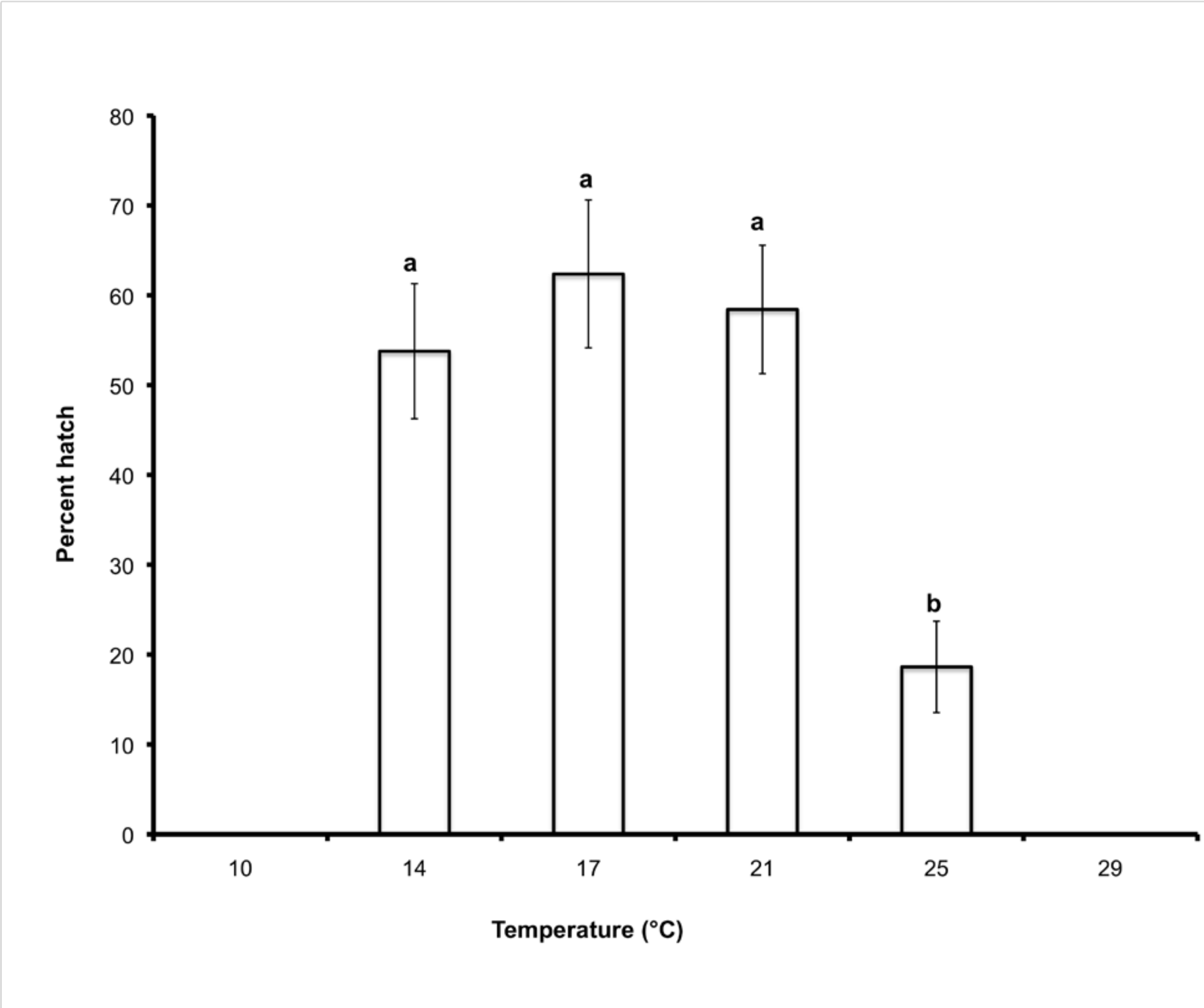

Figure 5-9. Mean (± SE) percent hatch of *Philomycus carolinianus* eggs held at six constant temperatures. Bars with the same letter label are not significantly different (α = 0.05; Tukey's test).

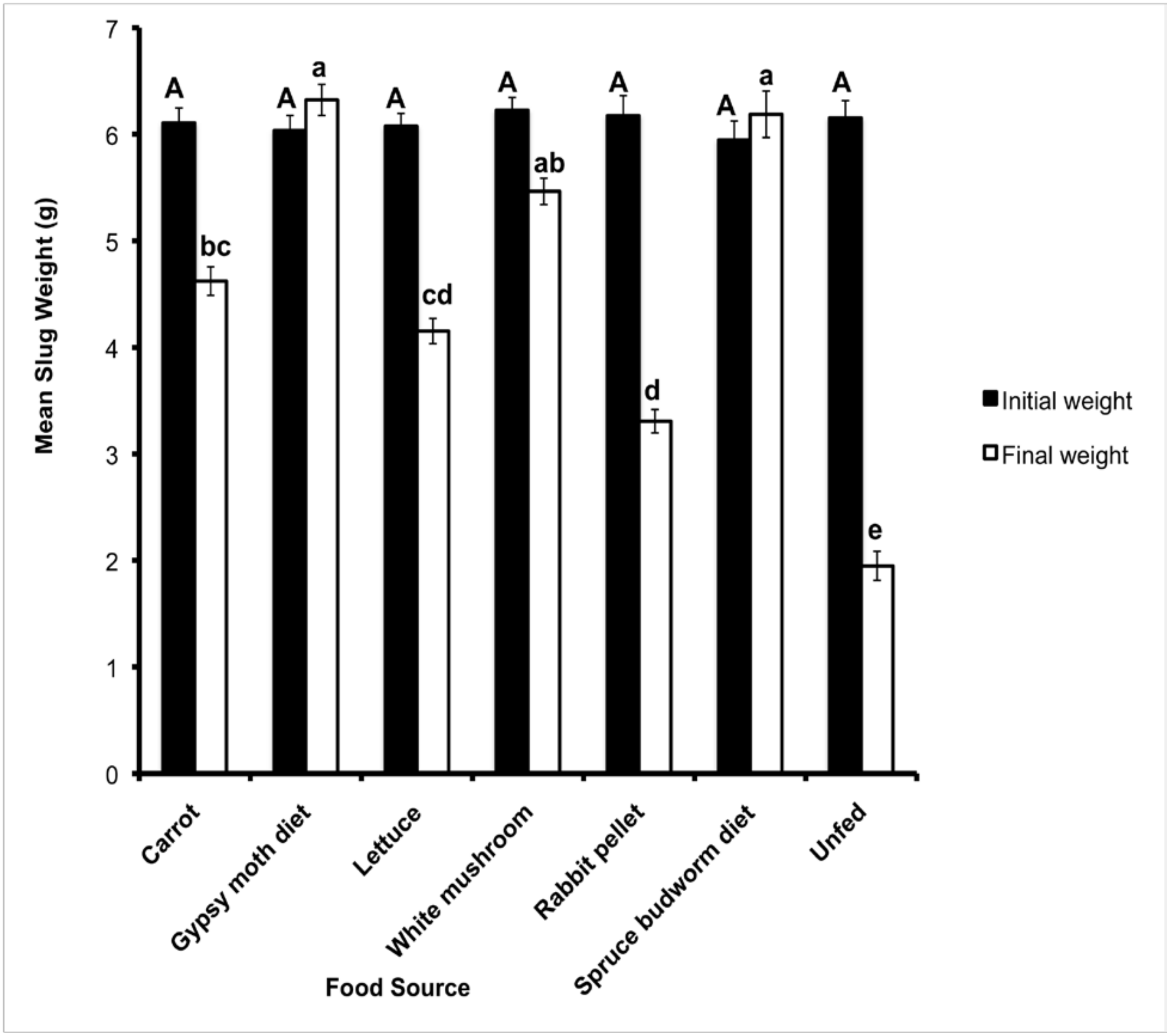

Figure 5-10. Mean (± SE) weight of *Philomycus carolinianus* slugs reared on seven test diets for eight weeks. Solid bars: initial, hollow bars: final weights. Weights with the same case letters are not significantly different (Tukey's test α = 0.05).

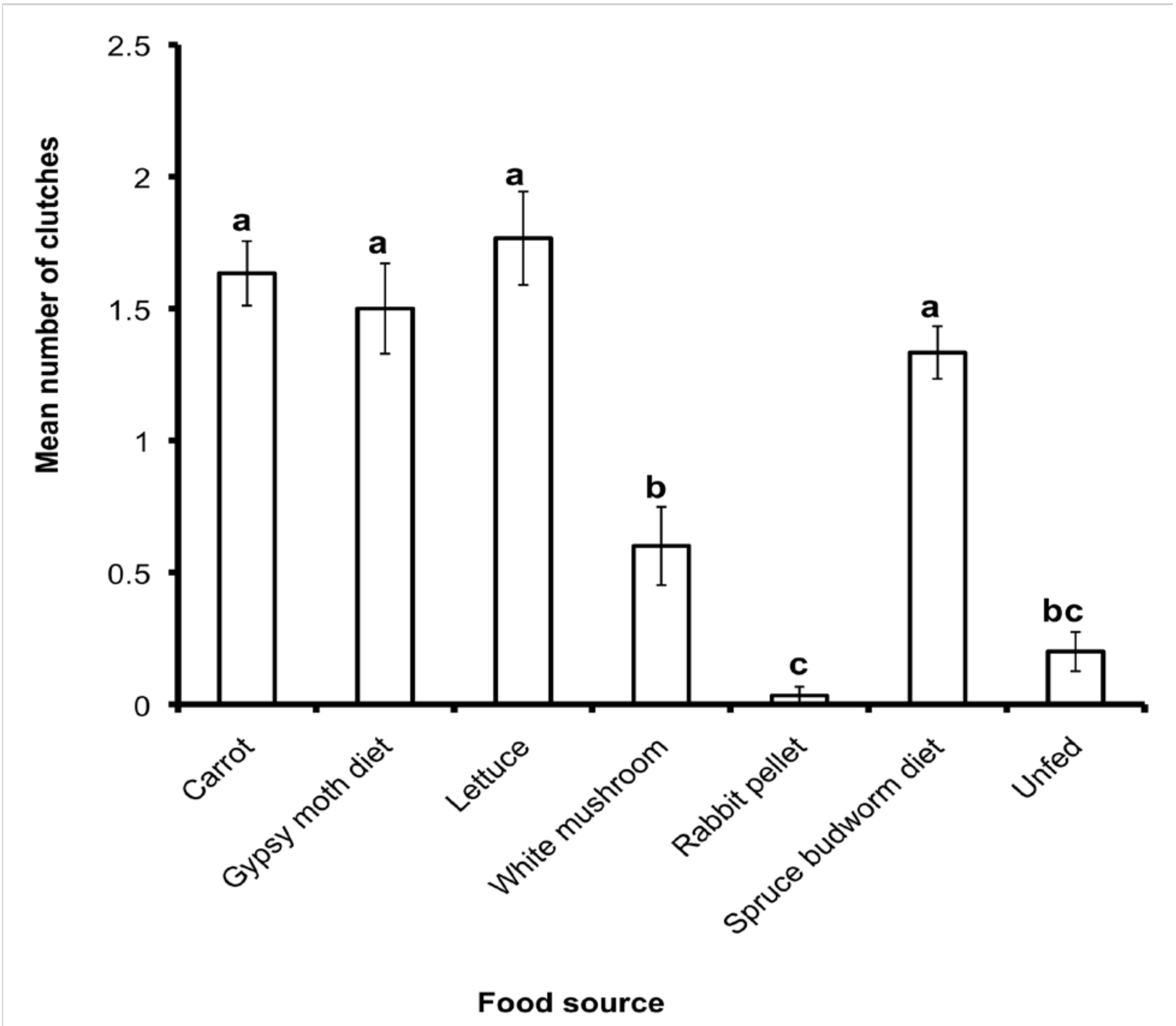

Figure 5-11. Mean (± SE) number of clutches produced in eight weeks by *Philomycus carolinianus*. Bars with the same letters are not significantly different (Tukey's test α = 0.05).

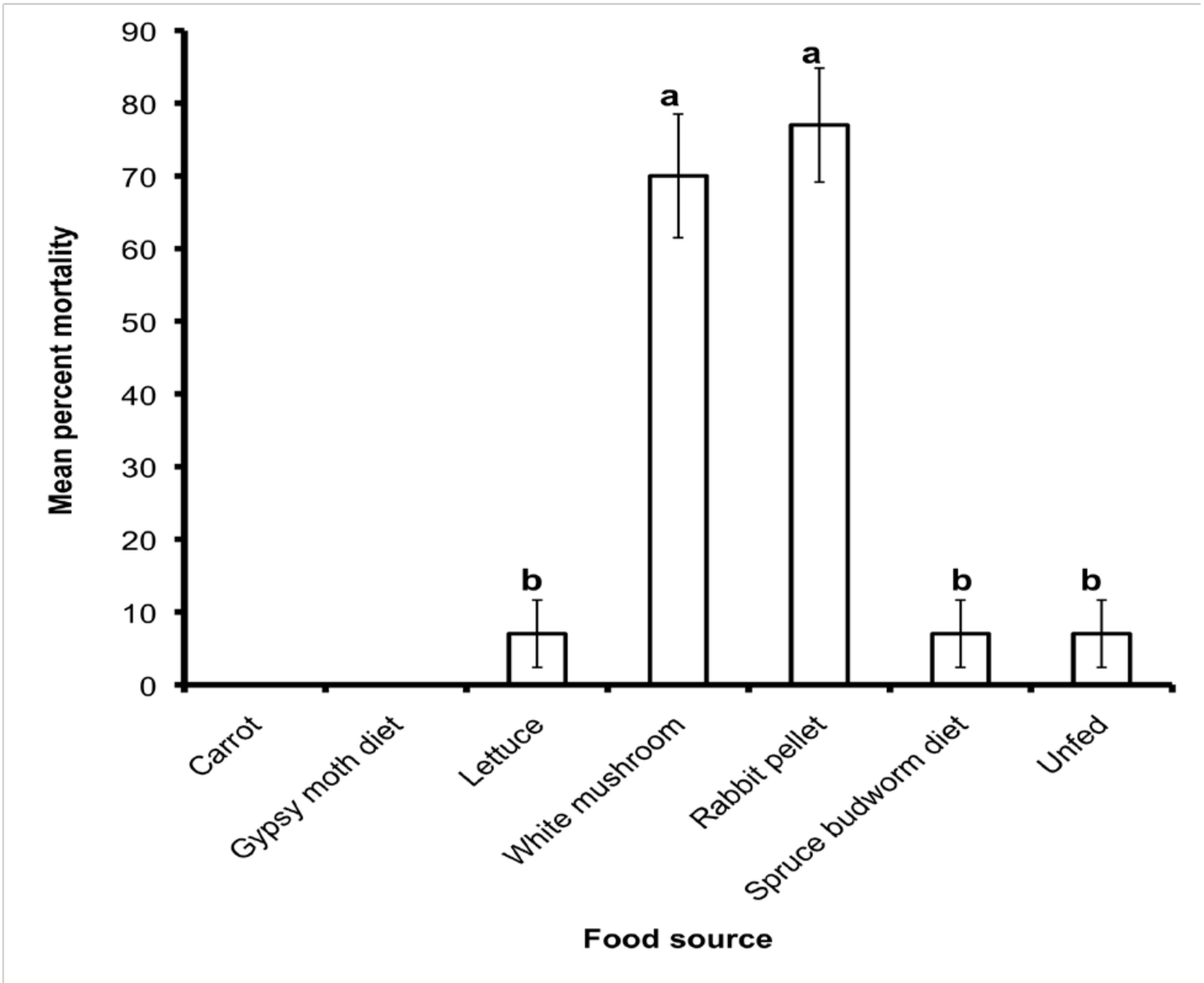

Figure 5-12. Mean (± SE) percent mortality of adult slugs of *Philomycus carolinianus* when reared on seven test diets for eight weeks. Bars with the same letters are not significantly different (Tukey's test $\alpha = 0.05$).

CHAPTER 6
PRELIMINARY FINDINGS ON THE EVISION OF THE GENUS *PHILOMYCUS* (PULMONATA: STYLOMMATOPHORA: PHILOMYCIDAE)

Introduction

Philomycus, type genus of the Philomycidae, are large slugs native to eastern North America. Like other Philomycidae they share the following characteristics: a mantle that extends over the dorsal surface of the animal, a foot with an undivided sole, a large empty shell sac (Burch 1962), and a penis that lacks an epiphallus (Pilsbry 1948). All species of *Philomycus* have a large calcareous stimulating organ, a synapomorphy which defines the genus. Members of this genus feed on fungi and forage at night or during wet weather (Ingram 1949) and are frequently observed ascending or descending trees (South 1992). During dry weather they aestivate on or under loose tree bark or decaying trees.

Species of *Philomycus* are defined largely by mantle color pattern. The shell, a rich source of taxonomic characters, cannot be used for shell-less slugs. Other traditional characters like genital anatomy as well as radula and jaw morphology are described for only two species of Philomycus: *P. togatus* (as *P. bisdosus* and *P. batchi)* and *P. venustus* (Branson 1968; Fairbanks 1989), making comparisons across species impossible. In fact, most species are known only from their original descriptions and no formal revision or synthesis of the group has been attempted. Therefore, no evaluation of the variation of mantle color pattern within species is possible, and this character's efficacy for species diagnosis remains poorly explored.

In order to evaluate mantle pattern variation as a means of species delineation, independent characters are needed to provide support for such categorization. A combination of external (mantle pattern) and internal (genital and jaw) morphological characters has been used to separate the species in other stylommatophora genera. Chichester and Getz (1968) noted that the use of genitalic characters for specific level diagnosis was reliable in almost all described terrestrial gastropod species. In this portion of the study, phylogenetic analyses and morphological (external and genitalic) characters of the species of *Philomycus* are used to conduct a complete revision of the group. As noted above, much of the prior taxonomy of this group was based on mantle color patterns, which can be quite variable within species and even populations. Genitalic, jaw, and radula characters as well as DNA sequence data will be used to evaluate mantle pattern variation as a justifiable means of separating the species in this genus.

Materials and Methods

Species Definition

Species boundaries are most effectively explored when species are sympatric, as then individuals of different forms have the opportunity to interbreed. Absence of significant gene flow between two forms in sympatry then provides strong evidence that these forms represent biological species. Absence of gene flow can be demonstrated when two independent morphological and/or genetic characters (such as mtDNA sequences and mantle color pattern) covary, so that each form has a unique combination of character states in these two characters. Similarly, demonstrated absence of gene flow between allopatric forms implies differentiation, but does not test for reproductive isolation as allopatric populations do not have the physical proximity to test for interbreeding. Such populations nevertheless fit the phylogenetic species concept. To test differentiation among forms and populations, mtDNA was sequenced, and color and anatomical characters determined for each slug.

Specimen Collection and Preparation

Collection. Specimens were collected from across each species' documented range, including their type localities. An albino *Philomycus* sp. collected from the Fakahatchee Strand Preserve, Copeland, Florida was also included. Specimens were drowned in water and fixed in 75% ethanol in the field; however, a few were preserved in 95% ethanol. They were then labeled and deposited under unique catalog numbers at the Florida Museum of Natural History, University of Florida, Gainesville (UF). Preserved material from the Field Museum of Natural History, Chicago (FMNH) was also evaluated.

Preparation. The collected specimens were photographed (alive and preserved) prior to being dissected under a dissecting microscope. It should be noted that mantle patterns are retained in preserved specimens. All adult specimens were scored except those that had deteriorated internally, totaling 24 *Philomycus* and 2 *Megapallifera* (Philomycidae- outgroup).

The hermaphroditic reproductive systems, were dissected from the specimens under a dissecting microscope, and photographed before being examined for distinguishing characters. Buccal masses and jaws were dissected and jaws photographed, then tissue removed by soaking in household bleach (sodium hypochlorite solution). The jaws and radulae exposed by this digestion were then rinsed in a series of distilled water baths to remove bleach crystals. Cleaned jaws and radulae were photographed using a field emission scanning electron microscope.

Morphological Characters

Thirty-four characters were evaluated for each specimen (Table 6-1). Character states were selected based on published work or by observations of preserved material. Anatomical traits from the reproductive system, jaw, radula and external color pattern were included. Geographic distribution was documented based on checked and verified specimens in UF and FMNH collections (Table 6-2).

Adult Reproductive System Characters

1. **Ovotestis color**. 0=cream; 1=gray. Pale-colored ovotestis were considered cream, regardless of whether they were off-white or cream. Ovotestis with other colors (ranging from a pale gray to slate gray) were coded as gray.

2. **Ovotestis.** 0=multilobed and compact; 1=multilobed and loose. The ovotestis of *Philomycus* appears multi-lobed but forms a single unit. The ovotestis of *Megapallifera* is multi-lobed, but each lobe hangs loosely and does not cluster together to form a single unit.

3. **Length of hermaphroditic duct.** 0=5-10mm; 1=10-15mm; 2=>15mm. This was measured from the obvious origin of the tube at the junction with the ovotestis, to that of the common duct (albumen gland).

4. **Length of free oviduct.** 0=3-5mm; 1=>5mm.

5. **Maximum diameter of free oviduct.** 0=0.1-0.5mm; 1=0.5-1.3mm.

6. **Bursa copulatrix diameter.** 0=0-3mm; 1=3.1-6mm. This was measured across its widest part.

7. **Bursa copulatrix duct length.** 0=5-10mm; 1=11-15mm; 2=16-20mm; 3=>21mm. The bursa copulatrix duct length was measured from origin of the tube at the base of the inflated distal end to the origin of the dart sac.

8. **Maximum diameter of bursa copulatrix duct.** 0=0.5-0.9mm; 1=>1mm.

9. **Dart sac as large as or larger than widest part of penis.** 0=no; 1=yes.

10. **Dart sac.** 0=absent; 1=present. *Philomycus* is the only genus of Philomycidae that posses a dart sac. This structure can be found at the junction of the free oviduct and the bursa copulatrix duct.

11. **Dart sac maximum diameter.** 0=0-2.5mm; 1=2.6-4.5mm; 2=>4.6mm.

12. **Atrium.** 0=short; 1=long. The atrium was considered short if it was < 10mm.

13. **Vas deferens of uniform thickness.** 0=no; 1=yes.

14. **Vas deferens length.** 0=15-20mm; 1=21-30mm; 2=31-39mm; 3=>40mm.

15. **Vas deferens maximum diameter.** 0=1-5mm; 2=>5mm.

16. **Vas deferens loops around penis.** 0=no; 1=yes. In *P. venustus*, the vas deferens typically encircles the distal portion of the penis as seen in Fairbanks (1989) Figure 6.

17. **Penial sheath as long as penis.** 0=no; 1=yes.

18. **Penial sheath uniform thickness.** 0=no; 1=yes.

19. **Penis shape.** 0=curved; 1=straight. When not everted, the penis of *Philomycus* is typically re-curved onto the atrium giving the organ a ‘c’-shaped appearance (curved). The penis of *Megapallifera* is cylindrical and elongated (straight).

20. **Proximal region of penis larger (wider) than distal portion.** 0=no; 1=yes

21. **Proportional length of penial sheath vs. length of penis.** 0=1/3 length of penis; 1=1/2 length of penis; 2=3/4-full length of penis. This ratio gives an estimation of the length of the penial sheath in relation to the length of the penis.

Dart Characters

22. **Dart present in dart sac.** 0=no; 1=yes.

23. **Dart shape.** 0=sigmoid (Figure 6-11A); 1=slightly curved (Figure 6-11C, D); 2=strongly curved (Figure 6-11B, E); 3=absent.

24. **Dart distally.** 0=closed; 1=open.

25. **Dart proximal opening.** 0=slit; 1=narrow; 2=wide; 3=absent. The opening of the dart is variable in shape (Figure 6-11A). The opening of *P. carolinianus* is always slit-like. The openings described as narrow were either obstructed or small and irregularly shaped, never slit-like. Openings described as wide are often unobstructed, open and obviously flared.

26. **Dart proximal end.** 0=ringed and thick (Figure 6-11A); 1=ringed and thin (Figure 6-11B); 2=not ringed (Figure 6-11D).

Jaw Characters

27. **Jaw pleated/ribbed.** 0=no; 1=yes. The jaws of *Philomycus* are never ribbed (Figure 6-12). There may be faint striations on the jaws but not deep grooves or folds (pleats) as in *Megapallifera*.

Tentacle Character

28. **Tentacle color.** 0=flesh colored; 1=soot colored. The tentacles of the albino color variant of *P. carolinianus* are flesh-colored (Figure 6-4). The tentacles of this species are of similar color to the mantle of the animal, unlike other species in the genus that have a soot-colored tentacle (Figure 6-4).

Mantle Characters

29. **Mantle peach colored.** 0=no; 1=yes. The peach-colored mantle may also be described as flesh-colored, but never white (Figure 6-4).

30. **Chevron stripes.** 0=absent; 1=present. The oblique stripes on the mantle of *Philomycus* have been termed chevrons (chevron in appearance-where the arms extend anteriorly from the center) in the literature, maintained for consistency here.

31. **Two rows of black spots.** 0=absent; 1=present. The two rows of black spots here refer to the two rows of black spots on the mantle that saddle the dark central band, typical of the traditional *P. carolinianus*.

32. **Double row of black spots extends 2/3 length of mantle.** 0=absent; 1=present. As figured in *P. sellatus* described by Hubricht (1972) fig. 1d-e.

33. **Dark transverse band across back.** 0=no; 1=yes. As figured in *P. sellatus* described by Hubricht (1972) fig. 1d-e.

34. **Anterior margin of dark transverse band cream colored.** 0=no; 1=yes. As figured in *P. sellatus* described by Hubricht (1972) fig. 1d-e.

Morphological Phylogenetic Analysis

The character matrix of 34 characters, was converted to a nexus file using Mesquite© (Maddison and Maddison 2011). Maximum parsimony (MP) analysis was conducted using PAUP version 4.0b10 (Phylogenetic Analysis Using Parsimony) (Swofford 2002), with 10000 bootstrap replicates: Heuristic search with 10 random addition sequence (total of 1364 trees retained), TBR (tree-bisection-reconnection) with 100 random additions, character optimization criteria set as accelerated transformation (ACCTRAN), topological constraints were not enforced, zero-length branches were not collapsed. All characters were unordered and equally weighted.

For the most parsimonious trees obtained, a strict and a 50% majority-rule consensus were constructed. An unconstrained topology was chosen as *Philomycus* is monophyletic. *Megapallifera mutabilis* (Philomycidae) was used as the outgroup.

Isolation of DNA, Amplification by PCR and Sequencing

Sixty-four specimens were sequenced (Table 6-3): 36 *Philomycus*, 12 *Pallifera* (Philomycidae), 12 *Megapallifera* (Philomycidae), 1 *Incilaria*

(Philomycidae), 1 *Meghimatium* (Philomycidae) and 2 *Limax* (Limacidae) (Figure 6-1). Specimens from several genera in Philomycidae were used to test whether *Philomycus* is monophyletic.

DNA was extracted from 'foot' tissue using the DNAzol (Molecular Research Center, Inc., Chomczynski et al. 1997) extraction protocol of Meyer (2003).

The CO1 mitochondrial gene region of interest was amplified using the Folmer et al. (1994) primers LCO-1490 (5'-3') (forward) TGTAA AACGACGGCCAGTGGTCAACAAATCATAAAGATATTGG, and HCO-2198 (5'-3') (reverse) CAGGAAAGCTATGACTAAACTTCAGGGTGACCAAAAAATCA.

The polymerase chain reaction was carried out in 25.5 µL volumes inclusive of 1 µL template. Each PCR reaction contained 10.4 µL ddH2O, 2.5 µL 10X PCR buffer, 3.0 µL MgCl2 solution (25 mM stock), 2.5 µL dNTPs (10 mM stock), 1.0 µL of each primer (HCO and LCO (10µM stock)), 4.0 µL BSA and 0.1 µL Taq (5 Units/µL stock). After an initial denaturation at 95ºC for 2.5 minutes, the reaction was run for 41 cycles under the following conditions: 94ºC for 40 sec (denaturation), then 42ºC for 40 sec (annealing), and 72ºC for 60 sec (extension). The final product was then held at 72ºC for 3 minutes, then at 4-10ºC until retrieval. The PCR products were electrophoresed on a 1% agarose gel and visualized with ethidium bromide staining. Successfully amplified PCR products were sequenced by Barcode of Life Data systems (BOLD, http://www.barcodinglife.org, Ratnasingham and Hebert 2007), using either one-half or one-quarter DyeDeoxyTerminator protocols (Perkins Elmer). The products were cleaned using either Centri-Sep Spin Columns (Princeton Separation) or ethanol precipitation following the manufacturer's instructions. Cleaned products were run on an ABI Prism 377 sequencer. Specimen data, images, trace files and resulting sequences are available in the project folder "Barcoding Philomycids" in BOLD. Sequences were aligned and edited for phylogenetic analyses using BioEdit (Biological sequence alignment editor, Ibis Biosciences, Carlsbad, CA).

Molecular Phylogenetic Analysis

Bayesian Analysis. Bayesian phylogenetic analysis was performed using Mr. Bayes (version 3.1.2, Huelsenbeck and Ronquist 2001; Ronquist and Huelsenbeck 2003), with the following parameters: flat priors, four Markov chains (three heated-set at default) were run for 3.3 million generations, sampling trees every 100 generations, and allowing the analysis to reach stationarity. Stationarity was determined by plotting the log likelihood scores against the generation time in the using Tracer (v1.41). The first 100,000 generations (1,000 trees) were excluded as the burn-in phase. After the removal of the burn-in samples, a majority rule consensus tree with posterior probability support values was generated. Values greater than 90% were considered strong support. *Limax maximus* was set as the outgroup.

Maximum likelihood analysis. Maximum likelihood analysis was performed using PAUP version 4.0 (Swofford 2002), with a bootstrap analysis (Felsenstein 1985) using 1000 replicates with heuristic search, tree bisection-reconnection branch-swapping algorithm, MulTrees option in effect and 100 random additions.

Neighborjoining Analysis. A phylogenetic tree was also constructed using the neighbor-joining (NJ) method in PAUP version 4.0 (Swafford 2002). The degree of support for internal branches was assessed by bootstrapping (Felsenstein 1985) with 1000 replicates using the default settings.

Modeltest. The best model fit for the maximum likelihood and Bayesian analyses was evaluated using the Akaike information criterion (AIC) (Akaike 1974), as implemented in ModelTest version 3.7 (ModelTest, Provo, UT)(Posada and Crandall 1998). A Transversional (TVM + I+ G) model was selected, with proportion of invariable site (I) = 0.4510 and gamma distribution of variable sites with shape parameter α = 0.4730.

Results

Morphological Phylogenetic Analysis

Maximum Parsimony Analysis. The MP analysis was unconstrained, equally weighted and the morphological data yielded 1364 equally parsimonious trees of 87 steps. The strict consensus tree with consistency index (CI) of 0.4713 and a homoplasy index (HI) of 0. 5287 for informative characters(31 of 34) and values of CI= 0. 4651 and HI= 0. 5349 for uninformative characters. The retention index (RI) was 0.7107 and the rescaled consistency index (RC) 0.3349. The tree was rooted using *Megapallifera mutabilis*. The tree topology generated from the morphological data was not strongly supported; however, it had similar topology to that of the molecular data, hence the morphological characters were mapped onto the molecular tree for greater resolution (Figure 6-4 to 6-8).

Molecular Phylogenetic Analysis

The amplified product of 654 bp was readily aligned as it lacked indels.

The Bayesian analysis conducted for the mitochondrial (CO1) data reached stationarity prior to 100,000 generations, but the first 1,000 trees were excluded as the burn-in phase (sample points prior to stationarity). The log likelihood score was 8494.3885. The tree generated for the CO1 data were completely resolved with high posterior probability scores for most nodes (Figure 6-1).

The neighbor-joining method yielded a tree with similar topology as the ML and Bayesian analyses (Figure 6-2). The CO1 support values generated from each analysis were high: posterior probability values > 90% and bootstrap values > 65% (Table 6-3).

Mitochondrial Clades

The phylogenetic analyses provided strong support for five reciprocally monophyletic clades. All five clades can also be recognized morphologically, thus they meet the criteria of phylogenetic species. Below is a list of these species and the morphological characters that are unique to each.

1. "*carolinianus*"-two rows of black spots straddle the central line that runs spans the entire length of the mantle or completely peach-colored. Large dart sac with a dart that is sigmoid shaped.
2. "*flexuolaris*"-dart sac smaller than distal end of penis.
3. "*sellatus*"-proximal end of dart ringed and thin, double row of black spots extends 2/3 the length of the mantle, dark transverse band across the back with a cream-colored anterior margin.

4. “*togatus*”- free oviduct 1-5mm long, and dart strongly curved with distal opening obstructed or closed.
5. “*venustus*”- vas deferens loops around penis.

Discussion

Separating species of *Philomycus* based on mantle pattern variation alone has been challenging. The results of this study indicate that there are five species of *Philomycus*, all of which demonstrate high levels of interspecific and even more intraspecific variation in mantle pattern. Identification based solely on mantle pattern variation is not diagnostic for all species. Instead, a combination of morphological and reproductive characters must be used.

The Bayesian, maximum likelihood (ML), neighbor-joining (NJ) and maximum parsimony (MP) analyses indicated similar assignment of individuals to the five species here recognized. There was strong support for these groupings in the molecular analyses, but less so in the morphological analysis, although there is some morphological support for each. In an attempt to demonstrate the degree of mantle pattern variation within each species, the unique morphological character for each species, and a photograph of the mantle for each specimen was mapped onto the NJ tree produced from the molecular data (Figures 6-4 to 6-8). Although posterior probabilities often over-exaggerate node support there was strong support for the molecular data (Figure 6-1 and 6-2) as the posterior probability value for each clade was greater than 0.9 and the bootstrap values mostly greater than 90%.

The genetic clade recognized as *P. carolinianus* is supported by a single homoplasious morphological character: vas deferens of uniform thickness. This character state also occurs in the two clades *P. flexuolaris* and *P. venustus. P. carolinianus* can also be separated from these other species by the synapomorphic character: sigmoid shaped dart. *P. carolinianus* can further be separated into two geographic forms that differ in color pattern, but are not different in CO1 sequence. The northern morph has two rows of black spots that straddle the central dark stripe on the mantle with soot-colored tentacles, whereas the southern morph has a pale or peach-colored with pale tentacles (Figure 6-4). Each morph can be separated by these synapomorphies, but it is unclear if gene flow is possible between morphs.

The genetic clade recognized as the species *P. flexuolaris* is supported by the synapomorphy: dart sac smaller than widest part of the penis. The mantle pattern of *P. flexuolaris* is very variable. The chevron stripes may or may not be present and there maybe large blotches or fine flecking depending on the individual. It is clear that the mantle pattern cannot be used to reliably identify this species, therefore dissection and examination of the reproductive system should be done to identify this species (Figure 6-5).

The third genetic clade, *P. sellatus,* is readily differentiated from all other species by several synapomorphies: proximal end of dart ringed and thin, double row of black spots extends 2/3 the length of the mantle, and the presence of a dark transverse band across the back with a cream colored anterior margin. This species is geographically restricted to the Cumberland Plateau of southeastern Tennessee and northeastern Alabama. This species, though distinct, is very similar to *P. carolinianus* (Figure 6-6).

The fourth genetic clade corresponds to the morphological species *P. togatus* that can be identified by a combination of the following homoplasious characters: free oviduct 1-5mm long, dart strongly curved, and the distal opening of the dart obstructed or closed. The mantle pattern of this clade is extremely variable. This variation is especially striking in the members collected for this study. The mantle color/pattern varies from jet black, to brown to completely white, but all animals have soot-colored tentacles. There are also individuals that have fine to abundant flecking and flecks can coalesce to form three rows of distinct narrow stripes. This extreme mantle variation was the primary character and sometimes only character used by previous authors to identify this species. For proper identification, dissection and evaluation of the genitalia should be done (Figure 6-7).

The fifth genetic clade corresponds to *P. venustus,* defined by a single synapomorphy: vas deferens loops around penis. This character is unique to this species. However, the mantle pattern is variable, and this species is difficult to separate from *P. flexuolaris* based on the mantle pattern. The geographic range of these species, therefore dissection and examination of the penis and dart sac is necessary for reliable identification (Figure 6-8).

Thus, the genetic and morphological evidence supports the existence of at least five named species in the genus *Philomycus*: *P. carolinianus*, *P. flexuolaris*, *P. togatus, P. venustus* and *P. sellatus*. Each can only be reliably identified based on genitalic and genetic characters. The albino specimens collected from southern Florida appears very similar to *P. carolinianus* and may only be color morphs of that species. However, this conclusion is tentative because the ranges of the two populations do not appear to overlap and there has been no independent test of their ability to interbreed. Also, the mantle pattern differences might be evolving more rapidly than other characters. It is recommended that additional sampling and characterization be carried out for a more thorough revision of the genus. Designating neotypes for *P. carolinianus* and *P. togatus* would further stabilize the taxonomy of this group.

There appear to be at least three undescribed species of Philomycus: species 1 (437739), species 2 (446552) and species 3 (447294 and 447223). These species differ genetically from all other species and though similar in mantle color pattern to *P. flexuolaris*, differ in that they have dart sacs that are as large or larger than the widest part of the penis. Additional samples should be collected to determine the range of variation within these species and as well as their geographic range.

Taxonomic History of *Philomycus*

Bosc (1802) described *Limax carolinianus*; his illustrations indicated a slug that possessed a greatly expanded mantle that was ash-colored, mottled with three obscure bands and had two rows of black spots that straddled the central band, all traversing the dorsal surface of the animal. Rafinesque (1820) proposed *Philomycus* for four species of fungi–feeding slugs (*P. quadrilus*, *P. oxyurus*, *P. fuscus* and *P. flexuolaris*). Rafinesque (1820) misinterpreted the greatly expanded mantle of the slugs to be the back of the animal, and contrasted the thus presumed absence of a mantle in *Philomycus* with the reduced mantle characteristic of *Limax*. Férussac (1821) suggested that based on the appearance of the drawing provided by Bosc (1802: plate III, fig. 1), *L. carolinianus* should be included in *Philomycus*.

Gould (1841) described *Limax togata*, noting that this slug had an extensive mantle that covered the entire back, and suggested that this species may deserve new generic placement due to this morphological peculiarity. Gould also noted that *L. togata* could be related to *L. carolinianus* Bosc, 1802. Binney (1842; 1851) recognized that the extensive mantle of *Limax carolinianus* Bosc, 1802 and *L. togata* Gould, 1841 was atypical of *Limax* and proposed a new generic name, *Tebennophorus,* to encompass those slug species with an extensive mantle that covered the entire dorsal surface. Binney (1842) proposed that *Philomycus* be retained for species that lacked a mantle as described by Rafinesque (1820).

After reviewing the literature, and available morphological and genitalic characters, Pilsbry (1890, 1891) suggested that *Limax carolinianus* Bosc, 1802, *L. togata* Gould, 1841, and *Tebennophorus caroliniensis* Binney, 1842 be placed in *Philomycus*. Pilsbry (1948) also re-evaluated the species in *Philomycus* based on external morphology, geographic distribution and novel genitalic characters and concluded that *P. flexuolaris* Rafinesque, 1820 be relegated to a subspecies of *P. carolinianus flexuolaris*.

Based on extensive collections, Hubricht (1951) compared the variation in the mantle pattern and reproductive anatomy of *Philomycus carolinianus flexuolaris* and *P. carolinianus* and concluded that *P. flexuolaris* should be re-elevated to specific rank. Comparison of the mantle patterns revealed that *P.*

flexuolaris had a distinct oblique (chevron) color pattern, which is not present in *P. carolinianus,* and the spots characteristic of *P. flexuolaris* were much larger and ill-defined when compared to those observed in *P. carolinianus*. Hubricht (1951) also evaluated the genitalia and noted that in addition to the smaller size of the dart sac, as noted by Pilsbry (1948), the entire reproductive system of *P. flexuolaris* was smaller than that of *P. carolinianus*. Hubricht (1951) also described a new subspecies, *P. carolinianus collinus,* differentiated from the coastal flood-plain woods species *P. carolinianus* by lacking the two rows of black spots, and being larger and browner, and inhabiting upland piedmont habitats. This larger subspecies also had a broad dorsal band and two narrower lateral bands with small spots scattered irregularly between them. Hubricht (1956) collected *P. carolinianus togatus* slugs from the Shenandoah National Park in Virginia and based on mantle coloration, synonymized his previously described subspecies (*P. carolinianus collinus* Hubricht, 1951) with the recently identified *P. carolinianus togatus*. In 1968, Hubricht elevated *togatus* to the species level without explanation.

Subsequent to 1951, Hubricht described three species of *Philomycus* based solely on differences of the mantle pattern: *Philomycus venustus* Hubricht, 1953, *P. virginicus* Hubricht, 1953 and *P. sellatus* Hubricht, 1972. *P. venustus* and *P. virginicus* were said to be similar but were distinguishable by the fine flecking on the mantle of *P. virginicus,* lacking in *P. venustus*. *Philomycus sellatus* was also diagnosed by a unique mantle pattern: a broad, dark-colored band that extends laterally across the antero-dorsal portion of the mantle. Branson (1968) described two additional species: *P. bisdosus* and *P. batchi*, collected in neighboring states and described based on differences in the mantle pattern, genitalic and jaw characters, as well as their distribution. These were the first descriptions within this genus to include characters other than the mantle pattern variation. Branson (1968) noted that both species bear similarity in the mantle pattern with previously described species. Juveniles of *P. bisdosus* were similar to mature specimens of *P. virginicus* except they were darker brown and more spotted, and adults of *P. virginicus* were much darker and their color pattern extended to the ventral edge of the mantle. Branson (1968) also suggested that *P. batchi* was similar to *P. flexuolaris*; however, *P. batchi* was nearly solid black and did not possess longitudinal stripes.

As of 1972 there were eight recognized species of *Philomycus*: *P. carolinianus* Bosc 1802, *P. flexuolaris* Rafinesque, 1820 and *P. togatus* (Gould, 1841), *P. venustus* Hubricht, 1953, *P. virginicus* Hubricht, 1953, *P. bisdosus* Branson, 1968, *P. batchi* Branson, 1968 and *P. sellatus* Hubricht, 1972 (Turgeon et al. 1988). All eight were thought to be distinguishable on the basis of mantle pattern variations, and two by genitalic characters (*P. bisdosus* and *P. batchi*).

Hubricht (1974) examined the morphological characters of type specimens of Branson's species and compared them to specimens that were collected previously (Hubricht 1953). Hubricht concluded that *Philomycus venustus* Hubricht, 1953 and *P. bisdosus* Branson, 1968 should be synonymized under the assumption that *P. venustus* was a very variable species and *P. bisdosus* was simply an extreme variant of *P. venustus*. Hubricht (1974) also concluded that *P.*

batchi was a melanistic variant of *P. carolinianus* and suggested that these species should also be synonymized.

In a later review of the reproductive and morphological anatomy of *Philomycus bisdosus* and *P. venustus,* Fairbanks (1989) provided evidence that *P. bisdosus* was not a synonym of *P. venustus* and he resurrected it from synonymy based on the following characters: (1) the free oviduct of *P. venustus* was significantly longer than that of *P. bisdosus,* (2) *P. venustus* had transverse oblique bands that may manifest as solid lines or spots arranged linearly, whereas *P. bisdosus* had no transverse bands, (3) *P. venustus* was larger than *P. bisdosus*, and (4) *P. venustus* had white foot margins, whereas *P. bisdosus* had gray foot margins.

Systematic Accounts

Family Philomycidae Gray 1847

Identification key to the New World genera of Philomycidae

1. Dart sac with dart present (located at the base of the bursa copulatrix) ……………………..*Philomycus*

- Dart sac absent ……………….........................………………………………..……2

2. Adult slug less than 40 mm long and 8 mm wide ..………….……………..*Pallifera*

- Adult slug greater than 40 mm long and 8 mm wide …....…………*Megapallifera*

Genus *Philomycus* Rafinesque 1820

Limacella Blainville 1817; Cockerell 1890; not Brard 1815

Philomycus Rafinesque 1820

Tebennophorus Binney 1842

Type species: *Philomycus carolinianus* Bosc 1802

Description: Mantle is greatly extended so that it covers the entire dorsal surface of the animal. The jaw is faintly striated, never ribbed. Centrals of the radula are unicuspid and laterals bear weak ectocones and no endocones. Initial marginal teeth may be bicuspid, but as you move towards the margin of the radula, they quickly become devoid of teeth, leaving small rectangular bases. The dart sac, located laterally on the vagina, and contains a calcified stimulator (dart) that may or may not be used during copulation. The vagina is often short and may be indistinct in some species. The penis does not bear an epiphallus. There is also a gland that envelops the atrium, which may be pigmented.

Distribution: *Philomycus* species are distributed throughout eastern North America.

***Philomycus carolinianus* (Bosc, 1802)**

Philomycus carolinianus (Bosc), Pilsbry, 1948, in part, LMNA, 2: 753, 754 fig. 404 a, b, c, d, e, g, and h.

Philomycus caroliniensis Férussac 1821, Tab. Syst. Anim. Moll., Famille des Limaces, pp. 14-15.

Limacella elfortiana Blainville, 1825, Man. De Malac., p. 464.?

Limacella lactiformis Blainville, 1817, Jour. De Phys., 85: 444, pl. 2, fig. v- Cockerell, 1890, Ann. Mag. N.H. 6: 380; Nautilus, 5: 5., Pilsbry and Cockerell, 1899, Nautilus, 13: 24.?

Limacella lactescens Ferussac, Histoire, pl. 7, fig. 1.?

Material examined: United States of America. ARKANSAS. Desha County. 34.12900162, -91.09899902, 12 June 1980, UF 28397 (2 specimens). FLORIDA.

Alachua County. 29.68829918, -82.37190247, February 2010, 50 m, UF 447268 (3 specimens); Collier County. 26.17000008, -81.34999847, 29 July 2004, UF 349468 (one specimen). 26.00799942, -81.41100311, 24 September 2010, 2 m, UF 445015 (8 specimens). 25.87599945, -81.23000336, 25 September 2010, 1 m, UF 445018 (3 specimens). Dade County. 25.56500053, -80.44200134, 28 September 2010, 2 m, UF 445045 (one specimen). ILLINOIS. Calhoun County. 39.06600189, -90.61000061, 12 July 1998, UF 284311 (one specimen). KENTUCKY. Clark County. 37.88690186, -84.24359894, 25 May 2011, 175 m, UF 447181 (one specimen). SOUTH CAROLINA. Berkeley County. 33.20750046, -79.46849823, 18 May 2011, 3 m, UF 447034 (one specimen).

Description: Foot white. Mantle color off-white to cream, and mottled with gray-brown. Mottling coalesces to form three dark gray stripes that run antero-posteriorly. These black stripes fuse towards the tail of the animal, and become indistinct at the head region. In addition, there are two rows of black spots that straddle the central dark gray stripe. (Figure 6-4). Tentacles of this species are soot-colored except in the albino variant, in which case they are pale or flesh-colored.

Jaw has slight median projection, and there are numerous shallow horizontal striae along the entire jaw (Figure 6-13). There are a few faint vertical striae that are unequally spaced (~0.8 x 1.9 mm).

Centrals of the radula bear a single cusp that is of similar height to the laterals. The mesocone of the central is robust approximate 4/5 the width of the laterals, and the base of mesocone bears a pair of projections. The base of the central is narrow proximally and becomes inflated distally. The lateral gradually transition into marginals, without any obvious distinction. Laterals are initially bicuspid, bearing only a large mesocone and a very small ectocone represented by a notch. The ectocone is approximate 2/3 the height of the mesocone, and becomes more prominent proximally. The base of the laterals are angular at the apex (Figure 6-12). The marginals are bicuspid but the ectocones gradually become obsolete, leaving unicuspid marginals. The base of the last set of marginals are devoid of cusps, leaving rectangular bases.

Reproductive system of this species was not described originally. Penis free from the atrium, and gradually tapers where it meets the retractor muscle. Vas deferens long and does not loop around the penis. Dart sac large, and approximately 2/3 the size of the penis (Figure 6-10). Dart sac encloses a dart that is sigmoid-shaped at the distal end and bears a thick, rough translucent band at the base. Ventral opening of the dart slit-like (Figures 6-11).

Distribution: This species has been reported to occur throughout eastern U.S. from the eastern regions of Kansas and southern Iowa, to the southern tips of Florida (Hubricht 1985). Records confirmed in this study from the following states: Arkansas, Florida, Illinois, Kentucky and South Carolina (Figure 6-13).

Remarks: Since the description of this species, specific diagnosis has remained fairly consistent. This species is easily distinguishable by the central mantle stripes, straddled by two rows of black spots and the absence of chevron markings. An albino morph of *Philomycus* was described by Blainville as *Limacella lactiformis*. This same specimen was also the type of *L. lactescens* and

L. elfortiana. Subsequent to these descriptions, albino specimens have been reported from multiple locations, in mixed populations of individuals with typical pigmentation (Pilsbry 1948). Recently, pure populations of an albino morph was discovered in southern Florida. The albino morph can be separated from all others by the absence of soot-colored tentacles (tentacles retain the flesh color of the mantle). Also, this albino morph is restricted to Southern Florida and does not appear to overlap in geographic range with other color morphs. Analysis of genitalic and molecular characters suggest that the albino species recently discovered in southern Florida, may be a color variant of *P. carolinianus* (Figure 6-1 and 6-2) and its geographic range appears to be limited to southern Florida, U.S.A. (Figure 6-14). However, it is difficult to determine at this time whether this morph is simply a color variant that has become isolated from a larger population or a result of recent divergence.

Original description of this species did not include the deposition of a type material by Bosc (1802). It is recommended that a neotype be established for this species to assist in stabilizing the genus.

***Philomycus flexuolaris* Rafinesque, 1820**

Philomycus carolinianus flexuolaris Rafinesque, Pilsbry, 1948, in part, LMNA 2: 756, 757 fig. 405 a, b, c, d, and e.

Philomycus flexuolaris Rafinesque, Hubricht, 1951, Nautilus 65: 21.

***Philomycus virginicus* Hubricht, 1953, Nautilus 66: 79. (New synonymy)**

Material examined: United States of America. GEORGIA. Union County. 34.84769821, -83.80010223, 3 June 2010, 870 m, UF 437711 (one specimen);

White County. 34.71659851, -83.86660004, 6 June 2010, 900 m, UF 437659 (2 specimens). KENTUCKY. Letcher County. 37.07040024, -82.82309723, 25 May 2011, 790 m, UF 447163 (5 specimens): 37.06520081, -82.83360291, 25 May 2011, 790 m, UF 447167 (one specimen); 37.06520081, -82.83360291, 25 May 2011, 790 m, UF 447168 (one specimen). MAINE. Oxford County. 44.47399902, -70.8010025, 4 June 2008, 250 m, UF 447270 (one specimen). NEW YORK. Greene County. GPS coordinates unknown, 16 Sep. 2011, elevation unknown, UF 448785 (14 specimens). NORTH CAROLINA. Buncombe County. 35.79600143, -82.3690033, 25 May 2009, 1023 m, UF 434323 (3 specimens); Mitchell County. 36.09799957, -82.09500122, 21 Aug. 2004, 1480 m, UF 348135 (one specimen); Transylvania County. 35.11199951, -82.8239975, 8 May 2007, elevation unknown, UF 416432 (2 specimens). VIRGINIA. Dickenson County. 37.28680038, -82.30090332, 24 May 2011, 485 m, UF 447143 (2 specimens); Madison County. 19 July 1953, FMNH 294085 (paratype) (7 specimens); Washington County. 36.86330032, -81.9253006, 24 May 2011, 700 m, UF 447140 (one specimen).

Description: Foot white. Mantle has three distinct stripes that run antero-posteriorly. Large dark blotches coalesce to form each stripe and are sometimes connected to each other by oblique lines. The oblique lines often make the (three) stripes appear to be flexuous (chevron in appearance-where the arms extend anteriorly from the center). The antero-posterior stripes rarely extend to the tip of the tail as distinct stripes. They often coalesce to form large blotches, or only the central stripe remains distinct. These stripes remain fairly distinct toward the head of the animals, except immediately in front of the pneumostome. This slug species never has the two rows of black or brown spots or elongated blotches that saddle the central stripe as seen in *P. carolinianus* or *P. venustus*. However, there may be small flecks on the mantle resembling those of *P. togatus* (Figure 6-7). Base color of mantle varies from cream to almost pale orange. Tentacles soot-colored.

Jaw has a slight median projection, with numerous shallow horizontal striae. There are a few faint vertical striae that are almost regularly spaced (Figure 6-13). (~0.8 x 1.6 mm)

Centrals of the radula bear a single cusp and are of similar height to laterals. Mesocone robust and approximate 4/5 the width of the laterals. The base of the central tooth expands distally. The lateral gradually transition into marginals, without any obvious distinction. Laterals are bicuspid, bearing only a large mesocone and a very small ectocone represented by a notch and the ectocone is approximately 2/3 the height of the mesocone (Figure 6-12). Marginals are bicuspid but the ectocones gradually become obsolete, leaving unicuspid marginals. Base of last set of marginals are devoid of cusps, leaving rectangular bases.

Penis short and robust, with distal end narrowing abruptly to form a tube as it approaches the penial retractor muscle. Vas deferens does not loop around the penis (Figures 6-10). Dart sac very small (less than 1/3 the size of the penis) and possesses a short strongly curved dart (Figures 6-11).

Distribution: This species is common throughout the Appalachian Mountains in Georgia, Kentucky, Maine, New York, North Carolina and Virginia (Figure 6-15).

Remarks: Material has been collected from the type locality and dissected but not yet sequenced. Specimens with similar genital anatomy were found from Maine to Georgia with little variation in CO1 sequence.

In addition to the chevron body markings, the dart sac of this species is characteristically much smaller than the penis. It is recommended that *Philomycus virginicus* be synonymized with *P. flexuolaris.* Observations of the chevron markings on the mantle (Figure 6-9) and the greatly reduced dart sac of the reproductive system (Figure 6-10) of a paratype of *P. virginicus* (FMNH 294085) suggest that these two species are the same, but confirmation awaits CO1 data.

The juveniles of this species are almost indistinguishable from that of *P. togatus*. It is recommended that juvenile specimens be allowed to mature before making a diagnosis or molecular techniques be used for juvenile stages.

***Philomycus sellatus* Hubricht, 1972**

Philomycus carolinianus (Bosc), Pilsbry, 1948, in part, LMNA, 2: 753, 754 fig. 404 f (non *carolinianus* Bosc).

Philomycus sellatus Hubricht, 1972, Nautilus 86: 17.

Material examined: Type material: United States of America. Alabama. Jackson County. GPS coordinates unknown, date unknown, elevation unknown, FMNH 157322 (one specimen).

Non-type material: United States of America. ALABAMA. Jackson County. 34.97999954, -86.08499908, 3 June 2006, 512 m, UF 382966 (6 specimens); 34.97679901, -86.08039856, 26 May 2011, 540 m, UF 447224 (7 specimens).

Description: Foot white. Anterior margin of the mantle irregularly mottled, and just behind this is an area where the pigmentation is sparse. Posterior to this pale region (approximately 1/3 the length of the animal) is a dark colored, transverse band with uneven margins. On the dorsal posterior 2/3 of the mantle, there is a broad dorsal stripe, which is straddled by a series of elongated black spots. Narrow lateral bands traverse each side of the mantle, with mottling above and below. Lateral bands may be obscured if the animal is heavily mottled, and may form a single continuous coloration on the posterior 2/3 of the animal (Figure 6-6). Base color of mantle white to rust colored. Tentacles dark gray in color.

Jaw has slight median projection. There are numerous shallow horizontal striae along the entire length of the jaw (Figure 6-13). There are a few faint vertical striae that are unequally spaced.

Penis robust, and tapers only slightly towards the penial retractor muscle. Vas deferens does not loop around the penis as in *P. venustus*. Dart sac large and inflated (Figure 6-10) and the dart is slightly curved with a flared base (Figure 6-11).

Distribution: This species was collected from the extreme northeastern region of Alabama (Figure 6-16), but also was reported from neighboring areas of Tennessee (Hubricht 1972).

Remarks: *Philomycus sellatus* is a morphologically distinct species. It is easily recognized by the broad band across the upper 1/3 of the mantle. This band is pale on the anterior margins, and the central stripe terminates into it on the posterior margin. This species has a well-defined distribution that is restricted to the Cumberland Plateau of southeastern Tennessee and northeastern Alabama (Hubricht, 1985).

***Philomycus togatus* Gould, 1841**

Philomycus carolinianus (Bosc), Pilsbry, 1948, in part, LMNA, 2: 753, 754 fig. 405 f and g.

Philomycus carolinianus collinus Hubricht 1951, The Nautilus 65: 20-22.

Philomycus carolinianus togatus (Gould) Hubricht 1956, The Nautilus, 70: 15-16.

***Philomycus batchi* Branson 1968, The Nautilus 81: 127. (New Synonymy)**

***Philomycus bisdosus* Branson 1968, The Nautilus 81: 127. (New Synonymy)**

Philomycus togatus (Gould) Hubricht 1974, Sterkiana 32: 1-6.

Material examined: Type material (paratype): United States of America. NORTH CAROLINA. Wilkes County. 24 September 1950, FMNH 293805 (A9966) (22 specimens).

Non-type material: United States of America. KENTUCKY. Clark County. 37.88690186, -84.24359894, 25 May 2011, 175 m, UF 447180 (one specimen); UF 447182 (2 specimens); Madison-Clark County line, 16 June 1967, FMNH 155478 (holotype) (one specimen). MAINE. Oxford County. 37.28680038, -

82.30090332, July 2009, 485 m, UF 447269 (2 specimens). VIRGINIA. Buchanan County. 23 July 1967, UMMZ 23065 (one specimen). Dickenson County. 37.29589844, -82.30190277, 31 May 2010, 550 m, UF 437707 (2 specimens). 37.29589844, -82.30190277, 31 May 2010, 550 m, UF 437708 (one specimen). 37.28680038, -82.30090332, 24 May 2011, 485 m, UF 447144C (one specimen). 37.28680038, -82.30090332, 24 May 2011, 485 m, UF 447155 (3 specimens): 37.28680038, -82.30090332, , 24 May 2011, 485 m, UF 447156 (one specimen). Grayson County. 36.7635994, -81.22399902, 23 May 2011, 1160 m, UF 447117 (9 specimens). Smyth County. 36.81669998, -81.4280014, 925 m, 24 May 2011, UF 447128 (3 specimens).

Description: Foot white, but the posterior tip (ventral side) usually black or soot-colored. Mantle base color off-white to cream, and is usually covered in small spots that often coalesce to form three distinct stripes. The broad central stripe is often dark-gray. Stripes are often overlain with minute black spots. In some cases, these central spots may be absent altogether. Lateral stripes may resemble the central stripe and occur high on the side of the mantle, but appear narrower and less organized. Stripes appear distinct towards the tail of the animal; however, they become disorganized as they approach the head of the animal, often diffusing to form minute flecks (Figure 6-7).

Described above is the typical color variant. Several color morphs of this species exist and range from unpigmented to completely brown to pitch black, with varying degrees of minute flecks, never large spots or blotches as in *P. flexuolaris* or *P. venustus* (Figure 6-7). Tentacles soot colored in all variants.

This species is extremely variable in appearance, even within single populations and may initially be confused with members of other species. The unpigmented morph of this species may be confused with the albino morph of *P. carolinianus*; however, both can be separated by the soot-colored tentacles of *P. togatus*. The mantle pattern of this species, though variable may be quite distinct depending on the morph. This species is the only species that has a brown body form that may, or may not, possess stripes. The typical morph of this species has fine flecking, never blotches, and does not have chevron stripes typical of *P. flexuolaris*.

Jaw strongly arched with a slight anterior projection, and weak striations. There are a few faint vertical striae that are unequally spaced (Figure 6-13). (~0.7 x 1.9 mm)

Centrals unicuspid, and of similar width to laterals and approximate 3/4 their height. Mesocone robust, and the base of central broader at the distal end. Laterals bear a single large mesocone and a very reduced ectocone represented by a notch. Ectocone approximate 2/3 the height of the mesocone. However, the ectocone becomes progressively prominent laterally and the mesocone narrows (Figure 6-12). Base of lateral angular at the distal end. The laterals gradually transition into marginals, without any obvious distinction. Laterals bicuspid. Ectocones gradually become obsolete, in marginals progressively to the margin of the radula. Base of last set of marginals devoid of cusps, leaving only their rectangular bases.

Penis enlarged basally, and retractor muscle is very narrow. Dart sac large, and vas deferens is long and tapers as it approaches the oviduct, but does not loop around penis (Figure 6-10). Dart short and strongly curved with a thick open base (Figure 6-11).

Distribution: The species evaluated in this portion of the study were collected or identified from the following states: Kentucky, Maine, North Carolina and Virginia (Figure 6-9).

Remarks: Gould, in 1841, described *Philomycus togatus* (*Limax togatus*), but did not deposit a type specimen. The lack of type material and Gould's brief description caused a great deal of confusion for later authors. In 1951, Hubricht described a new subspecies of *Philomycus*, (*P. carolinianus collinus)* from Pittsylvania County, Virginia. In the description of *P. carolinianus collinus*, Hubricht (1951) noted that this subspecies was illustrated in Figure 405-f, page 757 of Pilsbry (1948), Land Mollusca of North America, vol. II, under the name *P. carolinianus*. The new subspecies occurred in the piedmont of eastern states and differed from coastal plain *P. carolinianus* in mantle color pattern. After collecting more material between his populations on the central east coast and further north, Hubricht (1956; 1968) ultimately synonymized his species (*P. carolinianus collinus*) with *P. togatus.*

The morphotype of *P. togatus* described by Hubricht (1951) as *P. carolinianus collinus* was subsequently re-described as *P. bisdosus* by Branson (1968) along with another species from Kentucky, *P. batchi*. Branson (1968) distinguished his two species based on mantle color pattern and genitalic differences. Branson documented that both species could be separated on the basis that of the small dart sac of *P. bisdosus* and large dart sac of *P. batchi*. Also, the penis of *P. bisdosus* was slender, but that of *P. batchi* was inflated at the point of attachment to the vas deferens and also where it contacted the vagina area. However, his *P. batchi* specimens appeared to be immature and most differences could be attributed to ontogenetic changes. New material, including adults, were collected from each species' type locality by the author as a part of this study. Genitalia of adult *P. batchi* did not differ in the characters described by Branson (1968); therefore, I conclude that *P. batchi* as described by Branson (1968) was a juvenile of *P. bisdosus*.

Examination of the paratype of *P. carolinianus collinus*, holotype of *P. batchi,* and specimens of *P. bisdosus,* revealed that although the mantle pattern was variable, some characters were consistent for all three: (1) for those forms that were pigmented, the mantle pattern remained fairly consistent in that they all had characteristic small black spots or flecks distributed over the entire mantle (Figure 6-2, G-J) and (2) the penis of all three species are similar in having a large dart sac that contains a medium size (3-4 mm) dart that is strongly curved but not sigmoid, and has a narrow, rough translucent base (Figure 6-10). Also, the penis is attached to the atrium by connective tissue, not free as in other species. The combination of these characters suggest that all three species are the same as the previously described *P. togatus*.

Additionally, genetic material isolated from the collected specimens provide strong support for this conclusion (Figure 6-1). Although the mantle pattern of *P.*

togatus is highly variable, the molecular characters analyzed in this portion of the study using the CO1 gene suggest that all color morphs are sympatric, and display polymorphism within and between populations throughout its geographic range(Figure 6-7).

Gould (1841) did not designate a holotype for *Philomycus togatus* (formerly *Limax togata*), hence to stabilize the taxonomy, a neotype should be chosen, preferably from Massachusetts, where Gould's material was collected.

***Philomycus venustus* Hubricht, 1953**

Philomycus venustus Hubricht, 1953, Nautilus 66: 79.

Material examined: United States of America. VIRGINIA. Grayson County. 36.7635994, -81.22399902, 23 May 2011, 1160, UF 447116 (5 specimens); Smyth County. 36.68719864, -81.54570007, 24 May 2011, 1105 m, UF 447138 (4 specimens).

Description: Foot white. Mantle may have three distinct stripes or large dark blotches. For those specimens that have stripes, the central gray-black stripe has dark, irregular margins that may consist of distinct black blotches or large spots. Lateral stripes may be connected to the central stripe by faint oblique (chevron - where the arms extend anteriorly from the center) lines. These three stripes extend towards the tip of the tail, and remain distinct. These stripes also remain distinct towards the head of the animal but merge, forming minute flecks just prior to the margin of the mantle (Figure 6-8). Tentacles soot-colored.

Jaw has numerous shallow horizontal striae an obvious median projection. There are also a few faint vertical striae that are unequally spaced (Figure 6-13) (~0.9 x 2 mm).

Centrals of radula bear a single cusp and approximately 4/5 the height of the laterals. Mesocone of central robust approximate 4/5 the width of the laterals. Base of central mesocone bears a pair of projections. Basal plate of the central tooth narrow, but widens towards the anterior margins. First laterals appear tricuspid, but ever so slightly, bearing weak endocones and ectocones. Ectocone and endocone represented by faint notches, and are approximate 2/3 the height of the mesocone. However, on the other laterals, the endocone disappears, the ectocone becomes more prominent and the mesocone narrows and elongates. Base of lateral angular at the apex. Laterals bicuspid but the ectocones become obsolete on last couple of marginals (leaving unicuspid marginals). Base of the last set of marginals are typically devoid of cusps, leaving rectangular bases (Figure 6-12).

Penis of this species is robust, and tapers as it approaches the penial retractor muscle. Retractor muscle thick, and penial sheath extends to the junction of the penis and vas deferens. A unique character for members of this species: vas deferens loops around the penis at least twice before lying free. Dart sac large or larger than proximal width of penis (Figure 6-10). Dart slightly curved and opening either may be flared but is often obstructed or narrow (Figure 6-11).

Distribution: Samples of this species were collected in Virginia (Figure 6-18).

Remarks: There appears to be at least two distinguishing genitalic characters for this species. The penis is tubular, not curved as in the other species, and the vas deferens always coils around the penis before lying free. This species is often confused with *P. flexuolaris,* as individuals of both species may possess chevron markings, but both species can be distinguished based on their unique genitalic characters.

Philomycus spp.

Material examined: United States of America. ALABAMA. Jackson County. 34.97679901, -86.08039856, 26 May 2011, 540 m, UF 447223 (1 specimen); 34.97999954, -86.08499908, 03 June 2006, 512 m, UF 447294. NORTH CAROLINA. Swain County. 35.70600128, -83.25469971, 24 May 2011, 1105 m, UF 447138 (1 specimen). TENNESSEE. Blount County. 35.61199951, -83.93399811, 02 June 2010, 260 m, UF 437739 (1 specimen).

The resultant information (morphological and molecular) for the following specimens suggest that they may be new species: 437739, 446552, 447294 and 447223. They all have dart sacs that are as large or larger than the widest part of the penis, but otherwise bear internal morphological similarities to *Philomycus flexuolaris*. Additional specimens need to be collected and evaluated to determine the nature of these specimens.

Identification key to *Philomycus* spp.

1. Oblique (chevron) lines present on the lateral side of the mantle ……..………2

- Oblique (chevron) lines absent ……………..……………….……………….……..3

2. Dart sac smaller than proximal portion of penis …………………..……*flexuolaris*

- Dart sac as large or larger than proximal portion of the penis ……..…*venustus*

3. Two rows of distinct black spots/elongated blotches run antero-posteriorly 4

- Two rows of black spots or elongated blotches absent ………………………….5

4. Broad dark band across the anterior 1/3 (shoulder) of the mantle ..…..*sellatus*

- Broad band absent ……………………………………………….…….*carolinianus*

5. Small irregular spots or flecks cover the entire mantle ………………...*togatus*

- Large irregular spots or blotches cover the entire mantle or spots absent and no obvious body markings. Mantle pale or completely black …………………..….6

6. Large irregular spots or blotches cover the entire mantle ……………*venustus*

- No obvious body markings or mantle pale or completely black ………………...7

7. Length of the bursa copulatrix duct less than 11 cm in length, tentacles soot-colored …………………………..…………………………....…………..……..*togatus*

- Length of bursa copulatrix duct more than 11 cm in length, tentacles pale/flesh colored ...…...*carolinianus*

Table 6-1. Morphological character matrix

Species	Catalogue number	Character score
M. mutabilis	447272	11111001000110001110 20----11010000
M. mutabilis	447183	1111100100011000111020----11010000
P. carolinianus	28397	0000100011100100000121000001001000
P. carolinianus	445015	00-11-0011101--00001-1000000100000
P. carolinianus	445018	-0-01-01111011000001210000000100000
P. carolinianus	447034	1001100111101200000121000001001000
P. carolinianus	447268	1020101111101100000121000001001000
P. flexuolaris	416432	0----2-0100120000012121210001000 0
P. flexuolaris	437659	1001112101001200000121212101010000
P. flexuolaris	437711	1021113101001100000121212101010000
P. flexuolaris	447143	0021111101100200000121212101010000
P. flexuolaris	447163	1020011001000000000121212101010000
P. flexuolaris	447168	1011101001100000000121212101010000
P. flexuolaris	447270	00-110100100---0000121212101010000
P. flexuolaris	437739	0020113111101100100121----01001000
P. flexuolaris	446552	1010111111100300100121212101010000
P. flexuolaris	447223A	0010111111210200100121101001011000
P. sellatus	447224	1011111111200300000121102201001111
P. sellatus	382966B	000100111100300000121102201001111
P. togatus	447128	1010101111100100000121212001000000
P. togatus	447155	1021101111100100000121212001000000
P. togatus	447156	1021112111100100000121212001000000
P. togatus	447269	1021111111100100000121212001000000
P. togatus	447144C	1020101111100100000121212001000000
P. venustus	447116	0010110111101001100121101001011000
P. venustus	447138	10211101-1-01--11001-1101001010000

Table 6-2. Geographic locality of material sequenced and/or dissected.

	Catalogue no.	Location	Coordinates	
	UF		Latitude	Longitude
	Pallifera costaricensis			
1	445027	Cartago, Costa Rica	9.835000038	-83.55999756
2	445011	Puntarenas, Costa Rica	8.696000099	-83.20400238
3	318787	Dade County, Florida	25.52400017	-80.46800232
4	445023	Cartago, Costa Rica	9.835000038	-83.55999756
	Pallifera secreta			
5	447133	Smyth County, Virginia	36.68719864	-81.54570007
6	447129	Smyth County, Virginia	36.81669998	-81.4280014
7	447081	Page County, Virginia	38.61569977	-78.3506012
8	447087	Madison County, Virginia	38.60589981	-78.36640167
9	447080	Page County, Virginia	38.61569977	-78.3506012
	Pallifera varia			
10	447097	Madison County, Virginia	38.54510117	-78.40019989
11	447079	Madison County, Virginia	38.53379822	-78.42079926
12	447124	Grayson County, Virginia	36.7635994	-81.22399902
	Philomycus carolinianus			
13	028397	Desha County, Arkansas	*	*
14	447181	Clark County, Kentucky	37.88690186	-84.24359894
15	447268	Alachua County, Florida	29.68829918	-82.37190247
16	447034	Berkeley County, South Carolina	33.20750046	-79.46849823
17	445018	Collier County, Florida	25.87599945	-81.23000336
18	445045	Dade County, Florida	25.56500053	-80.44200134
19	445015	Collier County, Florida	26.00799942	-81.41100311
20	349468	Collier County, Florida	26.17000008	-81.34999847
21	349468	Collier County, Florida	*	*
	Philomycus togatus			

Table 6-2. Continued

22	447180	Clark County, Kentucky	37.88690186	-84.24359894
23	447182	Clark County, Kentucky	37.88690186	-84.24359894
24	447155	Dickenson County, Virginia	37.28680038	-82.30090332
25	447144	Dickenson County, Virginia	37.28680038	-82.30090332
26	437708	Dickenson County, Virginia	37.29589844	-82.30190277
27	437707	Dickenson County, Virginia	37.29589844	-82.30190277
28	447156	Dickenson County, Virginia	37.28680038	-82.30090332
29	447128	Smyth County, Virginia	36.81669998	-81.4280014
30	447269	Oxford County, Maine	44.31000137	-70.65000153
	Philomycus sellatus			
31	382966	Jackson County, Alabama	34.97999954	-86.08499908
32	447224	Jackson County, Alabama	34.97679901	-86.08039856
	Philomycus sp.			
33	447223	Jackson County, Alabama	34.97679901	-86.08039856
34	447294	Jackson County, Alabama	34.97999954	-86.08499908
	Philomycus flexuolaris			
35	348135	Mitchell County, North Carolina	36.09799957	-82.09500122
36	447270	Oxford County, Maine	44.47399902	-70.8010025
37	447167	Letcher County, Kentucky	37.06520081	-82.83360291
38	447168	Letcher County, Kentucky	37.06520081	-82.83360291
39	447163	Letcher County, Kentucky	37.07040024	-82.82309723
40	434323	Buncombe County, North Carolina	35.79600143	-82.3690033
41	447143	Dickenson County, Virginia	37.28680038	-82.30090332
42	437737	Dickenson County, Virginia	37.29600143	-82.30200195
43	437659	White County, Georgia	34.71659851	-83.86660004
44	416432	Transylvania County, North Carolina	35.11199951	-82.8239975
45	437711	Union County, Georgia	*	*
	Philomycus sp.			
46	446552	Swain County, North Carolina	35.70600128	-83.25469971

Table 6-2. Continued

47	437739	Blount County, Tennessee	35.61199951	-83.93399811
	Philomycus venustus			
48	447138	Smyth County, Virginia	36.68719864	-81.54570007
49	447116C	Grayson County, Virginia	36.7635994	-81.22399902
	Megapallifera mutabilis			
50	447272	Oxford County, Maine	44.47399902	-70.8010025
51	447293	Jackson County, Alabama	34.97679901	-86.08039856
52	447183	Clark County, Kentucky	37.88690186	-84.24359894
53	437698	White County, Tennessee	35.92290115	-85.39849854
54	447062	Carteret County, North Carolina	34.74779892	-77.02189636
	Megapallifera wetherbyi			
55	437770	Bell County, Kentucky	36.73799896	-83.72000122
56	447148	Dickenson County, Virginia	37.28680038	-82.30090332
57	437738	Dickenson County, Virginia	*	*
58	382931	Jackson County, Alabama	34.98899841	-86.10099792
59	447225	Jackson County, Alabama	34.97679901	-86.08039856
60	447245	Marion County, Tennessee	35.14820099	-85.78070068
	Megapallifera ragsdalei			
61	328353	Cleburne County, Arkansas	35.51399994	-92.99900055
	Incilaria sp.			
62	415475	Mascarene Islands, Reunion	-21.33600044	55.70600128
	Meghimatium sp.			
63	352004	Okinawa, Japan	26.83699989	128.2720032
	Limax maximus			
64	447073	Hyde County, North Carolina	*	*
65	444829	Flathead County, Montana	*	*
	FMNH			
	Philomycus togatus			

Table 6-2. Continued

66	155478	Madison County, Kentucky	*	*
67	293805	Wilkes County, North Carolina	*	*
	Philomycus flexuolaris			
68	294085	Madison County, Virginia	*	*

* Unable to determine satisfactory coordinates

Table 6-3. Species support.

Clade	CO1: Branch support value/Monophyly			Morphological character (synapomorphic)
	ML: Bootstrap	NJ: Bootstrap	BA: Posterior probability	
"*carolinianus*"	99.4/y	100/y	1/y	23-0
"*flexuolaris*"	58.5/y	62.9/y	0.85/y	9-0
"*togatus*"	95.2/y	100/y	1/y	*4-1; 23-2; 24-1
"*sellatus*"	100/y	100/y	0.98/y	26-2; 32-1; 33-1; 34-1
"*venustus*"	96.9/y	99.3/y	1/y	16-1

* At least one homoplasious character. y-yes

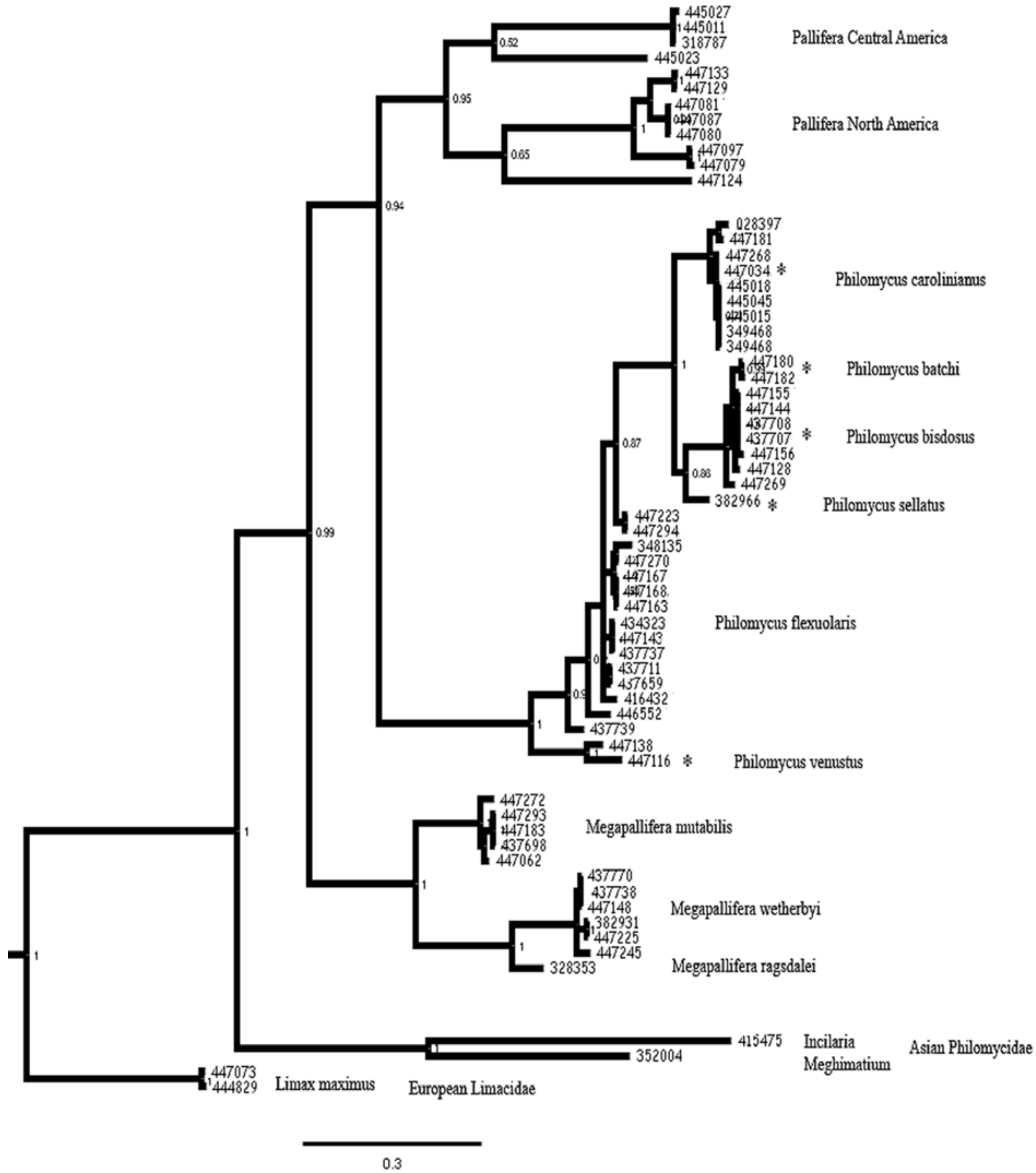

Figure 6-1. Phylogram of Bayesian analysis of 64 slug based on the cytochrome oxidase subunit (CO1) gene with branch lengths measured in expected substitutions per site. Posterior probability values printed at respective branches. *Limax maximus* (Limacidae) was used as an outgroup. Asterisks (*) indicate specimens collected at each species' documented type locality.

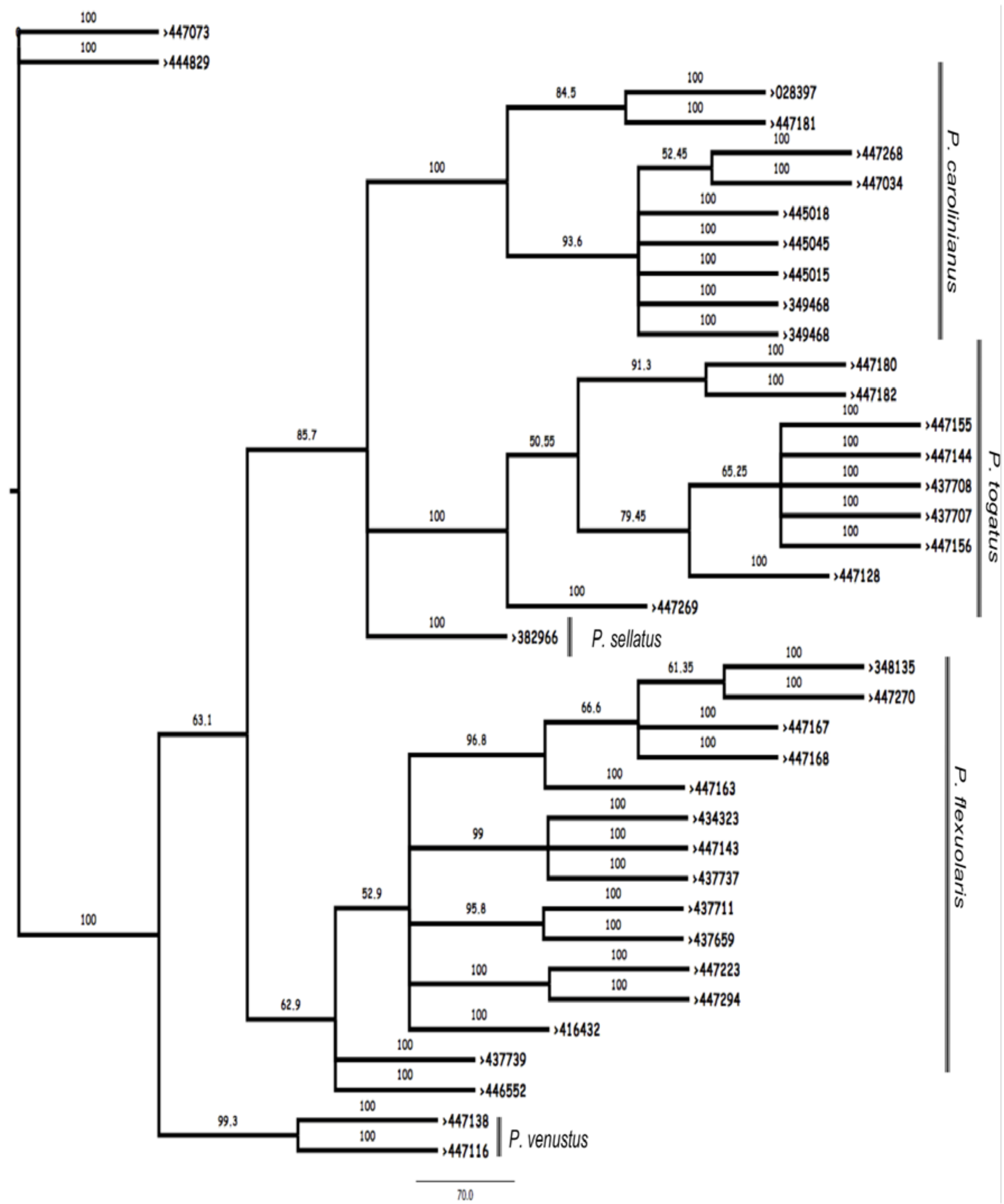

Figure 6-2. NJ tree of 38 individual Philomycus based on the cytochrome oxidase subunit (CO1) gene with branch lengths measured in expected substitutions per site. Bootstrap values printed at respective branches. *Limax maximus* (Limacidae) was used as an outgroup.

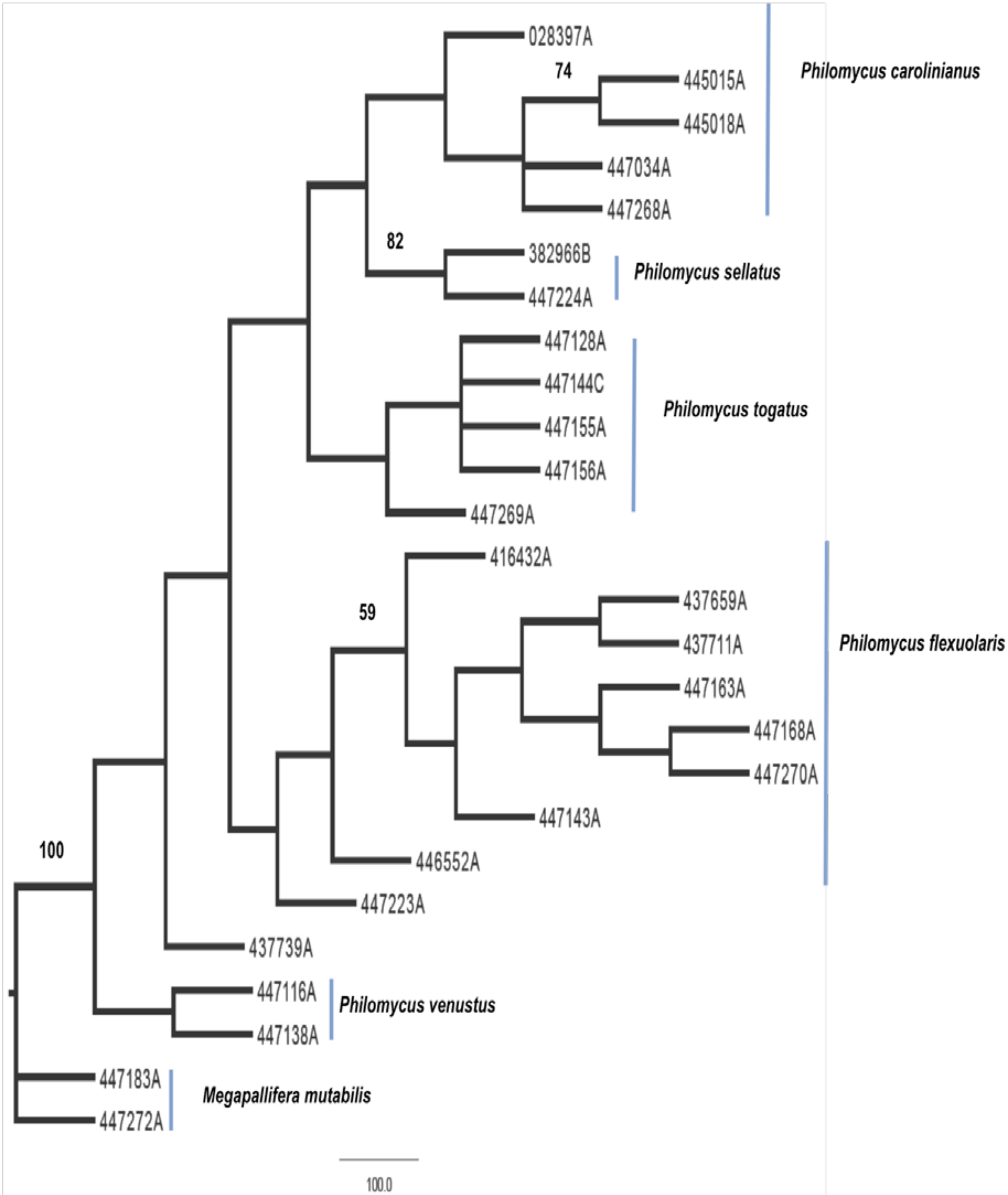

Figure 6-3. Phylogram of MP analysis of 26 slugs based on morphological characters. Bootstrap values printed at respective branches for 50% majority rule consensus tree. *Megapallifera mutabilis* (Philomycidae) was used as an outgroup.

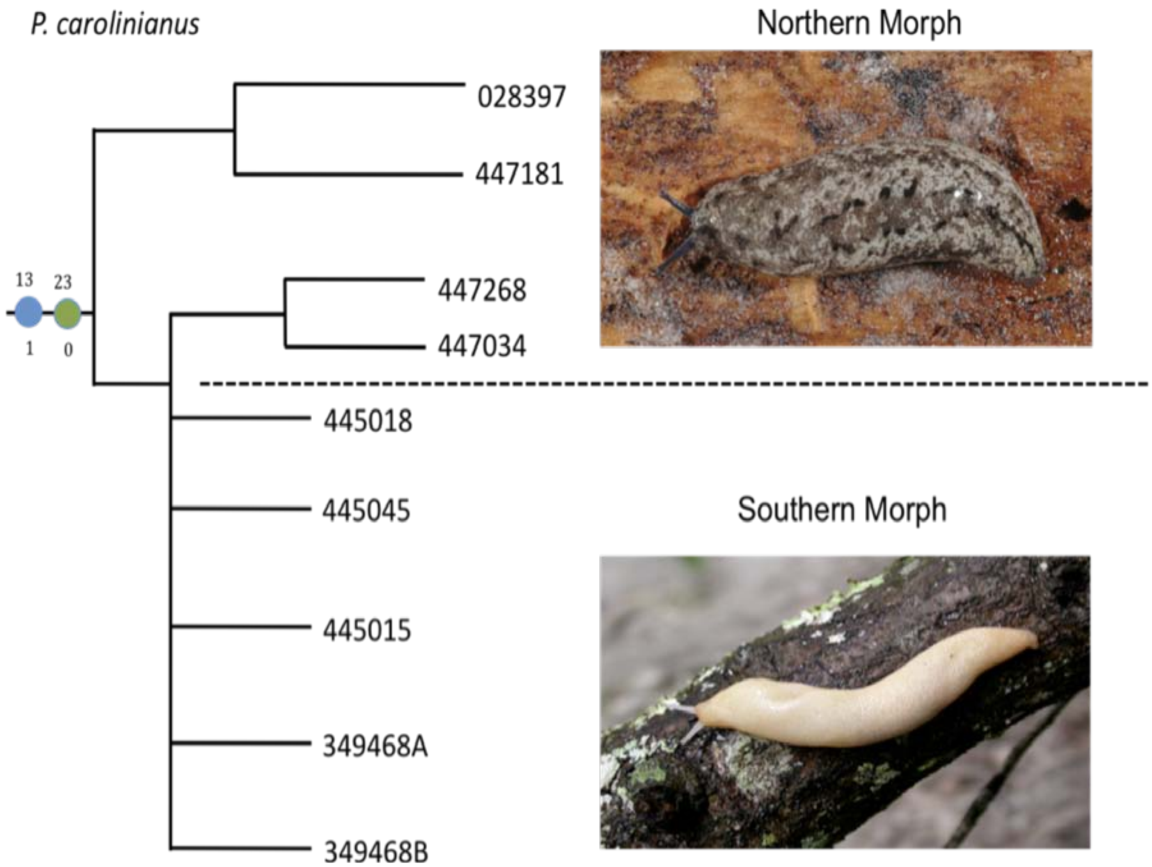

Figure 6-4. NJ tree showing unambiguous character state changes for the "*carolinianus*" clade form the MP analysis. Numbers above branches are character numbers; below branches are character states. Blue dots: homoplasious changes and green dots: nonhomoplasious changes (synapomorphies).

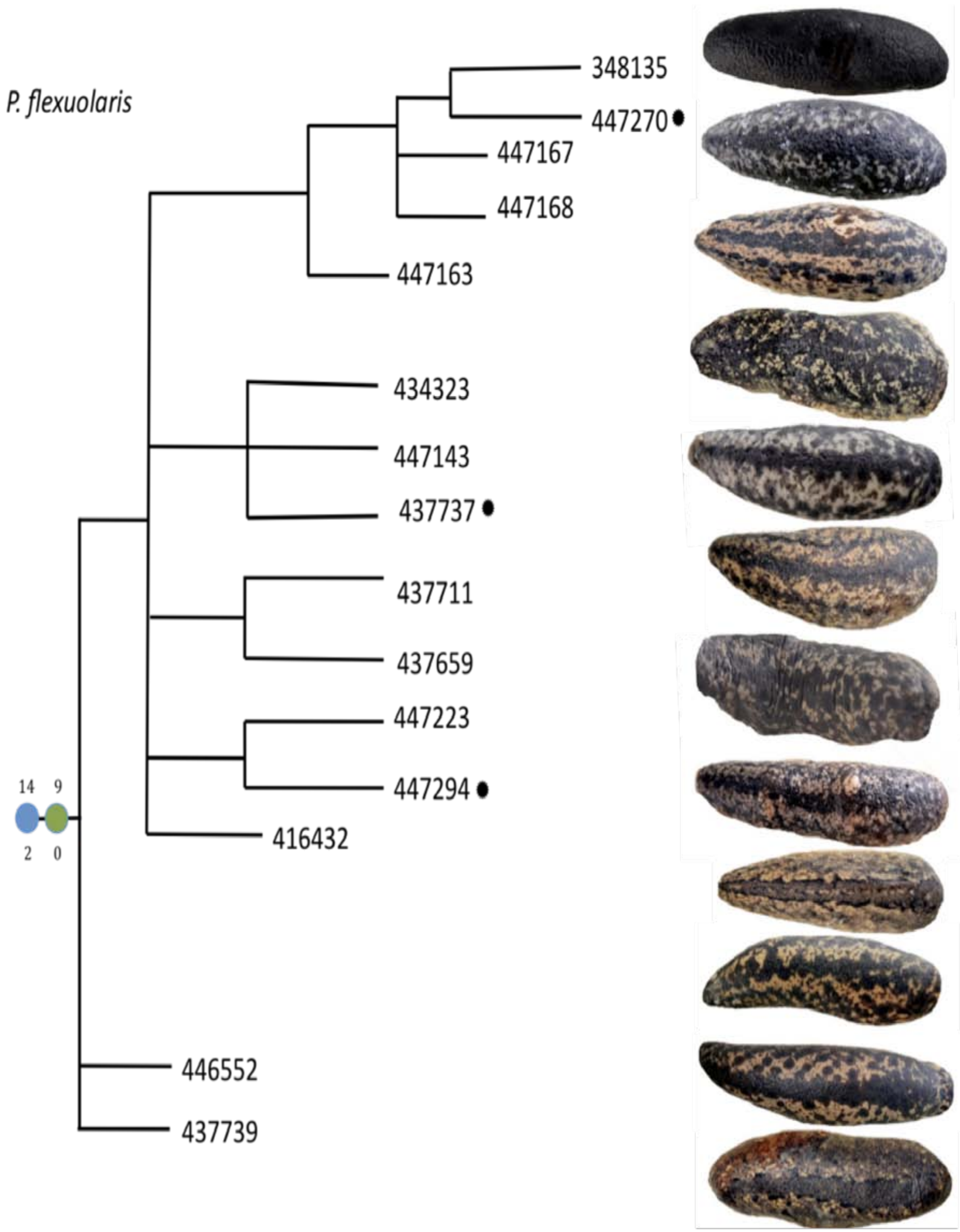

Figure 6-5. NJ tree showing unambiguous character state changes for the "*flexuolaris*" clade from the MP analysis. Numbers above branches are character numbers; below branches are character states. Blue dots: homoplasious changes and green dots: nonhomoplasious changes (synapomorphies). Mantle pattern ordered phylogenetically, but absent for specimens with asterisks (*).

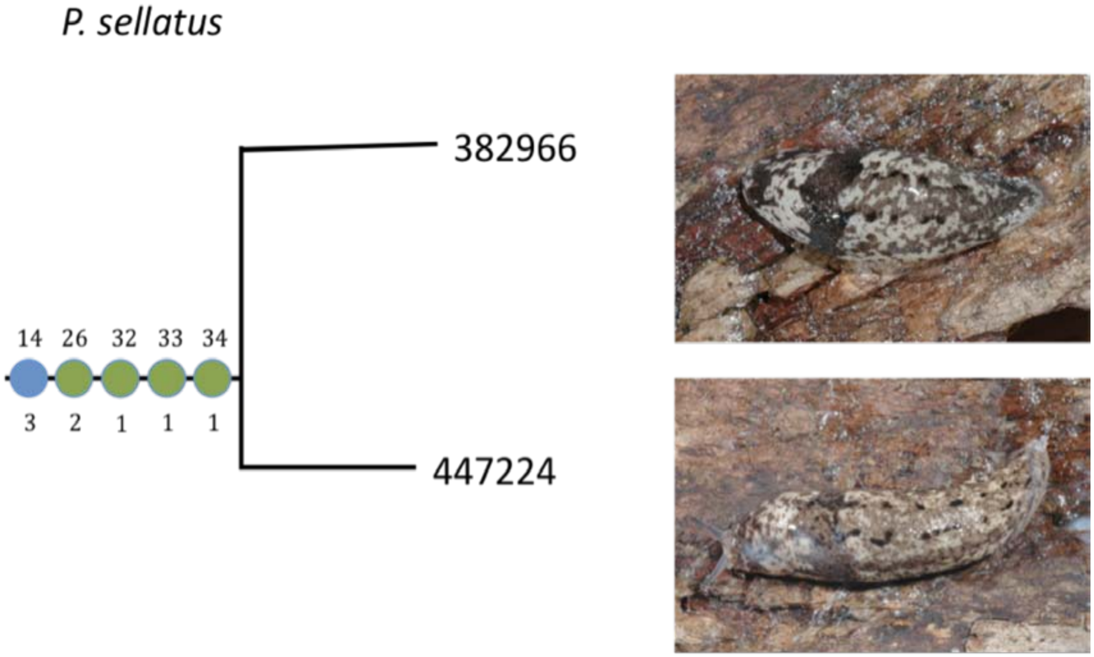

Figure 6-6. NJ tree showing unambiguous character state changes for the "*sellatus*" clade from the MP analysis. Numbers above branches are character numbers; below branches are character states. Blue dots: homoplasious changes and green dots: nonhomoplasious changes (synapomorphies).

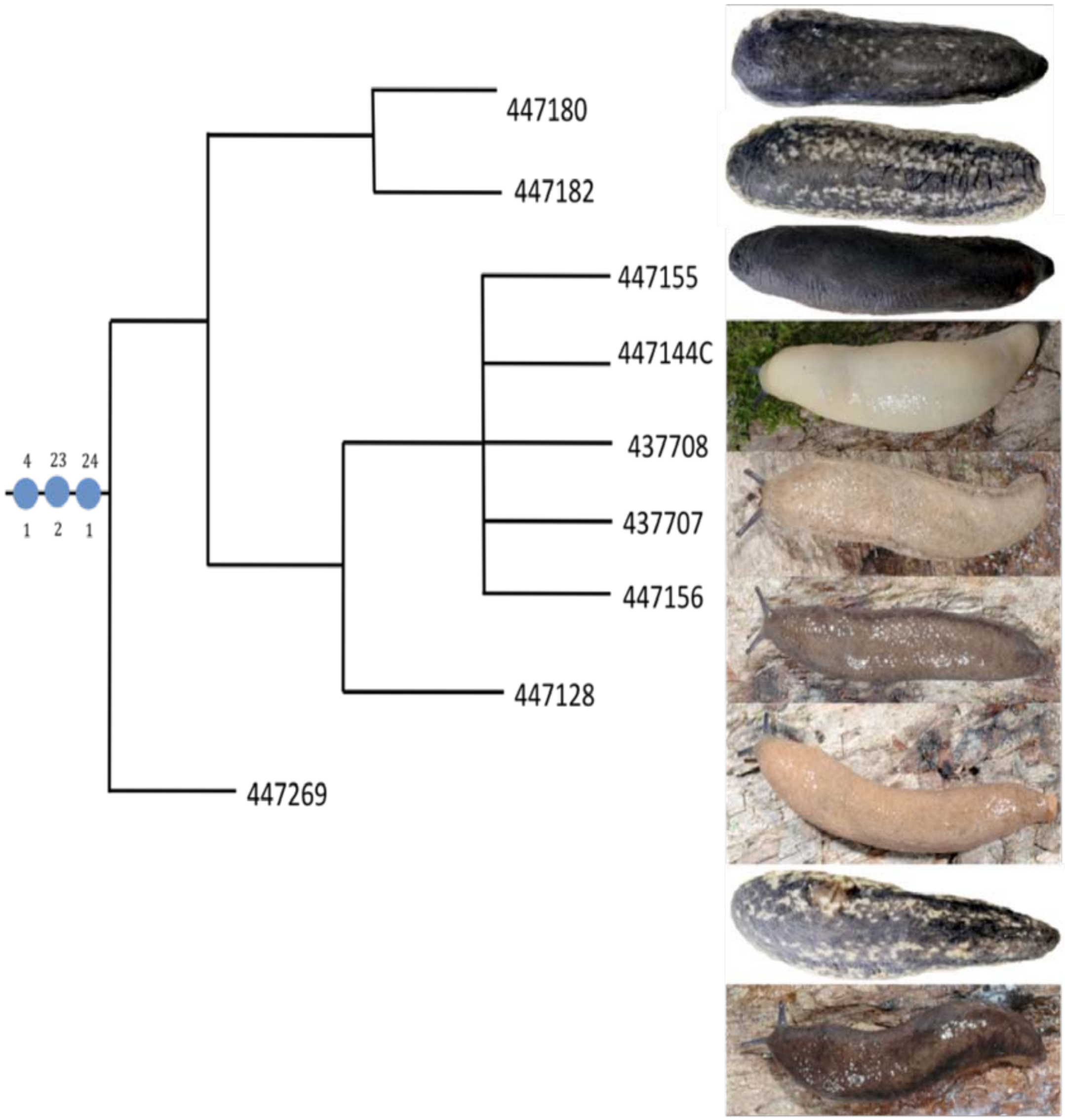

Figure 6-7. NJ tree showing unambiguous character state changes for the "*togatus*" clade from the MP analysis. Numbers above branches are character numbers; below branches are character states. Blue dots: homoplasious changes. Mantle pattern ordered phylogenetically.

Figure 6-8. NJ tree showing unambiguous character state changes for the "*venustus*" clade from the MP analysis. Numbers above branches are character numbers; below branches are character states. Green dot: nonhomoplasious changes (synapomorphies).

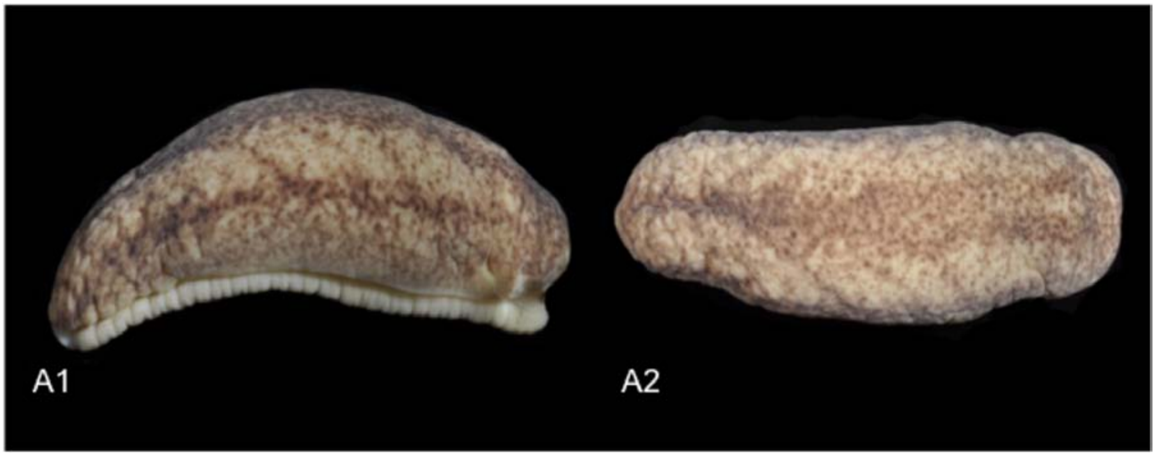

Figure 6-9. Mantle pattern of *Philomycus flexuolaris* (paratype of *P. virginicus*). A) Lateral view FMNH 294085. B) Dorsal view FMNH 294085.

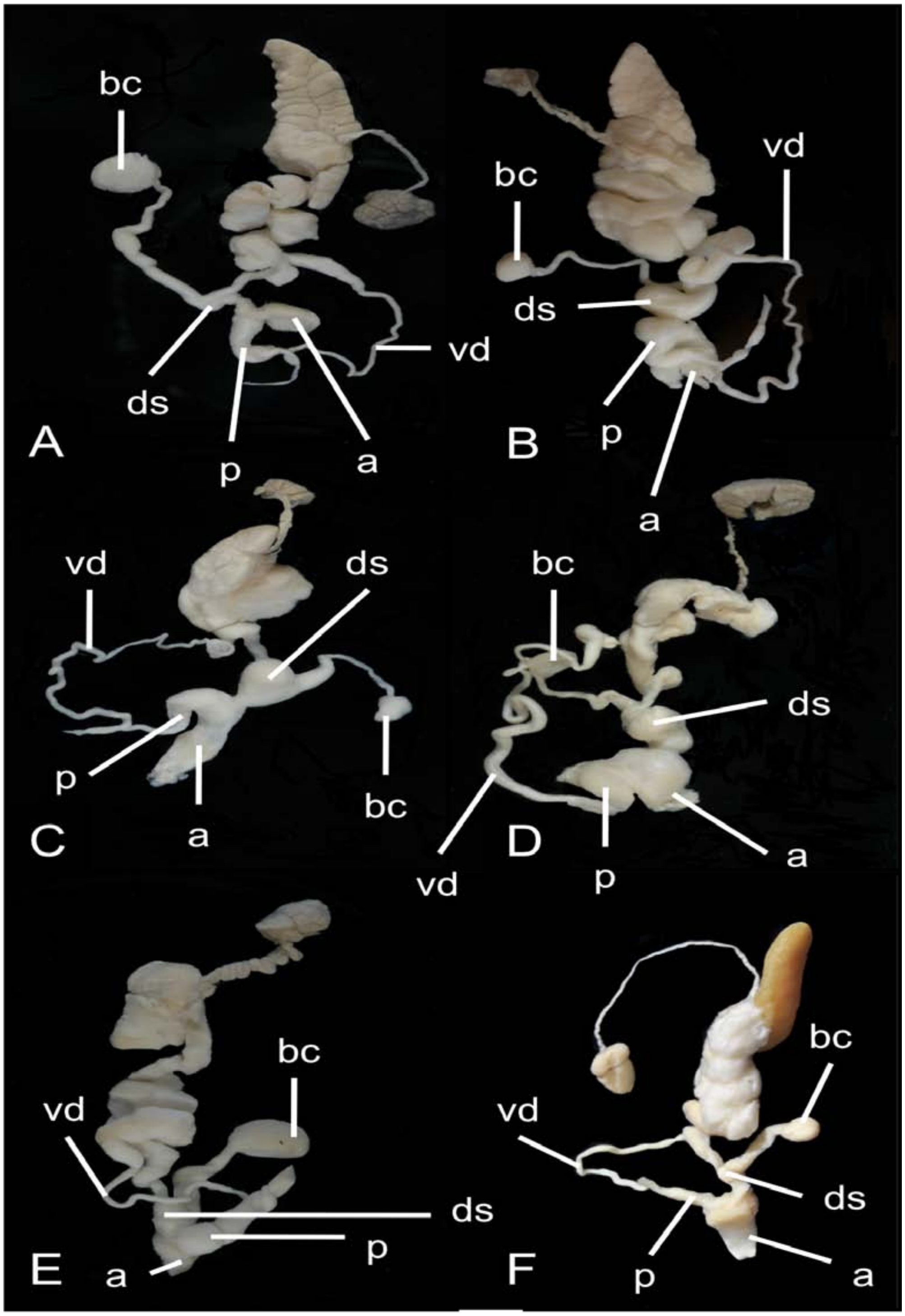

Figure 6-10. Genitalia of five *Philomycus* species. A) *P. flexuolaris* UF, B) *P. togatus* UF 447128, C) *P. carolinianus* UF 447034, D) *P. sellatus* UF 447224, E) *P. venustus* UF 447116, F) P. flexuolaris FMNH 294085. **a**= atrium, **bc**= bursa copulatrix, **ds**= dart sac, **p**= penis, **vd**= vas deferens.

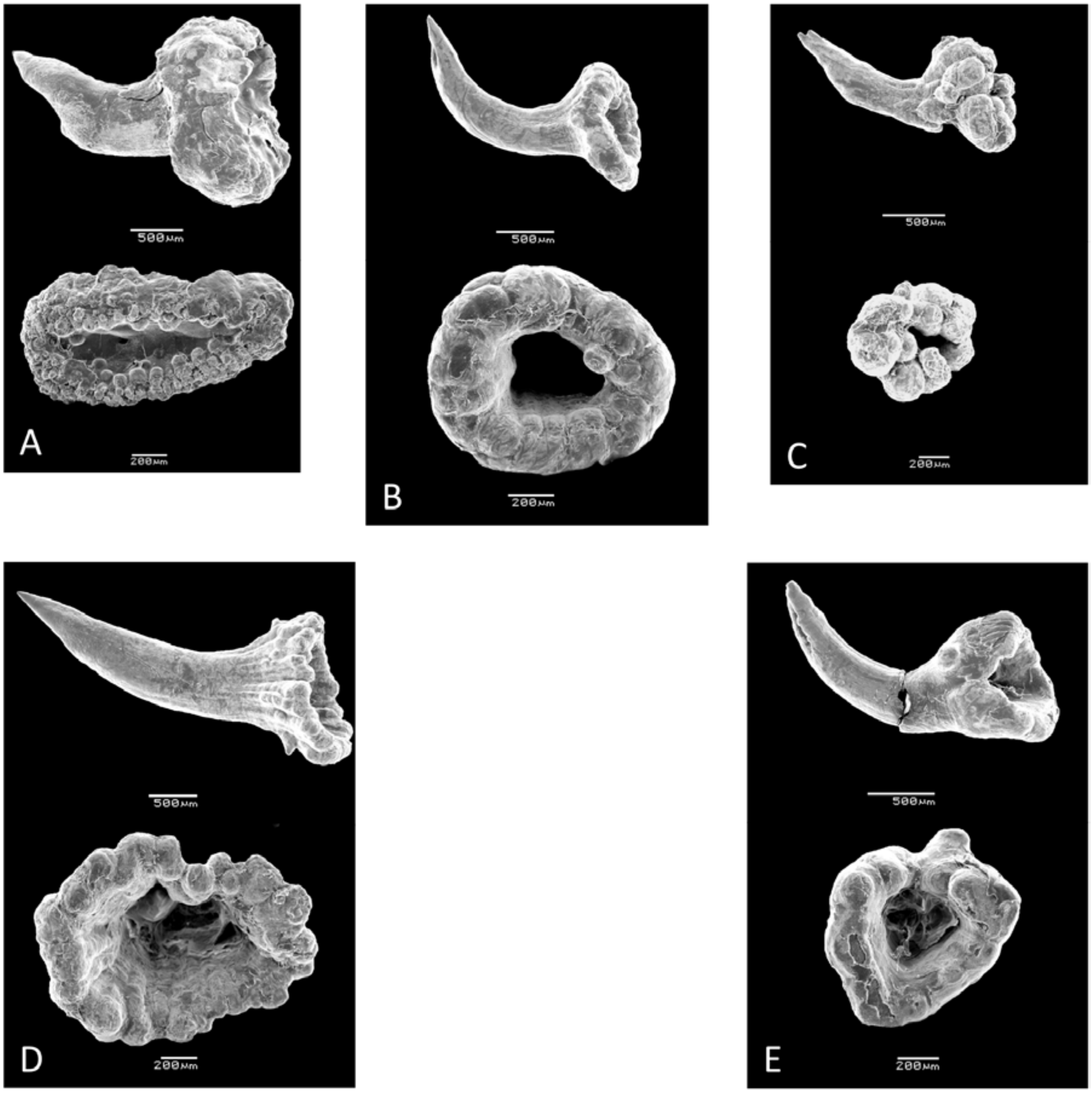

Figure 6-11. Darts of five *Philomycus* species: upper lateral view and lower image ventral view. A) *P. carolinianus* UF 447268, B) *P. flexuolaris* UF 447143, C) *P. venustus* UF 447116, D) *P. sellatus* UF 447224, E) *P. togatus* UF 447144.

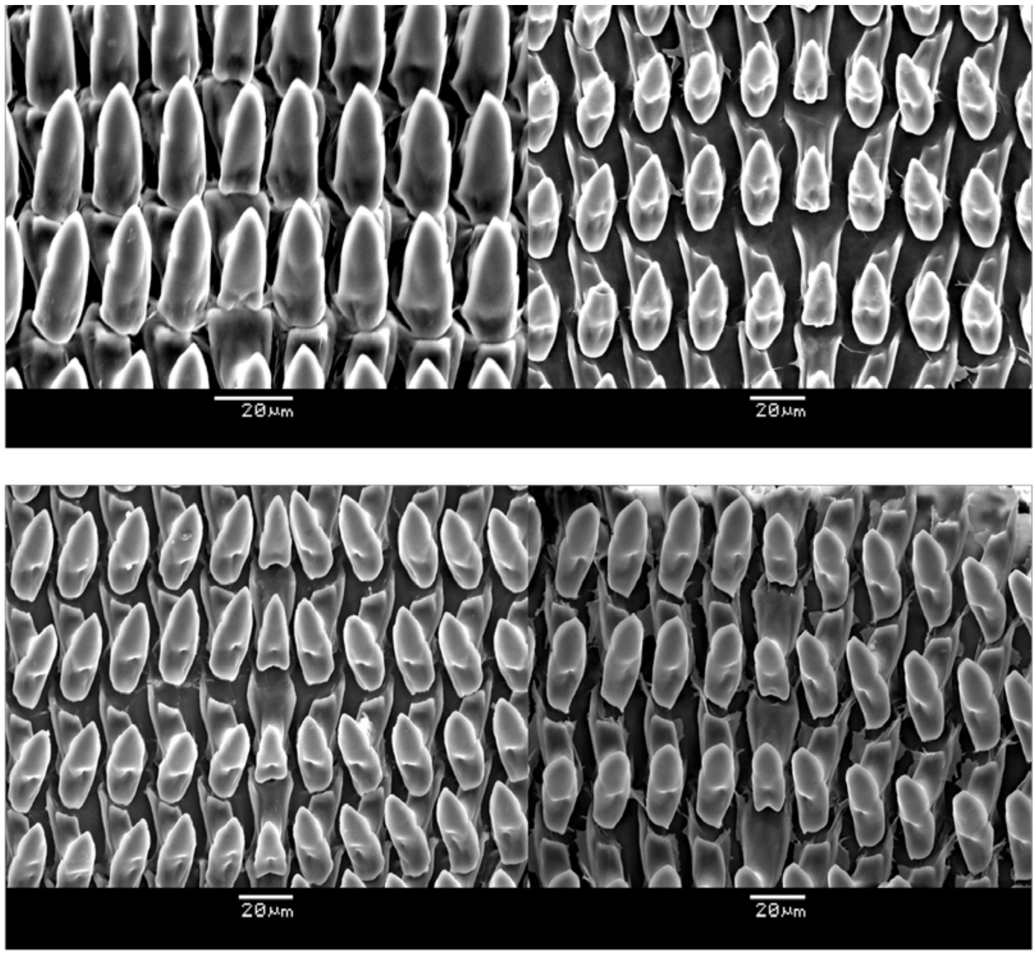

Figure 6-12. Central and lateral teeth of four *Philomycus* species. A) *Philomycus carolinianus* UF 447034, B) *P. venustus* UF 447116, C) *P. togatus* UF 447144C and D) *P. flexuolaris* UF 447163.

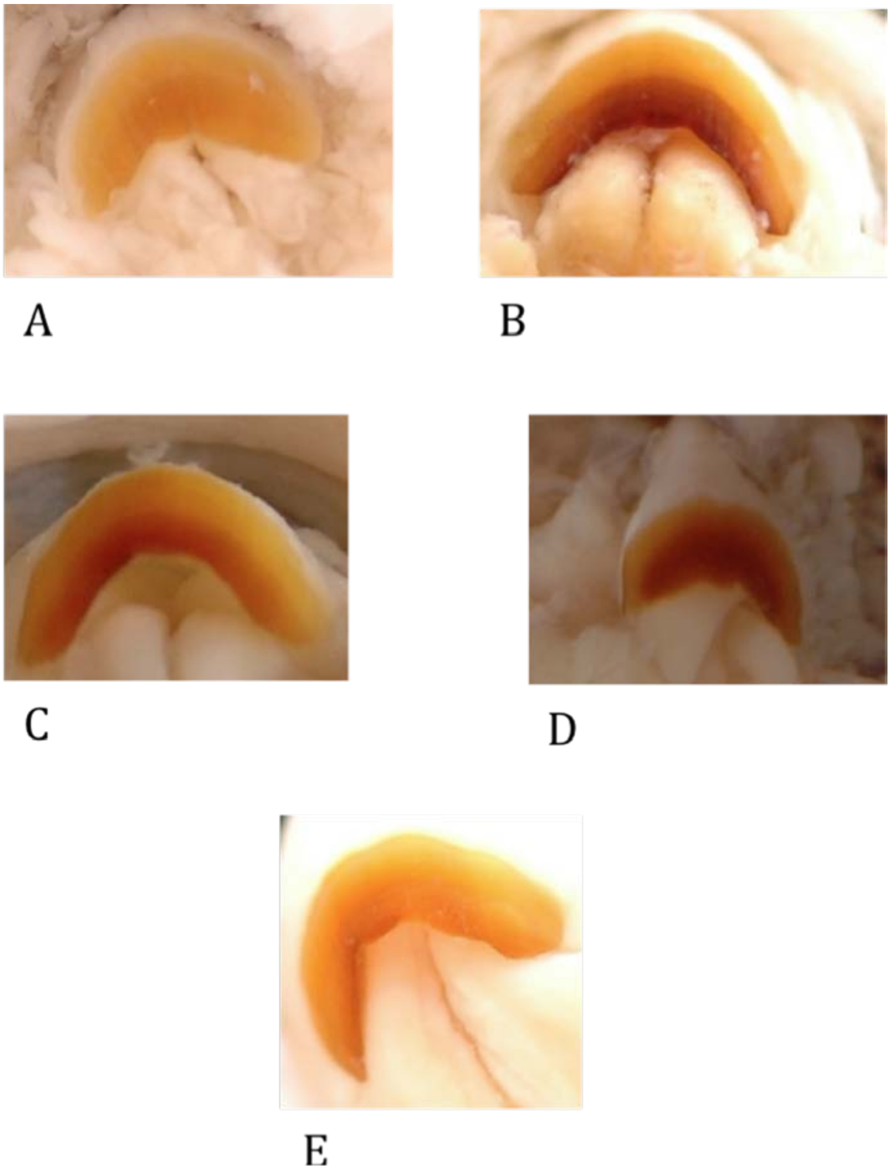

Figure 6-13. Jaws of five *Philomycus* species: A) *P. carolinianus* UF 447268, B) *P. flexuolaris* UF 447163, C) *P. togatus* 447144 UF, D) *P. venustus* UF 447116, E) *P. sellatus* UF 447224.

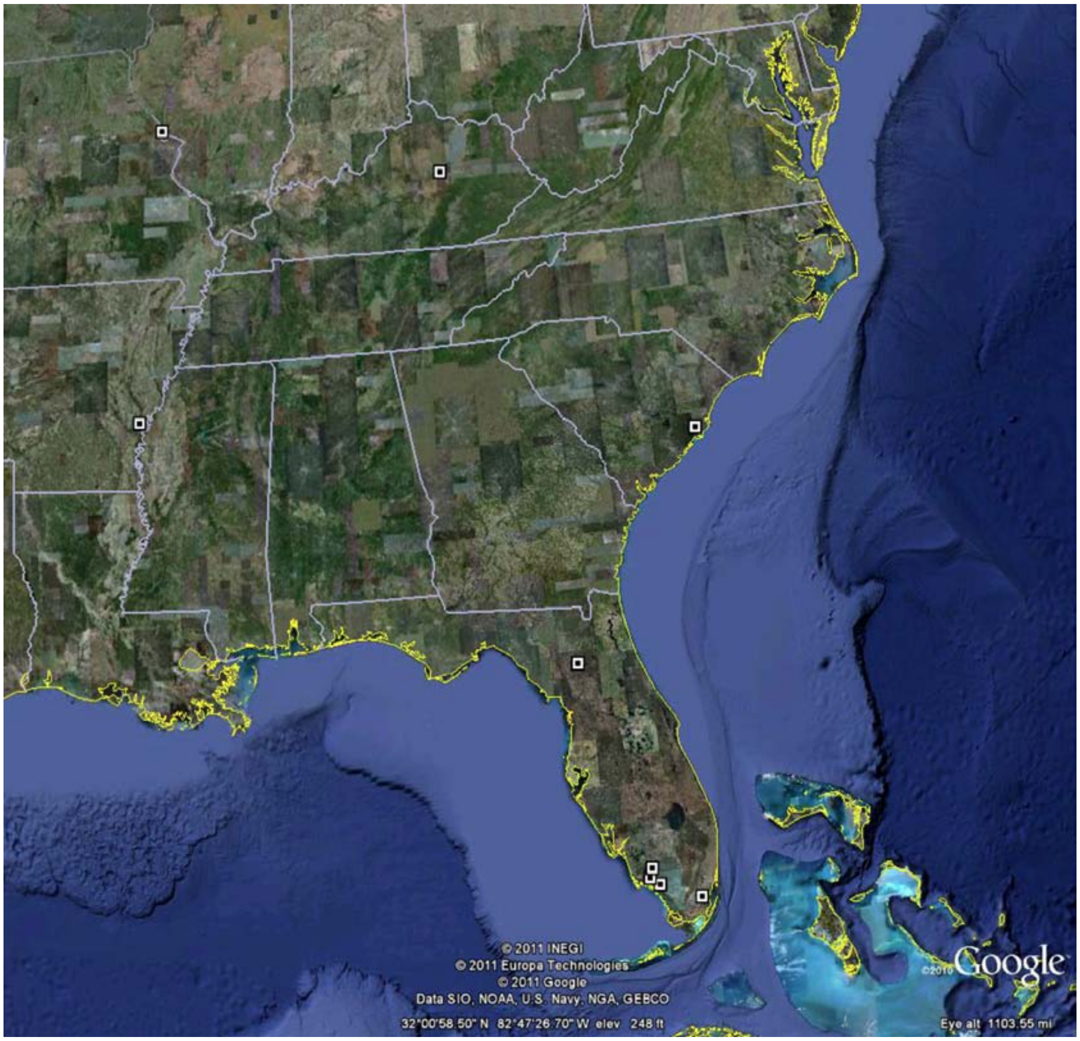

Figure 6-14. Distribution of *Philomycus carolinianus* throughout eastern United States.

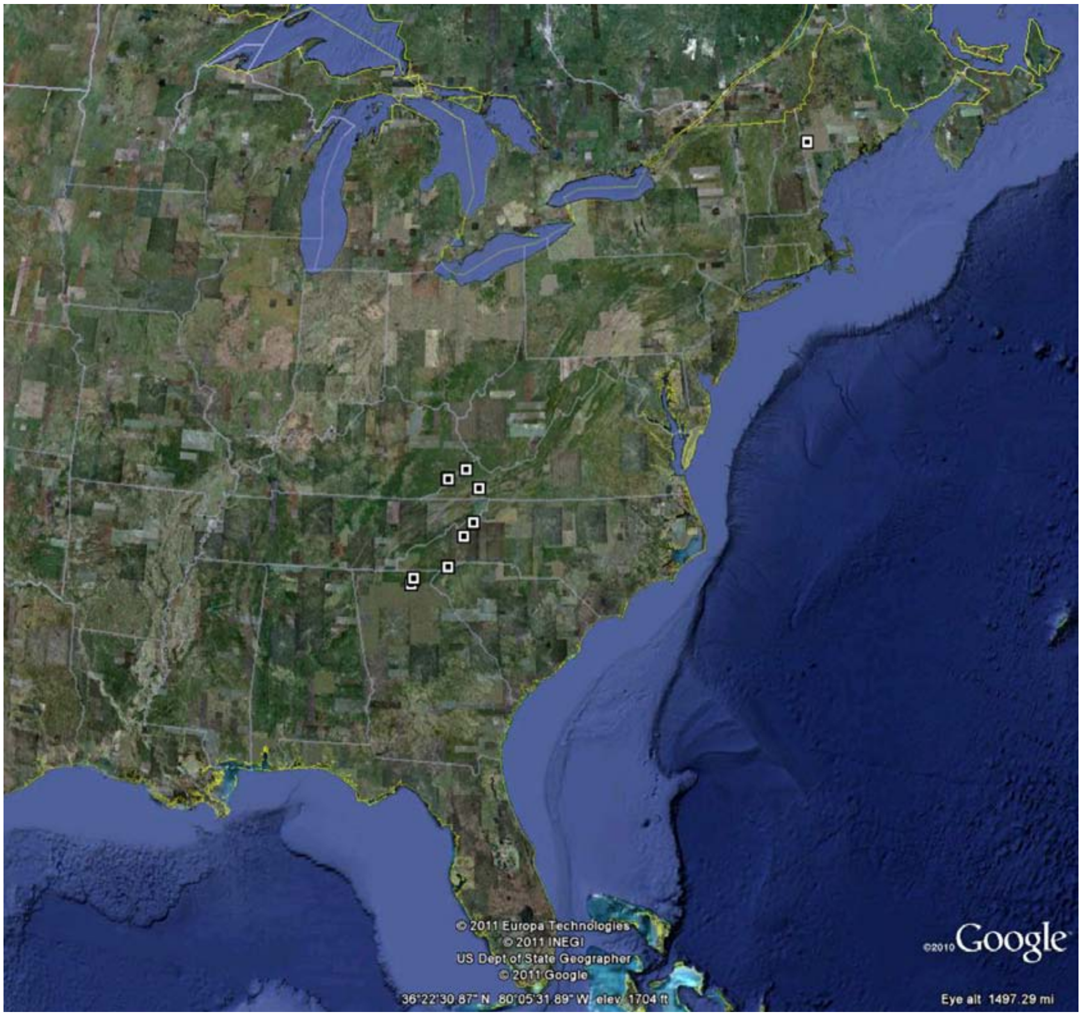

Figure 6-15. Distribution of *Philomycus flexuolaris* throughout eastern United States.

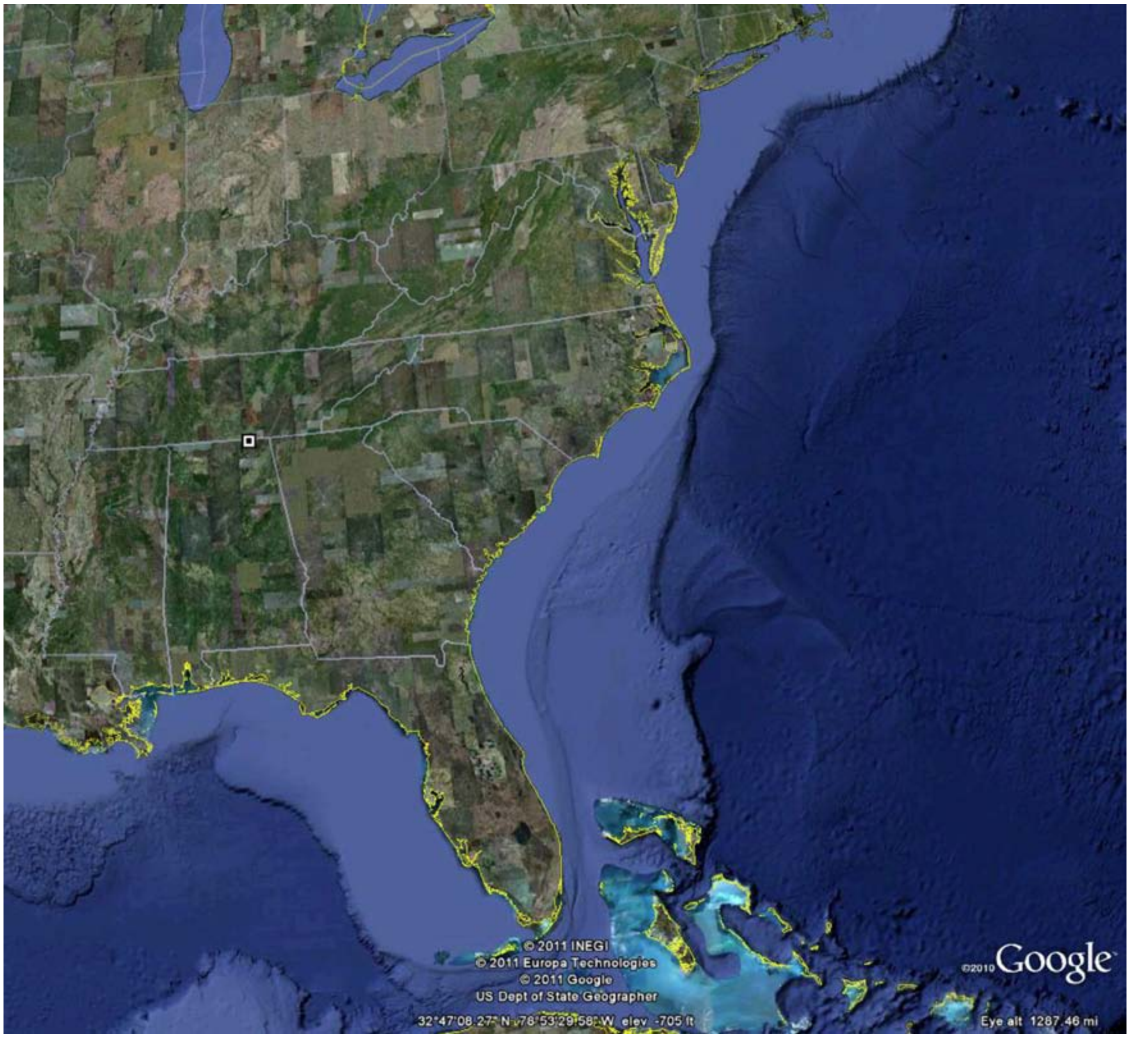

Figure 6-16. Distribution of *Philomycus sellatus* throughout eastern United States.

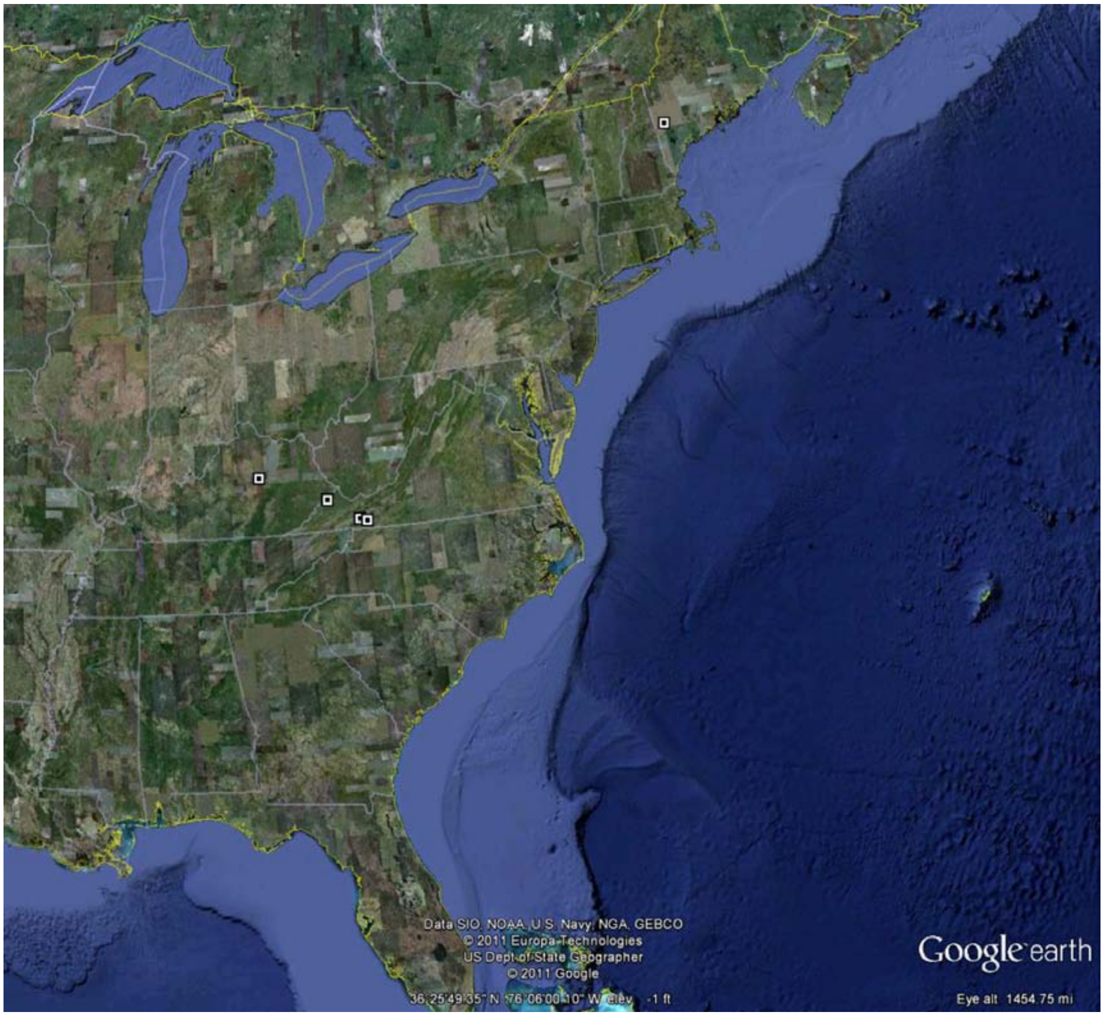

Figure 6-17. Distribution of *Philomycus togatus* throughout eastern United States.

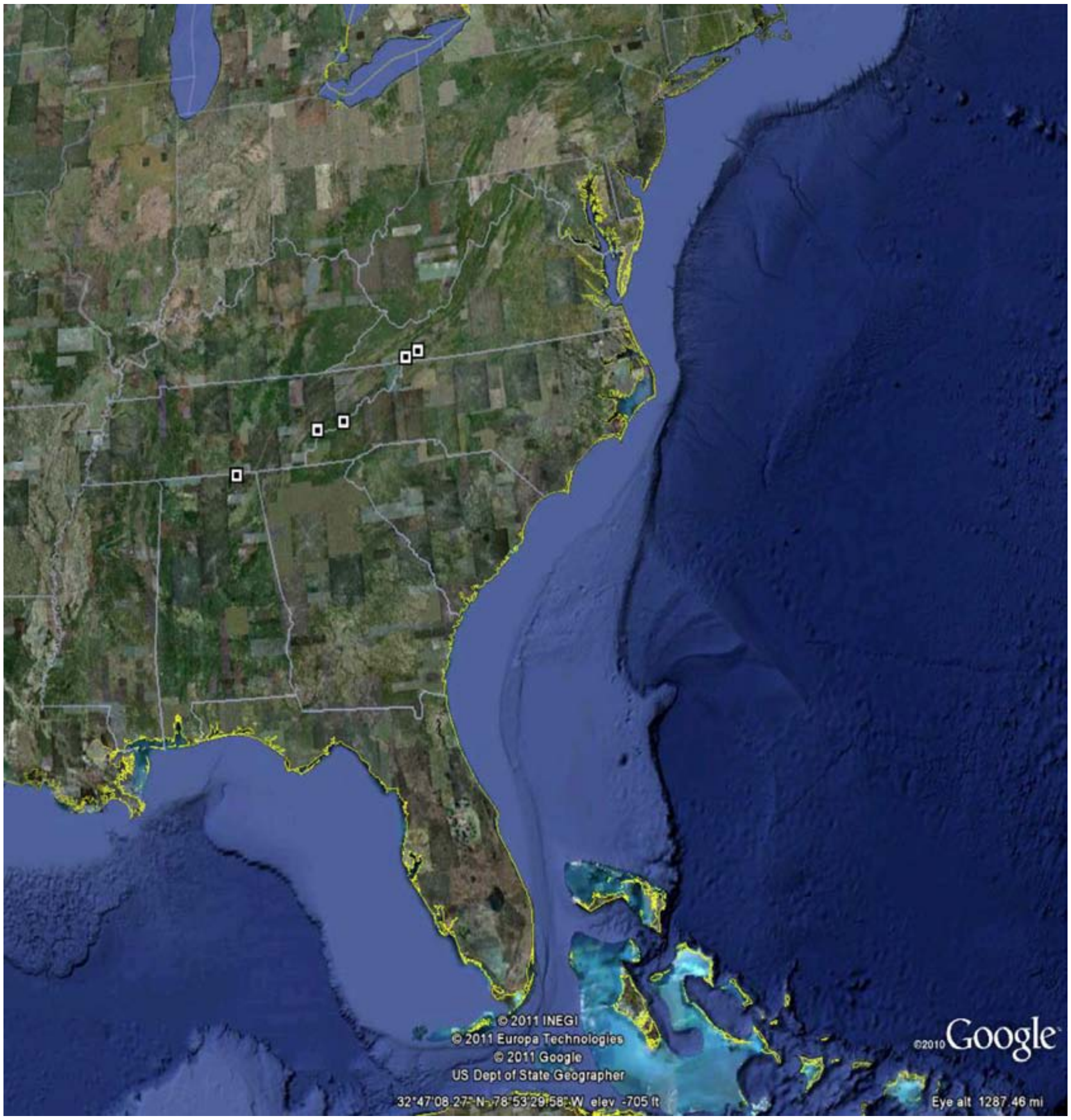

Figure 6-18. Distribution of *Philomycus venustus* throughout eastern United States.

CHAPTER 7
SUMMARY AND CONCLUSIONS

The over all goal of this research was to develop a web based user-friendly resource for timely and accurate identification of economically and ecologically important terrestrial gastropods, determine the pest potential of four select mollusc species and to clarify the biology, life-history and taxonomic ranking of species within the genus *Philomycus*. The Terrestrial Mollusc Tool (TMT) was developed through the compilation and synthesis of data from diverse sources into a single identification tool designed to meet the needs of inspectors at U.S.A. ports of entry and other non-malacologist end-users. The Terrestrial Mollusc Tool consists of a non-dichotomous pictorial key that allows the user to key specimens based on the presence or absence of pertinent morphological characters. Final selections are confirmed by consulting the fact sheets that provide specific information on the biology, ecology and distribution of each taxon. The fact sheets also provide high-resolution photographs and detailed line drawings of genitalic characters. A dissection tutorial is provided to assist the user to accurately determine the identity of closely related species. The pictorial key and factsheets of the TMT are designed to accommodate regular updates and the incorporation of new information to keep the tool current and maintain utility. The use of pictorial tools is a relatively new phenomenon facilitated by recent technological advances. As such future research should evaluate the utility of the TMT and other pictorial identification tools relative to traditional dichotomous keys.

Additional studies were conducted to specifically: (1) determine and compare the relative consumption potential and life history traits of *Deroceras reticulatum* and *D. leave* under laboratory conditions, (2) evaluate thirty seven annual and perennial plants species commonly grown in Florida for susceptibility to herbivory from *Zachrysia provisoria*, *Bradybaena similaris*, *D. reticulatum* and *D. leave*, (3) evaluate the effects of temperature and density on the consumption potential of *D. laeve* and *D. reticulatum*, (4) evaluate the biology, life history traits and feeding behavior of the Philomycus carolinianus under laboratory conditions and (5) review the taxonomy of the genus *Philomycus* using morphological (external and internal) and molecular characters.

The cosmopolitan slug *D. reticulatum* is considered a major agricultural pest worldwide and inhabits disturbed sites, whereas *D. laeve* is a pest of pastures and flourishes in agricultural systems where conservation tillage is employed. Laboratory evaluation of relative consumption potential and life history traits indicate that there was no significant difference in the quantity of host material consumed by both species. However, *D. reticulatum* has been documented to produce larger clutches of eggs and with greater frequency than *D. leave* under the laboratory and greenhouse conditions, suggesting that the greater reproductive potential of *D. reticulatum* may be a major contributing factor to the pest status of this species. The Florida population of *D. laeve* used in this study was more successful at higher temperatures in contrast to the Argentinean population used by Faberi et al. (2006) which performed better at lower temperatures. Additional research should be conducted to address populations of *D. laeve* collected worldwide to determine if there is some degree of speciation caused by geographic isolation or if we may be dealing with a species complex.

Results from the experiments evaluating 37 plants commonly grown in Florida for herbivory against *Zachrysia provisoria*, *Bradybaena similaris*, *Deroceras reticulatum* and *D. leave* indicate that *Z. provisoria* was the most polyphagous mollusc species consuming 84% of all test plants evaluated, whereas *D. reticulatum* consumed 11% and *D. leave* and *B. similaris* consumed 8% respectively. Annuals were generally more susceptible to herbivory when compared to perennials and one ornamental species (*Stromanthe sanguine* var*. tricolor)* was unacceptable to all mollusc species. Additional research should evaluate a wider range of plant species cultivated in Florida to determine those plant species least susceptible to herbivory.

Laboratory evaluation of the life history traits of *Philomycus carolinianus* indicated that this species employ self-fertilization as a reproductive strategy. The general growth curve for this species was sigmoidal; however, individuals within clutches displayed dramatic variation in weight gain. This may be attributed to genetic variation within the population and should be evaluated further. The experiment comparing the life history parameters of solitary and paired specimens indicated that paired specimens produced smaller clutches of eggs and oviposited less frequently when compared to solitary specimens. The data however, indicate that eggs from paired specimens produced higher mean percent hatch compared to solitary specimens. Additionally, the first clutch of eggs produced the highest mean percent hatch. Data derived from laboratory evaluation of temperature development thresholds for P. carolinianus eggs indicated that no eclosion resulted for eggs held 10 and 29°C. However eggs held at 10°C exhibited embryonic development and remained viable for up to 120 days hatching within 24h when temperature was increased to approximately 22°C. The ability of eggs to persist and remain viable at low temperatures could form an important survival strategy for this species.

Several synthetic (gypsy moth, spruce budworm and rabbit pellet) diets and natural (white mushroom, lettuce, carrot) materials were evaluated for the suitability as potential diets for short term rearing of *Philomycus carolinianus* in the laboratory. The synthetic insect diets (spruce budworm and gypsy moth) produced the greatest combination of favorable attributes of the diets evaluated and feasible diets for the maintenance of *P. carolinianus* laboratory colonies. Additional studies should be conducted to evaluate the suitability of these and other insect diets for short and long-term rearing of other mollusc species.

The natural diet of *Philomycus carolinianus* has been documented in the literature to consist of a wide variety of mushrooms; however, no record has been made on the variety and feeding preference of this species. The host range and feeding preference of *P. carolinianus* was evaluated in the laboratory using choice tests of 50 mushrooms (wild and cultivated) and a lichen species, using white mushroom as the control. The data indicated that *P. carolinianus* consumed all test mushrooms and lichen species evaluated in this study and displayed preferential feeding for select mushroom species. There was however, no evidence to support *P. carolinianus* feeding preference for higher taxonomic groups (genus, family order) of mushrooms. Several species of higher plants (understory vegetation and weedy plants) commonly found in habitats occupied by *P. carolinianus* was evaluated for potential herbivory using no-choice tests. No feeding activity was documented for these higher plants. There have been several observations of *Philomycus* consuming lichen; therefore, additional lichen species could be evaluated to determine *Philomycus* consumption preference.

The taxonomic revision of the genus *Philomycus* indicated that the genus is monophyletic and consist of at least five species: *P. carolinianus*, *P. togatus*, *P. venustus*, *P. flexuolaris* and *P. sellatus*. The results are however preliminary as additional specimens are required to further support the findings herein. It is recommended that additional species should be collected from a broader geographic range, examined and characterized to provide pertinent diagnostic characters in support of the genera *P. flexuolaris* and especially *P. venustus* as preliminary results suggests that these two genera may be species complexes or there may be additional species in the genus.

APPENDIX A
LIST OF SPECIES INCLUDED IN THE TERRESTRIAL MOLLUSC TOOL

Family: Achatinidae
Achatina (Lissachatina) fulica Bowdich, 1822
Achatina achatina (Linnaeus, 1758)
Archachatina marginata (Swainson, 1821)
Elasmias apertum (Pease, 1864)
Limicolaria aurora (Jay, 1839)

Family: Agriolimacidae
Deroceras agreste (Linnaeus, 1758)
Deroceras caucasicum (Simroth, 1901)
Deroceras laeve (O.F. Müller, 1774)
Deroceras panormitanum (= caruanae) (Lessona & Pollonera, 1891)
Deroceras reticulatum (O.F. Müller, 1774)

Family: Amphibulimidae
Amphibulima patula dominicensis Pilsbry, 1899

Family: Ampullariidae
Marisa cornuarietis (Linnaeus, 1758)
Pila conica (Wood, 1828)
Pomacea canaliculata (Lamarck, 1822)
Pomacea glauca (Linnaeus 1758)
Pomacea insularum (d'Orbigny, 1835)
Pomacea lineata (Spix, 1827)

Family: Arionidae
Ariolimax columbianus (Gould, 1951)
Arion ater (Linnaeus, 1758)
Arion circumscriptus Johnston, 1828
Arion distinctus Mabille, 1868
Arion fasciatus (Nielsson, 1919)
Arion hortensis Férussac, 1819
Arion intermedius (Normand, 1852)

Arion vulgaris (= lusitanicus) Moquin-Tandon

Arion owenii (Davies, 1979)
Arion rufus (Linnaeus, 1758)
Arion silvaticus Lohmander, 1937
Arion subfuscus (Draparnaud, 1805)
Prophysaon andersoni (Cooper, 1872)

Family: Helicarionidae
Parmarion martensi Simroth, 1893
Parmarion reticulates Hasselt, 1824
Mariaella dussumieri Gray, 1855

Family: Bradybaenidae
Acusta touranensis (Souleyet, 1842)
Bradybaena similaris (Rang, 1831)

Family: Camaenidae
Granodomus lima (Férussac, 1821)

Family: Chronidae
Ovachlamys fulgens (Gude 1900)

Family: Cochlicellidae
Cochlicella acuta (da Costa, 1778)
Prietocella barbara (Linneaus, 1758)
Cochlicella conoidea (Draparnaud, 1801
Cochlicella ventricosa (Draparnaud, 1801)

Family: Cochliocopidae
Cochlicopa lubrica (Müller, 1774)

Family: Discidae
Discus rotundatus (Müller, 1774)

Family: Euconulidae

Family: Helicarionidae
Guppya gundlachi (Pfeiffer, 1839)

Family: Helicidae
Cepaea hortensis (Müller, 1774)
Cepaea nemoralis (Linnaeus, 1758)
Cornu aspersum (Müller, 1774)
Eobania vermiculata (O.F. Müller, 1774)
Helicella italia (Linnaeus, 1758)

Helicogona arbustorum (Linnaeus, 1758)
Helix aperta Born, 1778
Helix lucorum Linneaus, 1758
Helix pomatia Linnaeus, 1758
Otala lactea (Müller, 1774)
Otala punctata (Müller, 1774)
Theba pisana (Müller, 1774)

Family: Hygromidae
Candidula intersecta (Poiret, 1801)
Cernuella neglecta (Draparnaud, 1805)
Cernuella virgata (DaCosta, 1778)
Hygromia cinctella (Draparnaud, 1801)
Microxeromagna armillata (Lowe, 1852)
Monacha cantiana (Montagu, 1803)
Monacha cartusiana (Müller, 1774)
Monacha syriaca (Ehrenberg, 1831)
Trichia striolata (C. Pfeiffer, 1828)
Trochoidea pyramidata (Draparnaud, 1805)
Trochulus hispidus (Linnaeus, 1758)
Xerolenta obvia (Menke, 1828)
Xeropicta vestalis (Pfeiffer, 1841)
Xerotricha conspurcata Draparnaud, 1801

Family: Limacidae
Lehmannia marginata (O.F. Müller, 1774)
Lehmannia valentiana (Férussac, 1823)
Lehmannia nyctelia (Bourguignat, 1861)
Limacus flavus (Linnaeus, 1758)
Limax maximus Linnaeus, 1758

Family: Lymnaeidae
Lymnaea stagnalis (Linnaeus, 1758)
Radix auricularia (Linnaeus, 1758)
Radix peregra (Müller, 1774)

Family: Megabulimidae
Megalobulimus oblongus (O.F. Müller, 1774)

Family: Milacidae
Milax gagates (Dreparnaud, 1801)
Tandonia budapestensis (Hazay, 1881)
Tandonia rustica (Millet, 1843)
Tandonia sowerbyi (Férussac, 1823)

Family: Orthalicidae
Bulimulus diaphanus fraterculus (Potiez and Michaud, 1835)
Bulimulus guadalupensis (Bruguière, 1789)

Family: Parmacellidae
Parmacella ibera Eichwald, 1841

Family: Philomycidae
Pallifera costaricensis (Morch, 1857)

Family: Physidae
Physella acuta (Draparnaud, 1805)

Family: Pleurodontidae
Zachrysia provisoria (Pfeiffer, 1858)
Zachrysia trinitaria (Pfeiffer, 1858)

Family: Polygyridae
Polygyra cereolus (Mühlfeld, 1816)
Praticolella griseola (Pfeiffer, 1841)

Family: Pupillidae
Lauria cylindracea (da Costa, 1778)
Pupisoma dioscoricola (Adams, 1845)

Family: Subulinidae
Allopeas gracile (Hutton, 1834)
Leptinaria unilamellata (D'Orbigny, 1835)
Rumina decollata (Linnaeus, 1758)
Subulina octona (Bruguière, 1798)

Family: Succineidae
Calcisuccinea luteola Gould, 1848
Calcisuccinea dominicensis (Pfeiffer)
Oxyloma pfeifferi (Rossmassler, 1835)
Succinea campestris Say, 1818
Succinea costaricana von Martens, 1898
Succinea horticola (Reinhardt, 1877)

Succinea putris (Linnaeus, 1758)
Succinea tenella Morelet, 1865

Family: Testacellidae
Testacella haliotidea

Family: Trochidae
Gibbula adriatica (Philippi, 1844)
Gibbula albida (Gmelin, 1791)

Family: Urocyclidae
Elisolimax flavescens (Keferstein, 1866)

Family: Veronicellidae
Belocaulus angustipes Heynemann, 1885
Diplosolenodes occidentalis (Guilding, 1825)
Leidyula moreleti (Crosse and Fischer, 1872)
Phyllocaulis gayi (Fischer, 1871)
Sarasinula plebeia (P. Fischer, 1868)
Sarasinula dubia (Semper, 1885)
Sarasinula marginata (Semper, 1885)
Vaginulus alte (Férussac, 1822)
Veronicella aff. *floridana* (Leidy, 1868)
Veronicella cubensis (Pfeiffer, 1840)
Veronicella laevis Blainville, 1817
Veronicella sloanei (Cuvier, 1817)

Family: Viviparidae
Viviparus viviparus (Linnaeus, 1758)

Family: Zonitidae
Oxychilus alliarius (Miller, 1822)
Oxychilus cellarius (O.F. Müller, 1774)
Zonitoides arboreus (Say, 1819)
Zonitoides nitidus (Müller, 1774)

APPENDIX B
TERRESTRIAL MOLLUSC TOOL WEBSITE CONTENT

Arion ater group: Arion rufus

Welcome to the Terrestrial Mollusc Tool.

Dissection Tutorial

Live specimens should be drowned in an airtight container that is completely filled with water. They should be left overnight or until completely...

Continue reading...

How to Use the Key

This key was created to assist inspectors at U.S. ports of entry who are inspecting cargo to determine the identity of potentially important, invading...

Continue reading...

Biology & Ecology

The phylum Mollusca includes a wide variety of invertebrates (animals without a spine) including gastropods (snails and slugs), cephalopods...

Continue reading...

About

Introduction to Terrestrial Mollusc Tool

The Terrestrial Mollusc Tool was specifically designed to assist in the identification of adult terrestrial slugs and snails of agricultural importance. The tool also includes species of quarantine significance as well as invasive and contaminant mollusc species commonly intercepted at U.S. ports of entry. This Lucid-based identification tool specifically targets federal, state and other agencies or organizations within the U.S. that are concerned with the detection and identification of molluscs of significance. This tool includes 33 families and 128 species. This resource also includes an interactive identification key, comparison chart, fact sheets, biological and ecological notes, a dissection tutorial, a glossary of commonly used terms, and a list of useful links and references. It should be noted that this dynamic tool is not inclusive of all mollusc pests, as new species of interest arise almost daily.

The list of species included in this tool was generated based on pest species reported in scholarly publications by Barker 2002, Cowie et al. 2009, and Godan 1983 as well as commonly intercepted species documented in the port of entry interception data from US Department of Agriculture's Animal and Plant Health Inspection Service's Plant Protection and Quarantine division (USDA-APHIS-PPQ) and the Florida Department of Agriculture and Consumer Services (FDACS) -Division of Plant Industry.

The pictorial key included in the Terrestrial Mollusc Tool is unable to identify a few entities below the family level. This is true especially for the families Veronicellidae and Succineidae. The major reason for this is the lack of diagnostic morphological characters and the variability of members of these groups. In many cases, it is recommended that molecular techniques be used in the identification of members of these families (Holland and Cowie 2007; Gomes et al. 2010). This inadequacy of the key is, however, mitigated by the fact that most if not all members of these problematic groups are pestiferous and as such are regulated at the family level. The same is true for the species complexes (e.g., *Arion hortensis* group, *A. ater* group) included in the tool.

The Terrestrial Mollusc Tool was developed and published by the Center for Plant Health Science and Technology (CPHST) as part of a cooperative agreement with the Department of Entomology and Nematology, University of Florida and the United States Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS), Plant Protection and Quarantine (PPQ) and is under the direction of Terrence Walters, CPHST Identification Technology Program (ITP) coordinator.

The photographs utilized in this tool were generously provided by those credited on each. The photographers and organizations that gave permission to use their images

are also credited in the acknowledgements. All drawings were produced by the University of Florida, unless otherwise noted.

See Copyright, Citation and Disclaimers for information about the use of content on these pages and all the pages included in this tool. For information concerning the Terrestrial Mollusc Tool or to offer any feedback or comments, please contact the author or the Entomology and Nematology department at the University of Florida, Gainesville, FL.

About the Key

This key was created to assist inspectors at U.S. ports of entry who are inspecting cargo to determine the identity of potentially important, invading organisms, specifically terrestrial molluscs.It is acknowledged that the scope of this key may be larger and as such may be used as an educational tool for a variety of fields.

The taxonomy of terrestrial molluscs is very dynamic, hence a large number of the entities (species, families, groups) included in this key may have been and continue to be revised. For each entity, a list of synonyms has been included in the supporting fact sheets to assist in clarifying the nomenclature.

It is recommended that the user read the “About this tool” and the “Biology” sections of this tool before attempting to use the pictorial key. The key can reliably identify only adult specimens, as juveniles may not possess the characteristic features of the species. This is true for both snails and slugs. Slugs are generally more difficult to key to the species level and often require dissection. If dissection is necessary, there is a dissection tutorial available in this tool to assist the user to successfully dissect a snail and/or a slug.

Equipment required for the optimal use of this key:

- Hand lens (10-20 X)
- Ruler or Caliper
- Adult specimens
- Anatomy drawing (located in Biology section)

It is important to remember that this key is not inclusive of all pestiferous mollusc species. This key is intended to serve as an aid in the identification of terrestrial mollusc species documented as major agricultural and ecological pests as well as contaminant and non-pest species that are commonly intercepted at U.S. ports of entry.

Collecting & Handling Specimens

It is advised to always exercise caution when handling terrestrial gastropods as several species act as intermediate and reservoir hosts for parasites that can cause serious diseases in humans and domestic animals. Gloves should always be worn in order to limit physical contact with living and dead specimens and their associated mucus secretions. In the event of direct external contact with snails, slugs or their secretions, immediately wash affected area carefully with warm soapy water.

Collection and Preservation

Live specimens should be drowned in an airtight container that is completely filled with water. They should be left until completely drowned (i.e., unresponsive to touch). The specimen should then be transferred to 70 % ethyl alcohol for at least one hour then the alcohol should be replaced with fresh 70% alcohol.

Labeling

The container should then be labeled with at least the following information: **collection date, collector's name and location**. Be sure to retain the label when transferring specimens. The information may be recorded directly on the container or on a label that is placed inside the container. Collection information is very important and should be recorded at the time of collecting the specimen. It is recommended that the label be written in pencil as ink may be destroyed by the alcohol. If specimens are collected from different areas, they should be submitted separately.

Submission

All samples collected should be submitted to the USDA-APHIS-PPQ-NIS, along with the appropriate form. It is required by the United States Department of Agriculture (USDA) that all domestically collected specimens be submitted with an accompanying *PPQ 391* (IBP Record) form; specimens associated with imported cargo require a *PPQ 309* record.

Lucid System Requirements

Option 1: Key Server

Accessing the key through the Lucid Key Server is the default option.

Advantages:

- It is fully web-based and requires no special software or add-ons.

- You do not have to wait for entire key to load.
- It can be used on mobile devices such as the iPad, iPhone, etc.

Disadvantages:

- The 4x4 viewing grid is not size adjustable.
- Because the entire key is not loaded, users may experience latency between character selections.

If the key does not load at first, please refresh the page.

Begin Key Server

Option 2: Java Key

Advantages:

- The key is pre-loaded, eliminating latency between character selections.
- The 4x4 viewing grid is size adjustable.

Disadvantages:

- Entire key must be loaded before it can be used.
- System requirements are more restrictive (see below).
- Java applets may be blocked as active content by certain organizations.
- Java applet will not run on many mobile devices.

Operating System: Windows 2000/XP/Vista, Mac OSX 10.4 or greater, Linux (that supports J2RE), Solaris 7-10. (The key will run on Windows 98/ME/NT4 but these platforms are no longer supported.)

System Memory: 256MB RAM (512MB or greater recommended).

Web browser: Java-enabled web browser such as Internet Explorer, Firefox, Chrome, or Safari.

NOTE: Web pages such as fact sheets attached to items in Lucid keys may be considered pop-ups by certain browsers (such as Internet Explorer [IE]). If your browser blocks these pop-ups, in your browser's Internet settings you should allow pop-ups for this tool. Additionally, Internet Explorer may block "active content" on web pages or interactive keys. To allow active content: in Internet Explorer under *Tools*, *Internet Options*, *Advanced* tab, *Security* category, the box next to the setting "Allow active content to run in files on My Computer" should be checked. Additionally, certain settings under *Tools, Internet Options, Security, Custom level, ActiveX controls and plug-ins*, may need to be changed.

The Lucid3 interactive key will run embedded within a web browser as a Java Applet Player. Java Runtime Environment (JRE) version 1.4.2 (1.5 or greater recommended) must be installed on your computer for the Lucid3 Applet Player to run successfully.

If in the box above you see text that says your Java status is version 1.4.2 (or greater) from Sun Microsystems Inc., and your computer meets the Lucid3 system requirements, you may open a key:

Begin Java Key

Java information

If you don't see the necessary text in the box above, if the version number displayed is less than 1.4.2, or you receive an error message stating "Java is an unknown command", you can download and install (make sure to uninstall old versions) the latest Java Runtime Environment version from the Java web site at

www.java.com

Note: Some Java versions greater than 1.4.2 may have bugs that affect operation of the interactive key. Bugs can usually be resolved by downloading the latest Java Runtime Environment version from the Java web site. Also, be aware that the JRE is continually being updated for compatibility with operating system updates. It's generally a good idea to have the latest JRE version installed.

You can verify your Java installation status by doing the following:

Windows

Type "java -version" at a Command Prompt window. You can get to the Command Prompt window by either going to *Run* from the *Start* button and typing "cmd" or by selecting the *Command Prompt* menu option from *Accessories*.

Mac OSX, Linux, Unix and other platforms

Type "java -version" at a terminal window.

Note to Macintosh users

OSX comes pre-installed with the JRE and is accessible using Safari. Ensure you have the latest version of JRE by running the software update utility. Internet Explorer version 5.2.3, which is the last version of IE for the Mac, does not support JRE, nor does Opera. Mozilla.org, however, has opted (at least since February 2007) to include the Java Embedding Plugin by default in all of its products (Firefox, Mozilla, or Camino browsers). This will enable them to access JRE and run the key. However, if you require the Java Embedding Plugin, see the links below for information regarding installation, compatibility and updates for the plugin. The Java Embedding Plugin does not work with Explorer or Opera.

Information and Installation instructions for the Java Embedding Plugin for Mac OSX can be found at:

http://javaplugin.sourceforge.net/

To download the plugin directly, go to the Java Embedding Plugin Summary at:

http://sourceforge.net/projects/javaplugin/

If Java version 1.4.2 or greater is now installed on your computer, you may open the key:

Begin Java Key

Lucid

Lucid3 is software for creating and using interactive identification keys. Lucid is developed by **QAAFI Biological Information Technology** at the University of Queensland in Australia. Visit the **Lucidcentral** web site for more information on Lucid3.

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Information and Links

Useful Resources:

Barker, G.M. (ed.) 2001. The biology of terrestrial molluscs. CABI Publishing, Wallingford, UK. pp558

Barker, G.M. (ed.) 2002. Molluscs as crop pests. CABI Publishing, Wallingford, UK. pp 468

Barker, G.M. (ed.) 2004. Natural enemies of terrestrial molluscs. CABI Publishing, Wallingford, UK. pp 644

Burch, J.B. 1962. How to Know the Eastern Land Snails. Wm. C. Brown Company Publishers, Dubuque, Iowa. pp 214

Cowie, R.H., R.T. Dillion Jr, D.G. Robinson and J.W. Smith. 2009. Alien non-marine snails and slugs of priority quarantine importance in the United States: a preliminary risk Assessment. American Malacological Bulletin 27: 113-132.

Forsyth, R.G. 2004. Royal BC museum handbook: land snails of British Columbia. Victoria, Canada: Royal BC Museum.

Godan, D. 1983. Pest slugs and snails. Biology and control. Springer-Verlag, Berlin.

Grimm, F.W., R.G. Frosyth, F.W. Scheler and A. Karstad. 2009. Indentifying land snails and slugs in Canada. Introduced species and native genera. Canada Food Inspection Agency. Ottawa, ON.

Hubricht, L. 1985. The distributions of the native land mollusks of the eastern United States. Fieldiana (Zoology) New Series 24. pp 191

McDonnell, R., T. Paine and M. J. Gormally. 2009. Slugs: A Guide to the Invasive and Native Fauna of California. Oakland: University of California Agriculture and Natural Resources Publ. 8336.

Pilsbry, H. A. 1939. Land Mollusca of North America north of Mexico vol. I part 1. Academy of Natural Sciences, Philadelphia. pp 1-574

Pilsbry, H. A. 1940. Land Mollusca of North America north of Mexico vol. I part 2. Academy of Natural Sciences, Philadelphia. pp 575-994

Pilsbry, H. A. 1946. Land Mollusca of North America north of Mexico vol. II part 1. Academy of Natural Sciences, Philadelphia. pp 1-520

Pilsbry, H. A. 1948. Land Mollusca of North America north of Mexico vol. II part 2. Academy of Natural Sciences, Philadelphia. pp 521-1113

Robinson, D.G. 1999. Alien invasions: the effects of the global economy on non-marine gastropod introductions into the United States. Malacologia 41: 413-438.

South, A. 1992. Terrestrial slugs: biology, ecology and control. Chapman and Hall, London. pp 428 pp

Online Publications- Management

Oregon State University. Pacific Northwest nursery IPM. Snails/slugs. http://oregonstate.edu/dept/nurspest/slugs.htm

University of California. Agriculture and Natural Resources. UC IPM Online. Snails and slugs: Integrated pest management for home gardeners and landscape professionals. http://www.ipm.ucdavis.edu/PMG/PESTNOTES/pn7427.html

University of Florida. Terrestrial slugs of Florida (Mollusca: Stylommatophora: Veronicellidae, Philomycidae, Agriolimacidae and Limacidae). EENY-493 (IN891). http://edis.ifas.ufl.edu/in891

Keys

Discover Life: Mollusc identification guide: http://www.discoverlife.org/20/q?guide=Molluscs

Identification guide to the land snails and slugs of western Washington: http://academic.evergreen.edu/projects/ants/TESCBiota/mollusc/key/webkey.htm

Jacksonville Shell Club. http://www.jaxshells.org/

Key to the genera of introduced and native land snails and slugs in Canada

Key to the snails of the Bristol Region: http://www.brerc.eclipse.co.uk/files/BRERC_snail_key.pdf

Key to the terrestrial gastropods of British Columbia: http://www.livinglandscapes.bc.ca/cbasin/molluscs/pdf/mollusc3.pdf

Land snails and slugs of Canada: http://www.mollus.ca/index.htm

Land snails of Pennsylvania: http://www.carnegiemnh.org/mollusks/palandsnails/

Mollus.ca: http://www.mollus.ca/index.htm

North American Land Snails: northamericanlandsnails.com/

Slugs: A guide to the invasive and native fauna of California: http://ucanr.org/freepubs/docs/8336.pdf

Tree snails (of Florida), Drymaeus, Orthalicus, Liguus spp (Gastropoda: Bulimulidae): http://edis.ifas.ufl.edu/in305

Fact Sheets

Achatina achatina

Family

Achatinidae

Species

Achatina achatina (Linnaeus, 1758)

Common Name

Giant African snail, Giant Ghana snail, Giant tiger land snail, Escargot geant, Achatine

Description

Similar to the other species in the genus, *Achatina achatina's* shell can attain a length of 200 mm and a maximum diameter of 100 mm. They may possess between 7-8 whorls and the shell is often broadly ovate. The body of the animal is silver-brown in color although albino morphs may exist.

Native Range

Northern section of West Africa

Distribution

North America: Currently not present, though it is commonly intercepted at U.S. ports.

Africa: Sierra Leone, Liberia, Ivory Coast, Togo, Dahomey, Ghana, Nigeria

Ecology

Achatinids are generally nocturnal forest dwellers but have the potential to adapt to disturbed habitats. Concealed habitats are generally preferred; however, individuals may colonize more open habitats in the event of overcrowding. Achatinids often become more active during periods of high humidity (e.g., after rainfall); however, the occurrence of large numbers of individuals especially during daylight may indicate high population density.

Achatinids normally lay their calcareous eggs in the soil, but they may be deposited under leaf litter or rocks. They feed on both living and dead plant material. In addition to being agricultural pests, achatinids can be a threat to public health as they act as a reservoir host of the rat lung parasites (*Angiostrongylus cantonensis* and *A.*

costaricensis), which cause eosinophilic meningoencephalitis in humans. They can also be an unsightly public nuisance during periods of population explosion.

Synonyms

References

Abbott 1989; Barker 2002; Cowie et al. 2008; Cowie et al. 2009

Allopeas gracile

Family

Subulinidae

Species

Allopeas gracile (Hutton, 1834)

Common Name

Graceful awl snail

Description

The elongated, conical shell of this snail measures approximately 12 mm high, with 7-9 whorls. Vacant shells are tan in color and living specimens are yellow. This species may be confused with *Subulina octona;* however, *Allopeas gracile* is smaller and does not have a truncated columella.

Native Range

Neotropics

Distribution

Pacific Islands: Hawaii

Central and South America: Mexico

Caribbean

Asia: Southeastern region

Ecology

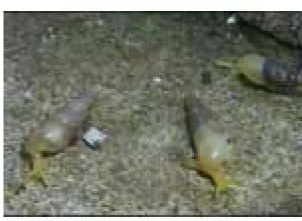
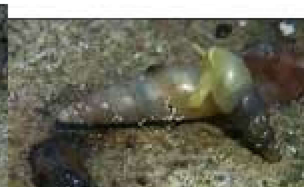
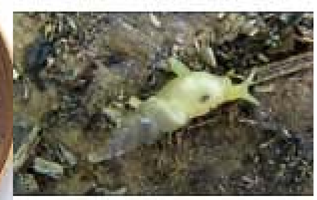
This species has been documented to occur in large numbers wherever it inhabits. These large numbers often result in outcompetition of other native species within a particular ecosystem. They often occur in greenhouses.

Synonyms

- *Bulimus gracilis* Hutton, 1834
- *Bulimus oparanus* Pfeiffer, 1846
- *Bulimus junceus* Gould 1846
- *Stenogyra upolensis* Mousson, 1865

References

Almeida and Bessa 2001; Burch 1962; Cowie 1997; Cowie et al. 2008; Juricková 2006; Meyer and Cowie 2010; Naggs et al. 2003; Robinson et al. 2009; Rosenberg and Muratov 2006

Amphibulima patula dominicensis

Family

Amphibulimidae

Species

Amphibulima patula dominicensis Pilsbry, 1899

Common Name

Widemouth bulimulus

Description

Mature individuals of this species can attain a length of approximately 25 mm, with a total of 3 whorls. The shell of this snail appears to be very small in relation to the body. The shell is purple-brown in color, with the apex having a more intense purple/pink color. The body of the snail is yellow-brown or tan in color.

Native Range

Dominica

Distribution

Caribbean: Dominica

Ecology

This pest is known to feed on the leaves of banana and citrus plants.

Synonyms

- *Amphibulima patula* (Bruguiere)
- *Amphibulima patula* var. *dominicensis* Pilsbry, 1899
- *Amphibulima patula dominicanus*

References

Robinson et al. 2009; Stange 2004

Archachatina marginata

Family

Achatinidae

Species

Archachatina marginata (Swainson, 1821)

Common Name

Giant African snail, Banana rasp snail, West African snail

Description

This species has the potential to get up to 210 mm in length and 130 mm in diameter, with 6-7 whorls. The shell has a brownish yellow background with fairly uniformly arranged bands and zigzag lines or spots that are dark-brown or reddish brown in color. The columella, outer lip and inside the aperture (mouth) are white or pale blue. The apex of the shell is slightly flattened, bulbous and pale or pinkish in color. The body color of the animal is variable (albino or tan to ash grey).

Native Range

West Africa

Distribution

North America: Currently not present, though it commonly is intercepted at U.S. ports.

Caribbean: Martinique

Africa: Dahomey to Congo, including Sao Thome, Ghana, Annobon

Ecology

Achatinids are generally nocturnal forest dwellers but have the potential to adapt to disturbed habitats. Concealed habitats are generally preferred; however, individuals may colonize more open habitats in the event of overcrowding. Achatinids often become more active during periods of high humidity (e.g., after rainfall); however, the occurrence of large numbers of individuals especially during daylight may indicate high population density.

Achatinids normally lay their calcareous eggs in the soil, but they may be deposited under leaf litter or rocks. They feed on both living and dead plant material. In addition to being agricultural pests, achatinids can be a threat to public health as they act as a reservoir host of the rat lung parasites (*Angiostrongylus cantonensis* and *A. costaricensis*), which cause eosinophilic meningoencephalitis in humans. They can also be an unsightly public nuisance during periods of population explosion.

Archachitina marginata has the ability to live up to 10 years, attaining sexual maturity at 9-10 months under laboratory conditions. Clutch size will vary but may be as large as 40 eggs. The eggs are yellowish in color and may have dark blotches. The eggs have an incubation period of approximately 40 days. They are usually laid below the soil surface; however, they may be found on the soil surface or in vegetation. Plants consumed by this species include banana, lettuce and papaya.

Synonyms

- *Buccinum parvum integrum* (Gualtieri, 1742) [Described as synonym by Bequaert and Clench, 1936. Since shown to be Achatina achatina (Linné)]
- *Achatina marginata* (Swainson, 1821)
- *Helix (Cochlitoma) amphora* (Férussac, 1821)
- *Cochlitoma marginata* (G. B. Sowerby, 1825)
- *Helix (Cochlitoma) marginata* (Rang, 1831)
- *Achatina (Achatina) marginata* (Beck, 1837)
- *Achatina amphora* (Catlow and Reeve, 1845)
- *Oncaea marginata* (Gistel, 1848)
- *Achatina (Archachatina) marginata* (Albers, 1850)

- *Achatina (Achatinus) marginata* (Pfeiffer, 1856)
- *Achatina paivana* (Vignon, 1888)
- *Archachatina marginata* (Pilsbry, 1904)
- *Archachatina marginata* var. *amphora* (Pilsbry, 1904)
- *Achatina schweinfurthi* var. *foureaui* (Germain, 1905)
- *Achatina (Archachatina) marginata* var. *foureaui* (Germain, 1908)
- *Achatina intuslalescens* "Paiva" (Nobre, 1909)
- *Archachatina (Megachatina) marginata* var. *foureaui* ("Germain" Dautzenberg, 1921)
- *Archachatina (Megachatinops) gaboonensis* var. *aequatorialis* (Bequaert and Clench, 1936)
- *Archachatina (Megachatina) marginata* (Bequaert and Clench, 1936)
- *Archachatina aequatorialis* (Dartevelle, 1939)
- *Archachatina (Calachatina) marginata* (C. R. Boettger, 1940)

References

Abbott 1989; Barker 2002; Cowie et al. 2009

Arianta arbustorum

Family

Helicidae

Species

Arianta arbustorum (Linnaeus, 1758)

Common Name

Copse snail

Description

The color pattern of this species is highly variable; however, most individuals are light brown with straw-colored spots and a large dark brown stripe. The heliciform shell will also vary in size (10-22 mm high and 14-28 mm wide with 5-6 whorls). The umbilicus is completely covered by the columellar edge of the aperture. The lip of the shell is bone white. Sinistral (mouth on left) and dextral (mouth on right) specimens exist. The body of the animal typically is black.

Native Range

Western and Central Europe

Distribution

North America:

- Canada: Newfoundland

Europe: Western and Central

Ecology

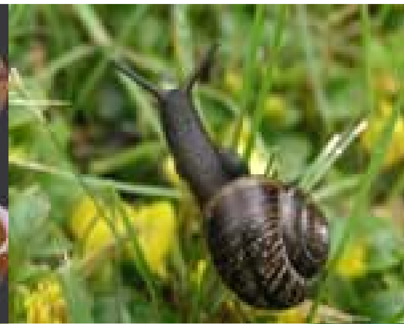
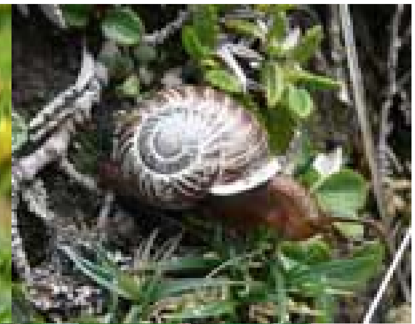
This snail survives in damp meadows, marshy habitats as well as mountains and sandhills. Its longevity is approximately 14 years, attaining maturity at 2-4 years.

Synonyms

- *Helix arbustorum*
- *Helicigonia arbustorum*

References

Anderson 2005; Boycott 1934; Kerney et al. 1979

Ariolimax columbianus

Family

Arionidae

Species

Ariolimax columbianus (Gould, 1851)

Common Name

Pacific banana slug

Description

This robust slug can attain a length of 185 to 260 mm and may weigh up to 72 g at maturity. This species is normally yellow in color; however, several color morphs exists, that range from white to tan-green, red-brown, brown-green, olive green, slate green and ochre yellow. The mantle and body of the slug is usually of uniform color; however, the mantle in any of the color morphs may possess dark-brown to black spots, while the body remains a uniform color. In some specimens, this pattern is reversed and the body possess spots that are not present on the mantle. In some specimens, the black blotches occur simultaneously on the mantle and body and may even coalesce to give the slug a solid black. The juveniles of this species are finely speckled. This slug has a caudal mucus pore with the pneumostome (breathing pore) located behind the midpoint of the often finely granulated mantle. The keel appears undulating in strongly contracted individuals and does not reach the mantle. The sole of the foot is usually much wider than the body.

Slugs in this genus are similar in appearance; however, they can be separated based on the following genitalic characters:

A. columbianus: The penis permanently evaginated, and the apical portion is rounded/blunt. The retractor muscle is narrow and strap-shaped, and originates on the apex of the penis.

A. californicus (Cooper, 1872): The penis forms a hollow tube and can be completely invaginated. The apical portion of the penis is slender and is 1 to 1 2/3 times the length of the basal portion. The retractor muscle is broadly flabellate, and originates close to the apex of the penis.

A. dolichophallus (Mead, 1943): The penis forms a hollow tube and can be completely invaginated. The apical portion of the penis bears a flagellum that is 2 to 4 times the length of the basal portion. The retractor muscle is narrow and strap-shaped, and the point of origin is not at the apex of the penis. This species may also be aphallic (does not have a penis).

Native Range

North America

Distribution

North America:

- U.S.: Alaska, California, Idaho, Oregon, Washington
- Canada: British Columbia

Ecology

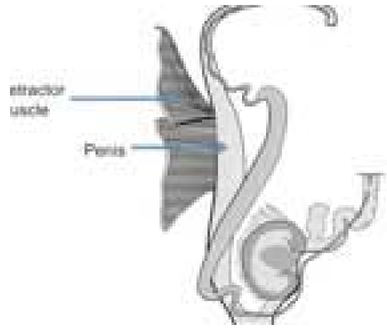
The Pacific banana slug can be found inhabiting humid coastal forests. They often are intercepted when they attempt to cross trails. This is not a pest species; however, it is commonly intercepted and may be mistakenly classified as a pest due to its large size. They are infamous for gnawing off their mating partner's penis after copulation. Oval eggs (about 5 x 8 mm) are typical of this species. The eggs are laid in clutches in the soil from autumn to early spring, maturing after three to eight weeks. The slug's diet includes fungi, feces and carrion of other slugs, and detritus and necrotic vegetation. It has been noted that *A. columbianus* displays homing behavior.

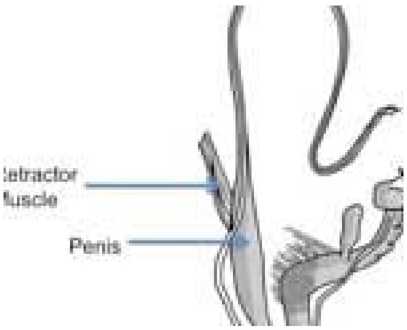
Synonyms

- *Limax columbianus* Gould 1851, in Binney,Terr. Moll. U.S., 2:43, pl. 66, fig. 1; 1852, U.S. Expl. Exped. Moll., p.3, pl. 1, fig. 1.
- *Ariolimax columbianus* Gould, Morch, 1859, Malak, Blatter, 6:110; W. G. Binney, 1865, Amer. Jour. Conch., 1:48, pl. 6, figs. 11-13.
- *Ariolimax columbianus* var. *maculatus* "Cockerell", Binney, 1890, Third Suppl., Bull. M.C.Z., 19: 211, pl. 6, figs. A, G.
- *A. columbianus* forma typicus and forma *maculatus*, Cockerell, 1891, Nautilus, 5:31; forma niger, 5:32 (All form British Columbia).
- *A.* subsp. *Californicus* forma *maculatus* Cockerell, 1891, Nautilus, 5:31, foot-note; 1897, Nautilus, 11:76. (No locality given).
- *Aphallarion buttoni* Pilsbry & Vanatta, 1896, Proc. Acad. Nat. Sci. Phila., p. 348, pl. 12, figs. 3, 4, 5; pl. 13, fig. 4; pl. 14, fig. 11, 12.

References

Burch 1962, Forsyth 2004; Mead 1943; Pilsbry 1948





Arion ater group: Arion ater

Family

Arionidae

Species

Arion ater Linnaeus, 1758

Common Name

Black arion, Black slug, Red slug

Description

This slug belongs to a species complex that can only be differentiated by dissecting the genitalia. There are three species in this complex (*Arion ater* group): *Arion ater*, *A. rufus* and *A. vulgaris*. These slug species range from 75-180 mm in length at maturity. They may be dark brown, black, orange or reddish in color. They are large and bulky with long, coarse tubercles on the side and back. The juveniles of these species have an even wider range of colors and can be distinguished from mature adults by the presence of lateral stripes. Juveniles of the *Arion ater*-complex may be confused with adults of other *Arion* species. The contracted body of this species is bell-shaped. The sole of the foot may be black or tripartite (pale with a black vertical line down the center). The foot fringe may possess any of the following colors with vertical black bands: red, orange, yellow or grey. The mucus of this slug group is colorless and they lack a keel. Molecular techniques can also be used to identify members of this group.

* It should be noted that hybrids between *Arion ater* and *Arion vulgaris* have been reported by Hagnell et al. 2003.

Genitalic characters used to distinguish the three species:

Arion ater: genitalia with a slender symmetrical atrium.

Arion rufus: genitalia with large, thick asymmetrical atrium.

Arion vulgaris: genitalia with a short, abbreviated atrium.

Native Range

Western and Central Europe

Distribution

North America:

- U. S.: Maine, Michigan, New York, Oregon, Wisconsin
- Canada: Newfoundland, Quebec, Ontario

Europe

Ecology

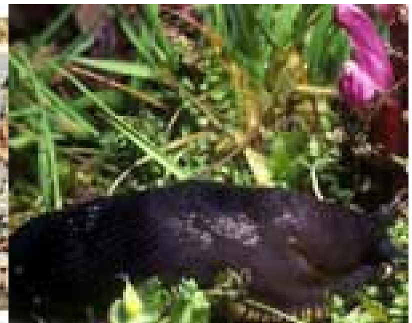
These plant pests are often found in disturbed sites. This includes gardens, greenhouses and campgrounds. This omnivore's diet includes living and dead plant material, fungi, feces and carrion. It is most damaging to ornamental, vegetable (e.g., strawberry, sunflower, potato, cabbage, parsley, bean) and fodder crops (e.g., clover) from seedlings to fully mature plants. The mating season lasts from summer through early autumn. If disturbed, an individual from the *Arion ater*-complex will contract its body, often twisting it and rocking side to side. It has been noted that both *Arion ater* and *A. rufus* will interbreed. This interbreeding behavior has not been recorded for *Arion vulgaris*. *A. vulgaris* has the potential to live up to one year and can lay up to 400 eggs in a single summer. These eggs often hatch within just 3.5-5 weeks.

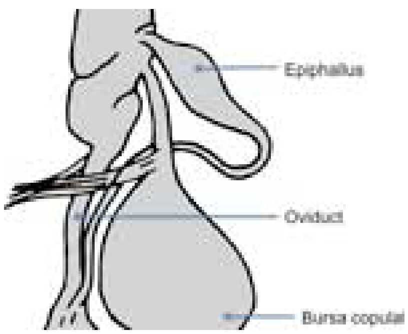
Synonyms

- *Limax ater* Linnaeus, 1758
- *Arion empiricorum* Férussac, 1819 pars.

References

Anderson 2005; Cowie et al. 2009; Forsyth 2004; Grimm et al. 2009; Hagnell et al. 2003; Horsák 2004; Kantor et al. 2009; Kerney et al. 1979; Koztowski 2005; Weidema 2006





Arion ater group: Arion rufus

Family

Arionidae

Species

Arion rufus Linnaeus, 1758

Common Name

Chocolate arion, European red slug

Description

This slug belongs to a species complex that can only be differentiated by dissecting the genitalia. There are three species in this complex (*Arion ater* group): *Arion ater*, *A. rufus* and *A. vulgaris*. These slugs species range from 75-180 mm in length at maturity. They may be dark brown, black, orange or reddish in color. They are large and bulky with long, course tubercles on the side and back. The juveniles of these species have an even wider range of colors and can be distinguished from mature adults by the presence of lateral stripes. Juveniles of the *Arion ater*-complex may be confused with adults of other *Arion* species. The contracted body of this species is bell-shaped. The sole of the foot may be black or tripartite (pale with a black vertical line down the center). The foot fringe may possess any of the following colors with vertical black bands: red, orange, yellow or grey. The mucus of this slug group is colorless and they lack a keel. Molecular techniques can also be used to identify members of this group.

Genitalic characters used to distinguish the three species:

Arion ater: genitalia with a slender symmetrical atrium.

Arion rufus: genitalia with large, thick asymmetrical atrium.

Arion vulgaris: genitalia with a short, abbreviated atrium.

Native Range

Western and Southern Europe

Distribution

North America:

- U. S.: California, Maine, Michigan, New York, Oregon, Wisconsin
- Canada: Newfoundland, Quebec, Ontario

Europe

Ecology

These plant pests are often found in disturbed sites. This includes gardens, greenhouses and campgrounds. This omnivore's diet includes living and dead plant material, fungi, feces and carrion. It is most damaging to ornamental, vegetable (e.g., strawberry, sunflower, potato, cabbage, parsley, bean) and fodder crops (e.g., clover) from seedlings to fully mature plants. The mating season lasts from summer through early autumn. If disturbed, an individual from the *Arion ater*-complex will contract its body, often twisting it and rocking side to side. It has been noted that both *Arion ater* and *A. rufus* will interbreed. This interbreeding behavior has not been recorded for *Arion vulgaris*. *A. vulgaris* has the potential to live up to one year and can lay up to 400 eggs in a single summer. These eggs often hatch within just 3.5-5 weeks.

Synonyms

- *Limax rufus* Linnaeus, 1758
- *Arion ater* of authors, not Linnaeus, 1758.
- *Arion empiricorum* Férussac, 1819 pars.

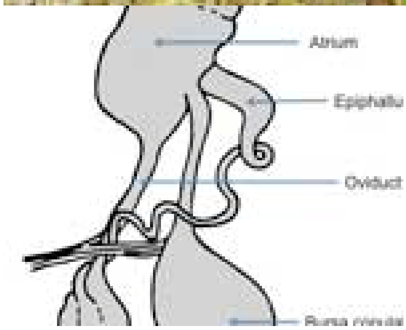
References

Anderson 2005; Cowie et al. 2009; Forsyth 2004; Grimm et al. 2009; Horsák 2004; Kantor et al. 2009; Koztowski 2005; Roth and Sadeghian 2006; Weidema 2006









Arion ater group: Arion vulgaris

Family

Arionidae

Species

Arion vulgaris Moquin-Tandon, 1855

Common Name

Spanish arion, Iberian slug, Lusitanian slug

Description

This slug belongs to a species complex that can only be differentiated by dissecting the genitalia. There are three species in this complex (*Arion ater* group): *Arion ater, A. rufus* and *A. vulgaris*. These slugs species range from 75-180 mm in length at maturity. They may be dark brown, black, orange or reddish in color. They are large and bulky with long, course tubercles on the side and back. The juveniles of these species have an even wider range of colors and can be distinguished from mature adults by the presence of lateral stripes. Juveniles of the *Arion ater*-complex may be confused with adults of other *Arion* species. The contracted body of this species is bell-shaped. The sole of the foot may be black or tripartite (pale with a black vertical line down the center). The foot fringe may possess any of the following colors with vertical black bands: red, orange, yellow or grey. The mucus of this slug group is colorless and they lack a keel. Molecular techniques can also be used to identify members of this group.

* It should be noted that hybrids between *Arion ater* and *Arion vulgaris* have been reported by Hagnell et al. 2003.

Genitalic characters used to distinguish the three species:

Arion ater: genitalia with a slender symmetrical atrium.

Arion rufus: genitalia with large, thick asymmetrical atrium.

Arion vulgaris: genitalia with a short, abbreviated atrium.

Native Range

Western and Southwestern Europe

Distribution

North America:

- U. S.: Maine, Michigan, New York, Oregon, Wisconsin
- Canada: Newfoundland, Quebec, Ontario

E**urope**

Ecology

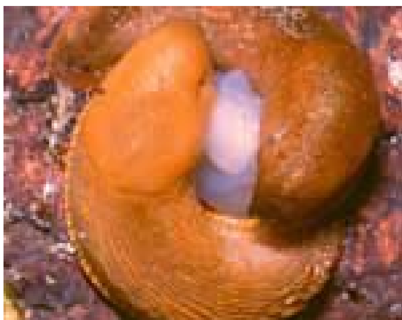
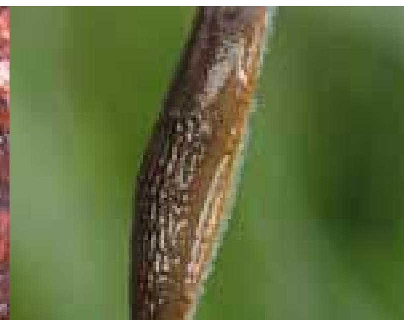
These plant pests are often found in disturbed sites. This includes gardens, greenhouses and campgrounds. This omnivore's diet includes living and dead plant material, fungi, feces and carrion. It is most damaging to ornamental, vegetable (e.g., strawberry, sunflower, potato, cabbage, parsley, bean) and fodder crops (e.g., clover) from seedlings to fully mature plants. The mating season lasts from summer through early autumn. If disturbed, an individual from the *Arion ater*-complex will contract its body, often twisting it and rocking side to side. It has been noted that both *Arion ater* and *A. rufus* will interbreed. This interbreeding behavior has not been recorded for *Arion vulgaris*. *A. vulgaris* has the potential to live up to one year and can lay up to 400 eggs in a single summer. These eggs often hatch within just 3.5-5 weeks.

Synonyms

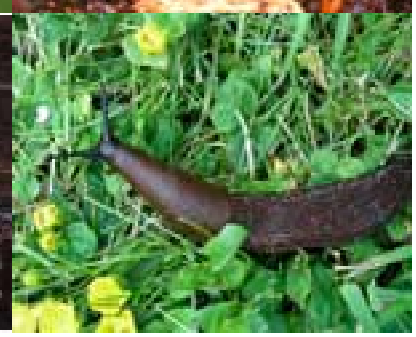
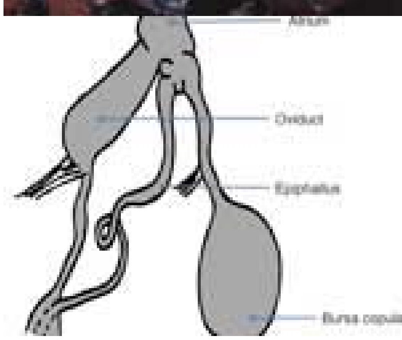
- *Arion rufus* var. *vulgaris* Moquin-Tandon, 1855
- *Arion lusitanicus* auctt., non Mabille, 1868

References

Anderson 2005; Cowie et al. 2009; Forsyth 2004; Grimm et al. 2009; Hagnell et al. 2003; Horsák 2004; Kantor et al. 2009; Kerney et al. 1979; Koztowski 2005; Weidema 2006



Arion fasciatus group: Arion circumscriptus

Family

Arionidae

Species

Arion circumscriptus Johnston, 1828

Common Name

Brown-banded arion, White-soled slug

Description

This slug belongs to a species complex that range in length from 30 to 40 mm as fully mature adults. This species-complex (*Arion fasciatus* group) contains the following species: *Arion silvaticus*, *A. circumscriptus* and *A. fasciatus*. Species in this group can be separated based on their genitalia. The body of the slugs is grayish centrally and white laterally with a pair of dark-colored stripes that run longitudinally. The stripes are often broken at the posterior edge of the mantle. The body often appears to have a granular texture. There may also be a slight reddish color to the dorsal surface of the animal. The slightly granular mantle is rusty-gray in color and lacks markings (except in *Arion circumscriptus*). The tentacles and head are black in color. The pneumostome (breathing pore) occurs in the anterior one-third of the slug's mantle on the right side of the body. In contracted individuals the body is bell-shaped. No keel is present in this group; however, an enlarged row of pale colored tubercles may create an impression that one may exist (false keel). As the common name (White-soled slug) suggests, the sole of this species-complex is pale colored, similar to the foot fringe. The mucus secreted by this group is colorless or yellow. Molecular techniques can also be used to identify members of this group.

Genitalic characters used to distinguish the three species:

Arion fasciatus: genitalia with a short atrium, a narrow oviduct and an unpigmented thick epiphallus.

Arion circumscriptus: genitalia with a long narrow atrium, a relatively narrow oviduct and a pigmented epiphallus.

Arion silvaticus: genitalia with a long atrium, a broad oviduct and an unpigmented narrow epiphallus.

Native Range

Europe

Distribution

North America:

- U.S.: Northern United States

- Canada: Ontario, Quebec, Newfoundland, British Columbia

Ecology

The slugs in the *Arion fasciatus* group are typically found in disturbed habitats; however, they commonly invade natural areas. The brown-banded arion (*Arion circumscriptus*) is primarily nocturnal. All three species have been reported in greenhouses and may become a serious agricultural pest. Reproduction is primarily through self-fertilization.

Synonyms

- *Arion bourguignati* Mabille, 1868

References

Anderson 2005; Branson 1959; Hutchinson and Heike 2007; Grimm et al. 2009; Kantor et al. 2009; Kerney et al. 1979

Arion fasciatus group: Arion fasciatus

Family

Arionidae

Species

Arion fasciatus (Nilsson, 1919)

Common Name

White-soled slug, Orange-banded arion

Description

This slug belongs to a species complex that range in length from 30 to 40 mm as fully mature adults. This species-complex (*Arion fasciatus* group) contains the following species: *Arion silvaticus*, *A. circumscriptus* and *A. fasciatus*. Species in this group can be separated based on their genitalia. The body of the slugs is grayish centrally and white laterally with a pair of dark-colored stripes that run longitudinally. The stripes are often broken at the posterior edge of the mantle. The body often appears to have a granular texture. There may also be a slight reddish color to the dorsal surface of the animal. The slightly granular mantle is rusty-gray in color and lacks markings except in *Arion circumscriptus*). A useful field identification character for this species is the presence of a yellow flush below the dark lateral bands. The tentacles and head are black in color. The pneumostome (breathing pore) occurs in the anterior one-third of the slug's mantle on the right side of the body. In contracted individuals the body is bell-shaped. No keel is present in this group; however, an enlarged row of pale colored tubercles may create an impression that one may exist (false keel). As the common name (White-soled slug) suggests, the sole of this species-complex is pale colored, similar to the foot fringe. The mucus secreted by this group is colorless or yellow. Molecular techniques can also be used to identify members of this group.

Genitalic characters used to distinguish the three species:

Arion fasciatus: genitalia with a short atrium, a narrow oviduct and an unpigmented thick epiphallus.

Arion circumscriptus: genitalia with a long narrow atrium, a relatively narrow oviduct and a pigmented epiphallus.

Arion silvaticus: genitalia with a long atrium, a broad oviduct and an unpigmented narrow epiphallus.

Native Range

Northwestern Europe

Distribution

North America:

- U.S.: Kentucky, Northern United States
- Canada: Ontario, Quebec, Newfoundland

Ecology

The slugs in the *Arion fasciatus* group are typically found in disturbed habitats; however, they commonly invade natural areas. The brown-banded arion (*Arion circumscriptus*) is primarily nocturnal. All three species have been reported in greenhouses and may become a serious agricultural pest. Reproduction is primarily through self-fertilization.

Synonyms

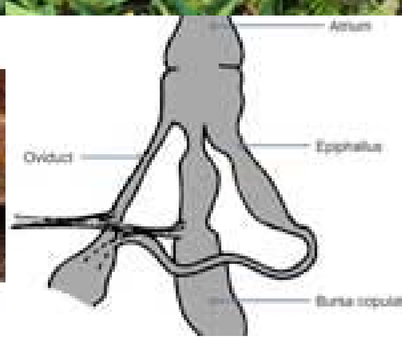
- *Limax fasciatus* Nilsson, 1823 (non 1822)
- *Arion nilssoni Pollonera, 1887*

References

Anderson 2005; Branson 1959; Hutchinson and Heike 2007; Grimm et al. 2009; Kantor et al. 2009; Kerney et al. 1979; Thomas et al. 2010







Arion fasciatus group: Arion silvaticus

Family

Arionidae

Species

Arion silvaticus Lohmander, 1937

Common Name

Forest arion

Description

This slug belongs to a species complex that range in length from 30 to 40 mm as fully mature adults. This species-complex (*Arion fasciatus* group) contains the following species: *Arion silvaticus*, *A. circumscriptus* and *A. fasciatus*. Species in this group can be separated based on their genitalia. The body of the slugs is grayish centrally and white laterally with a pair of dark-colored stripes that run longitudinally. The stripes are often broken at the posterior edge of the mantle. The body often appears to have a granular texture. There may also be a slight reddish color to the dorsal surface of the animal. The slightly granular mantle is rusty-gray in color and lacks markings (except in *Arion circumscriptus*). The tentacles and head are black in color. The pneumostome (breathing pore) occurs in the anterior one-third of the slug's mantle on the right side of the body. In contracted individuals the body is bell-shaped. No keel is present in this group; however, an enlarged row of pale colored tubercles may create an impression that one may exist (false keel). The sole of this species-complex is pale colored, similar to the foot fringe. The mucus secreted by this group is colorless or yellow. Molecular techniques can also be used to identify members of this group.

Genitalic characters used to distinguish the three species:

Arion fasciatus: genitalia with a short atrium, a narrow oviduct and an unpigmented thick epiphallus.

Arion circumscriptus: genitalia with a long narrow atrium, a relatively narrow oviduct and a pigmented epiphallus.

Arion silvaticus: genitalia with a long atrium, a broad oviduct and an unpigmented narrow epiphallus.

Native Range

Europe

Distribution

North America:

- U.S.: California, Northern United States

- Canada: Ontario, Quebec, Newfoundland, British Columbia

Ecology

The slugs in the *Arion fasciatus* group are typically found in disturbed habitats; however, they commonly invade natural areas. The brown-banded arion (*Arion circumscriptus*) is primarily nocturnal. All three species have been reported in greenhouses and may become a serious agricultural pest. Reproduction is primarily through self-fertilization.

Synonyms

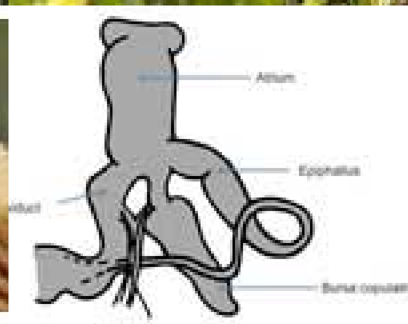
- *Arion fasciatus* of authors, in part, not Nilsson, 1823
- *Arion circumscriptus* var. *silvaticus* Lohmander, 1937

References

Anderson 2005; Branson 1959; Hutchinson and Heike 2007; Grimm et al. 2009; Kantor et al. 2009; Kerney et al. 1979; McDonnell et al. 2009







Arion hortensis group: Arion distinctus

Family

Arionidae

Species

Arion distinctus Mabille, 1868

Common Name

Dark-face arion

Description

This slug belongs to a species-complex called the *Arion hortensis* group, which is comprised of *Arion hortensis*, *A. owenii* and *A. distinctus*. The *Arion hortensis* group is typically 25-35 mm long, and is only distinguished by the morphology of the genitalia. These slugs have two color morphs (dark grey or bluish grey) that are more common than the brownish morph. They possess dark lateral stripes, where the stripe on the right side of the animal encompasses the pneumostome (breathing pore). Like the body, the tentacles are bluish grey with a contrasting pale yellow or orange sole. The animals have no keel. Contracted specimens are rounded in cross-section. This group has a characteristic yellow-orange mucus. Molecular techniques can also be used to identify members of this group.

Genitalic characters used to distinguish the three species:

Arion distinctus: epiphallic structure conical in cross-section, and covers the entire opening of the epiphallus.

Arion hortensis: epiphallic structure raised with "finger-like" projections, and only partially covers the opening of the epiphallus.

Arion owenii: epiphallic structure flattened and irregularly shaped, and does not cover the opening of the epiphallus.

Native Range

Western Europe

Distribution

North America:

- U.S.: California, Pennsylvania
- Canada: Vancouver, Southern Vancouver Island, Halifax, near Ottawa and Kingston

Australasia: New Zealand

Europe

Ecology

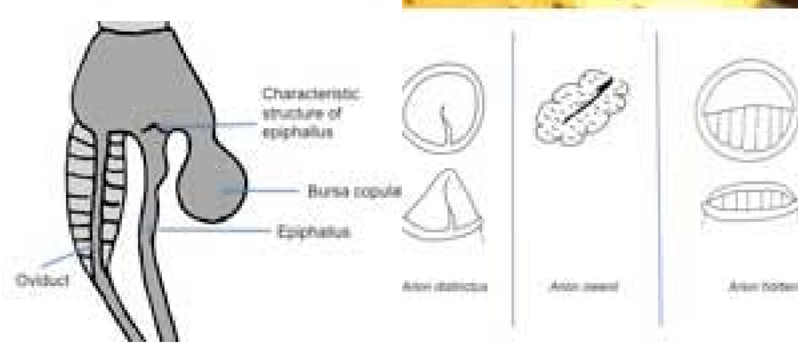
This slug consumes agriculturally important crops and often inhabit disturbed sites (e.g., gardens, roadsides). *Arion hortensis* and *A. distinctus* reproduce by cross fertilization. The means by which *A. owenii* reproduces has not been documented. In England, *A. hortensis* mates in the fall and winter while *A. distinctus* mates during spring and summer months. They can live up to one year.

Synonyms

- *Arion hortensis* of authors in part, not Férussac, 1819
- *A. hortensis* form 'A' of authors.

References

Davies 1977; Davies 1979; Grimm et al. 2009; Horsák 2004; Hunter 1966; Iglesias and Speiser 2001; Kantor et al. 2009; Roth and Sadeghian 2006



Arion hortensis group: Arion hortensis

Family

Arionidae

Species

Arion hortensis Férussac, 1819

Common Name

Garden slug, Yellow-soled slug, Garden arion, Black field slug, Southern garden slug

Description

This slug belongs to a species-complex called the *Arion hortensis* group, which is comprised of *Arion hortensis*, *A. owenii* and *A. distinctus*. The *Arion hortensis* group is typically 25-35 mm long, and is only distinguished by the morphology of the genitalia. These slugs have two color morphs (dark grey or bluish grey) that are more common than the brownish morph. They possess dark lateral stripes, where the stripe on the right side of the animal encompasses the pneumostome (breathing pore). Like the body, the tentacles are bluish grey with a contrasting pale yellow or orange sole. The animals have no keel. Contracted specimens are rounded in cross-section. This group has a characteristic yellow-orange mucus. Molecular techniques can also be used to identify members of this group.

Genitalic characters used to distinguish the three species:

Arion distinctus: epiphallic structure conical in cross-section, and covers the entire opening of the epiphallus.

Arion hortensis: epiphallic structure raised with "finger-like" projections, and only partially covers the opening of the epiphallus.

Arion owenii: epiphallic structure flattened and irregularly shaped, and does not cover the opening of the epiphallus.

Native Range

Western and Southern Europe

Distribution

North America:

- U.S.: California, Delaware, Kentucky, Maryland, Michigan, Minnesota, New Jersey, New York, Ohio, Pennsylvania, Washington, Wisconsin
- Canada: Newfoundland, Quebec, British Columbia, New England

Australasia: New Zealand

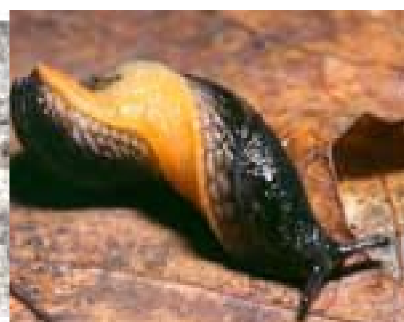
Europe

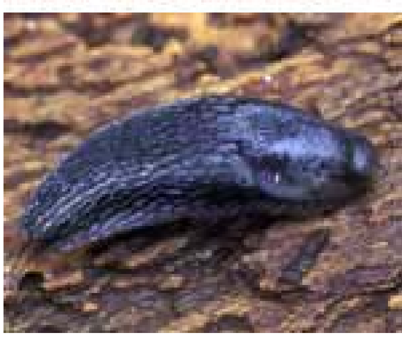
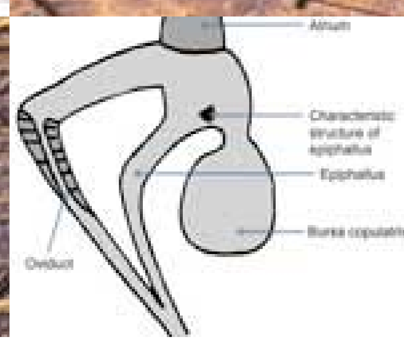
Ecology

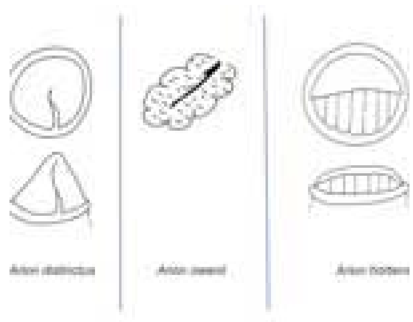
This slug consumes agriculturally important crops and often inhabit disturbed sites (e.g., gardens, roadsides). *Arion hortensis* and *A. distinctus* reproduce by cross fertilization. The means by which *A. owenii* reproduces has not been documented. In England, *A. hortensis* mates in the fall and winter while *A. distinctus* mates during spring and summer months. They can live up to one year.

References

Anderson 2005; Davies 1977; Davies 1979; Grimm et al. 2009; Horsák 2004; Hunter 1966; Iglesias and Speiser 2001; Kantor et al. 2009; Kerney et al. 1979; McDonnell et al. 2009; Roth and Sadeghian 2006; Thomas et al. 2010



Arion hortensis group: Arion owenii

Family

Arionidae

Species

Arion owenii (Davies, 1979)

Common Name

Warty arion, Inishowen slug

Description

This slug belongs to a species-complex called the *Arion hortensis* group which is comprised of *Arion hortensis*, *A. owenii* and *A. distinctus*. The *Arion hortensis* group is typically 25-35 mm long, and is only distinguished by the morphology of the genitalia. These slugs have two color morphs (dark grey or bluish grey) that are more common than the brownish morph. They possess dark lateral stripes, where the stripe on the right side of the animal encompasses the pneumostome (breathing pore). Like the body, the tentacles are bluish grey with a contrasting pale yellow or orange sole. The animals have no keel. Contracted specimens are rounded in cross-section. This group has a characteristic yellow-orange mucus. Molecular techniques can also be used to identify members of this group.

Genitalic characters used to distinguish the three species:

Arion distinctus: epiphallic structure conical in cross-section, and covers the entire opening of the epiphallus.

Arion hortensis: epiphallic structure raised with "finger-like" projections, and only partially covers the opening of the epiphallus.

Arion owenii: epiphallic structure flattened and irregularly shaped, and does not cover the opening of the epiphallus.

Native Range

Europe

Distribution

North America:

- U.S.: Not reported

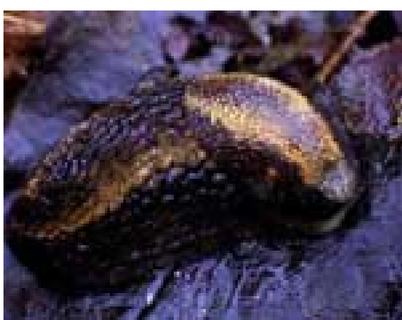
Europe: Ireland

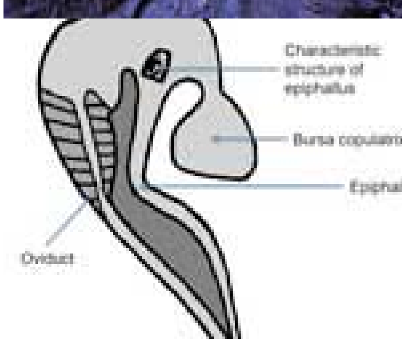
Ecology

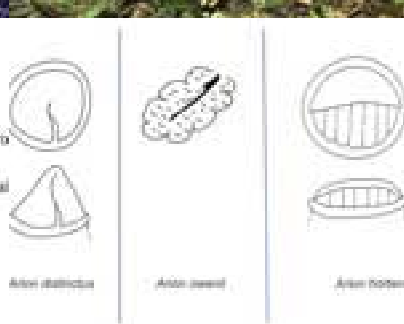
This slug consumes agriculturally important crops and often inhabit disturbed sites (e.g., gardens, roadsides). *Arion hortensis* and *A. distinctus* reproduce by cross fertilization. The means by which *A. owenii* reproduces has not been documented. In England, *A. hortensis* mates in the fall and winter while *A. distinctus* mates during spring and summer months. They can live up to one year.

References

Anderson 2005; Davies 1977; Davies 1979; Grimm et al. 2009; Horsák 2004; Hunter 1966; Iglesias and Speiser 2001; Kantor et al. 2009





Arion intermedius

Family

Arionidae

Species

Arion intermedius (Normand, 1852)

Common Name

Hedgehog Arion, Hedgehog slug

Description

Arion intermedius is one of the smaller *Arion* species. This slug ranges in length from 15-20 mm long with a yellow to grey body and dark grey tentacles and head. The contracted body of this specimen is not bell-shaped in cross-section. Upon close observation the tubercles are noted to form sharp, transparent points, giving the animal a prickly appearance. The tail of the slug has a pale, narrow foot fringe and also lacks a keel. The sole of the foot is quite distinguishable from other slug species in North America by being yellow-grey to pale orange in color. The mucus produced by this species is pale yellow to bright yellow in color. Though this species is quite distinguishable, it can be mistaken for juveniles of other species (e.g., *Arion rufus*).

Native Range

Western Europe

Distribution

North America:

- U.S.
- Canada

Pacific Islands: Hawaii

Australasia: New Zealand

Asia: Sri Lanka

Europe: Western and Central Europe

Ecology

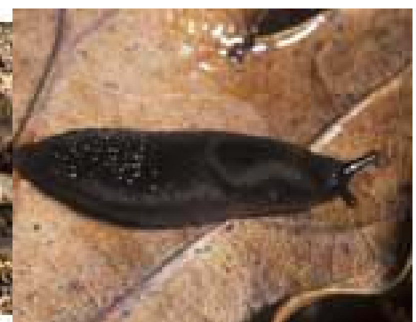
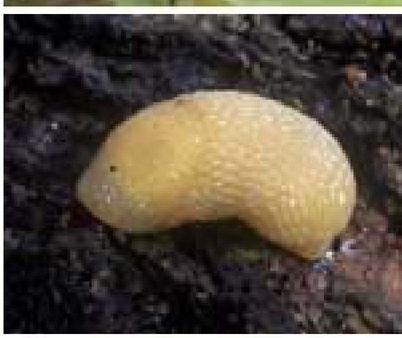
The diet of *Arion intermedius* includes living plant tissue and fungi. In areas where it has been introduced, this species can be very destructive. It has been recorded to consume ornamental plants and field crops (e.g. wheat, corn). Self-fertilization is the primary means of reproduction although out-crossing has been noted to occur. Habitats for this species include fields, grassy roadsides, mature gardens and woods. It is capable of living up to a year.

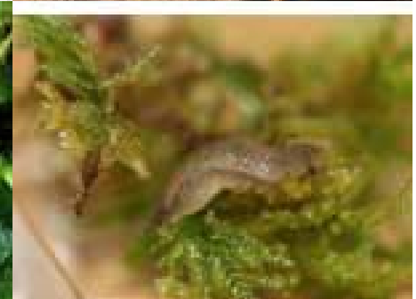
Synonyms

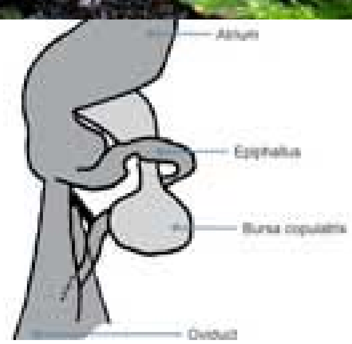
References

Forsyth 2004; Grimm et al. 2009; Kantor et al. 2009; Kerney et al. 1979; Meyer and Cowie 2010; Naggs et al. 2003







Arion subfuscus group: Arion fuscus

Family

Arionidae

Species

Arion fuscus (Müller, 1774)

Common Name

None reported

Description

The *Arion subfuscus* group typical contains slugs that are fairly large, often attaining a maximum length of 70 mm as fully mature adults. *A. subfuscus* and *A. fuscus* were treated as the same species (A. subfuscus) until recently. They can be separated by molecular techniques as well as by internal morphological characters explained below. They range in color from grey-brown to orange brown and usually have dark brown bands running down the sides, laterally. The pneumostome is encircled by the stripe on the right side of the animal. Unlike others in this genus, individuals in the *A. subfuscus* group are rounded when contracted. The tubercles are minute and elongated, and the keel is absent. The foot fringe has vertical bands running its length. The sole of this group is dirty-white, and the mucus produced may either be yellow, orange and on rare occassions clear. Molecular techniques can also be used to identify members of this group.

The distinguishing morphological features of each species are:

Arion subfuscus (Draparnaud, 1805) - Genitalia large, light lavender in color and located on the margin of the digestive gland

Arion fuscus (Muller, 1774) - Genitalia small, dark in color and completely embedded in the digestive gland.

Native Range

Europe

Distribution

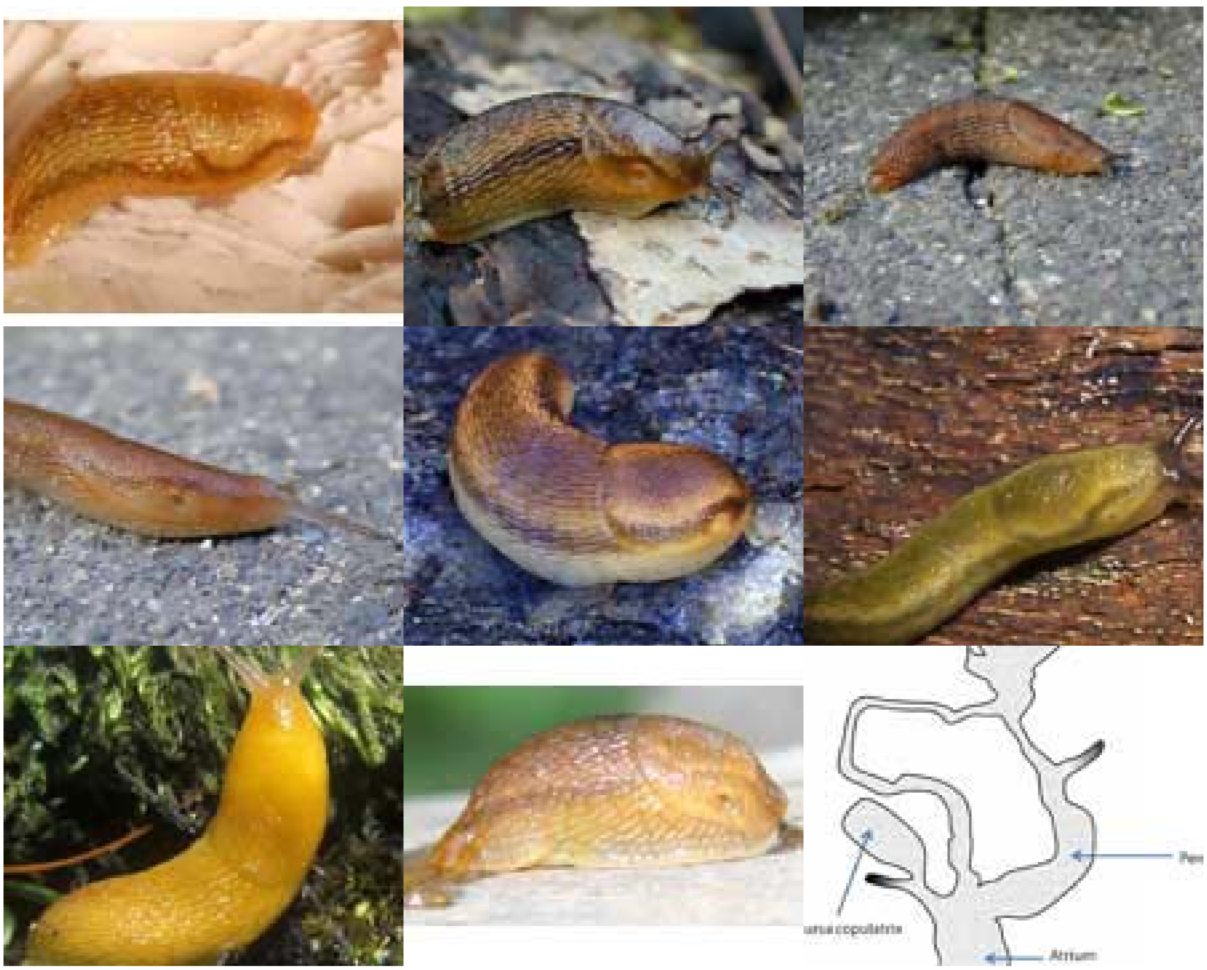
Europe

Ecology

This pestifierous species can be found in a variety of habitats (e.g. forests, fields, gardens).

References

Anderson 2005; Beyer and Saari 1978; Grimm et al. 2009; Kantor et al. 2009; McDonnell et al. 2011; Pinceel et al. 2005



Arion subfuscus group: Arion subfuscus

Family

Arionidae

Species

Arion subfuscus (Draparnaud, 1805)

Common Name

Dusky arion

Description

The *Arion subfuscus* group typically contains slugs that are fairly large, often attaining a maximum length of 70 mm as fully mature adults. *A. subfuscus* and *A. fuscus* were treated as the same species (A. subfuscus) until recently. They can be separated by molecular techniques as well as by internal morphological characters explained below. They range in color from grey-brown to orange brown and usually have dark brown bands running down the sides, laterally. The pneumostome is encircled by the stripe on the right side of the animal. Unlike others in this genus, individuals in the *A. subfuscus* group are rounded when contracted. The tubercles are minute and elongated and the keel is absent. The foot fringe has vertical bands running its length. The sole of this group is dirty-white, and the mucus produced may either be yellow, orange and on rare occassions clear. Molecular techniques can also be used to identify members of this group.

The distinguishing morphological features of each species are:

Arion subfuscus (Draparnaud, 1805) - Genitalia large, light lavender in color and located on the margin of the digestive gland

Arion fuscus (Muller, 1774) - Genitalia small, dark in color and completely embedded in the digestive gland.

Native Range

Northern and Western Europe

Distribution

North America:

- U.S.: California, Connecticut, Delaware, Kentucky, Maine, Maryland, Massachusetts, New Hampshire, New York, North Carolina, Pennsylvania, Rhode Island, Vermont, Virginia, Washington D.C., Wisconsin
- Canada

Europe

Ecology

This pestifierous species can be found in a variety of habitats (e.g. forests, fields, gardens). It has been suggested that *Arion subfuscus* may be a very competitive species as it has been documented that in some areas where the slug has been introduced, it occurs in numbers larger than that of native species.

Synonyms

- *Limax subfuscus* Draparnaud, 1805
- *Arion krynickii* Kaleniczenko, 1851
- *Arion brunneus* Lehmann, 1862
- *Arion esthonicus* Poska-Teiss, 1927

References

Anderson 2005; Beyer and Saari 1978; Grimm et al. 2009; Kantor et al. 2009; McDonnell, R.J. et al. 2011; Pinceel et al. 2005; Roth and Sadeghian 2006

Boettgerilla pallens

Family

Boettgerillidae

Species

Boettgerilla pallens Simroth, 1912

Common Name

Wormslug

Description

The wormslug is very narrow in appearance. It has the ability to measure up to 60 mm when fully extended, although individuals measuring between 30-40 mm are more common. The slug's color varies form a pale yellow to grey to blue-grey. In most individuals the back, mantle, head and tentacles are slightly darker than the rest of the body. The sole of the foot is a pale yellow-grey and produces a clear mucus. The keel of this slug extends from the tip of the tail to the posterior edge of the mantle. The juveniles of this species are much paler than the adults and in some cases may be pale grey-white.

Native Range

Southeastern Europe

Distribution

North America:

- Canada: British Columbia

South America: Columbia

Europe

Ecology

The wormslug can be found in greenhouses, gardens, recreational areas, natural areas and nurseries. It is often found in the soil, and is capable of burrowing as deep as 60 cm. It may also occupy burrows made by earthworms. The diet of this slug includes fungi, detritus material, carrion and eggs of other terrestrial molluscs. This slug also consume plant roots, and are thus an important nursery and greenhouse pest.

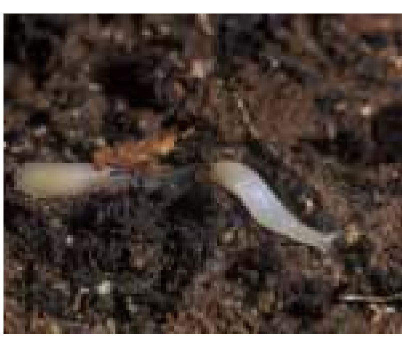
Synonyms

- *Boettgerilla vermiformis* Wiktor, 1959. Simroth 1912: 55, pl. 3, fig. 50, pl. 8, fig. 32

References

Anderson 2005; Grimm et al. 2009; Gunn 1992; Horsak et al. 2004; Kantor et al. 2009; Kerney et al. 1979; Reise et al. 2000



Bradybaenidae

Family

Bradybaenidae

Species

Acusta touranensis (Souleyet, 1842)

Bradybaena similaris (Ferussac, 1821)

Fruticicola fruticum (Muller, 1774)

Common Name

Acusta touranensis: None reported

Bradybaena similaris: Asian tramp snail

Fruticicola fruticum: Bush snail

Description

The Asian tramp snail is approximately 12 mm in length and 12-18 mm wide with 5.5 whorls. In this species, both sinistral (mouth on the left) and dextral (mouth on the right) individuals exist. There are four distinct color morphs: 1. yellow-tan without a band, 2. yellow-tan with a chestnut colored stripe, 3. pale brown without a band, 3. pale brown with a chestnut color band.

The bush snail is also variable in color ranging from pale yellow, to white to light red-brown, sometimes with a dark chestnut colored stripe. This snail is approximately 10-19 mm high and 13-23 mm wide, although specimens measuring up to 25.4 mm have been documented. Adults often possess 6 whorls, but a range of 5-6.5 is not uncommon.

Native Range

Bradybaena similaris: Southeast Asia

Fruticicola fruticum: Central and Eastern Europe, and Asia

Distribution

North America:

- U.S.: southeastern U.S. including Alabama, Florida, Louisiana, Mississippi, Texas

Central and South America

Pacific Islands: Hawaiian Islands

Caribbean: Puerto Rico, Jamaica

Europe (*Fruticicola fruticum*)

Auatralasia: Australia

Asia

Africa

Ecology

This tropical pest species (Asian tramp snail) has been known to consume cucurbits, grapes, *Hibiscus* sp., legumes and various ornamental plants. Self-fertilization is possible in this snail. This species achieve full maturity in 100 days on average and longevity is approximately 144 days. The number of eggs produced per clutch ranges form 1 to 202.

The bush snail typically matures within a year of hatching and can persist for as many as 5 years or longer. This species is frequently found along roadsides and in lush, damp vegetation.

Synonyms

Fruticicola fruticum:

- *Helix fruticum* (Muller, 1774)
- *Bradybaena fruticum* (Muller, 1774)

References

Airo et al. 2003; Barker 200; Carvallo et al. 2008; Chang 1990; Cowie et al. 2008; Cowie et al. 2009; Falniowski et al. 2004; Godan 1983; Kerney et al. 1979; Komai and Emura 1955; Naggs et al. 2003; Rosenberg and Muratov 2006; Solem 1959; Utsuno and Asami 2010

Bulimulus spp.

Family

Orthalicidae

Species

Bulimulus diaphanus fraterculus (Potiez and Michaud, 1835)

Bulimulus guadalupensis (Bruguiere, 1789)

Common Name

Bulimulus diaphanus fraterculus: Clear bulumulus

Bulimulus guadalupensis: The Guadaloupe snail, West Indian bulimilus, Snubnose sculpin

Description

Bulimulus diaphanus fraterculus: This species will measure up to 18 mm high and 8 mm wide.

Bulimulus guadalupensis: The thick, opaque shell of this species does not exceed 24 mm in height. The apex of the shell is off-white to brown in color. There may be one or two faint or three strong brown stripes following the whorls of the shell. There may also be a thin, white, spiral stripes.

Native Range

Lesser and Greater Antilles

Distribution

North America:

- U.S.: Florida

Caribbean: Throughout e.g., Saint Martin; Saint Barts; Saint Kitts; Barbuda; Antigua; Guadeloupe; Les Saintes, Dominica, Puerto Rico, Jamaica

Synonyms

Bulimulus diaphanus fraterculus:

- *Helix (Cochlogena) fraterculus* Ferussac, 1821
- *Bulimus fraterculus* Ferussac, 1835
- *Bulimulus diaphanus*

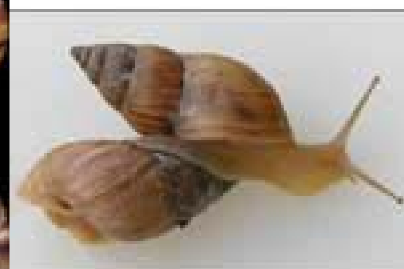
Bulimulus guadalupensis:

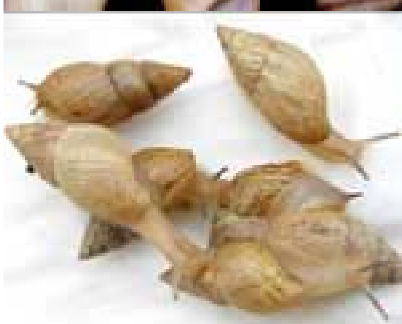
- *Bulimulus exilis*

- *Bulumulus guadalupensis*
- *Helix exilis*
- *Thaumastus exilis*

References

Abbott 1989; Lechmere Guppy 1866; Robinson et al. 2009; Rosenberg and Muratov 2006




Candidula intersecta

Family

Hygromiidae

Species

Candidula intersecta Poiret, 1801

Common Name

Wrinkled dune snail

Description

The wrinkled dune snail's shell can attain a height of 5-8 mm and a width of 7-13 mm, with 5 to 6 1/2 whorls. The shell is off-white to pale yellow in color with brown bands or spots. The color pattern of this species is variable. There is often an irregular white stripe on the body whorl. Albino or brown-colored morphs of this species have been reported in Europe. The body of the animal is pale yellow or blue-gray in color.

Native Range

Western Europe

Distribution

North America:

- U.S.: Oregon

South America: Columbia, Chile

Australasia: New Zealand, Australia

Europe

Ecology

This species is often found in open, dry areas (e.g., pastures and coastal plains). It is reported to be a pest of apples, pears, plums and peaches. The snail will damage the fruit while it is still attached to the tree. Apart from the direct, reduced market value of the fruit, this type of feeding damage allows for secondary infections to the fruit and tree. In some instances, the tree may die from such infections. This species also feeds on both the seeds and the seedlings of cereal crops. The wrinkled dune snail has the propensity to aggregate on vertical structure (e.g., plants, fences); as such, they often pose a contamination risk to cereal grains during harvest, as well as allow for secondary infestation by fungal pathogens, which may make the grain toxic. In field cropping systems, this species is able to survive cultivation, therefore making it difficult to manage.

Synonyms

- *Helix intersecta* Poiret, 1801

References

Anderson 2005; Godan 1983; Kerney et al. 1979

Cepaea hortensis

Family

Helicidae

Species

Cepaea hortensis (Muller, 1774)

Common Name

White-lipped snail, Small banded snail

Description

The glossy shell of this snail ranges in height from 10 to 18 mm and a diameter of 14 to 22 mm. The number of whorls on the shell may be either 5 - 5 1/2 depending on locality. The shell is smooth and may have a uniform color that ranges from primrose yellow, olive-yellow, grey-yellow or grey-yellow brown with the lip being white in color. The shells may have one or five stripes that are chestnut-brown in color. There are also fine growth lines on the external surface of the shell.

Cepaea nemoralis and *C. hortensis* can be separated by the their distinctly colored apertural lip. In adult specimens of *C. nemoralis* the lip is always brown, while that of *C. hortensis* is white. Also *C. nemoralis* is larger than *C. hortensis.*

Native Range

Western and Central Europe

Distribution

North America:

- U.S.: Massachusetts, New York, Vermont
- Canada: Newfoundland, Quebec

Atlantic Islands: Iceland

Europe: Central and Northern

Ecology

This snail typically infests greenhouses and its longevity is approximately 5 years.

Synonyms

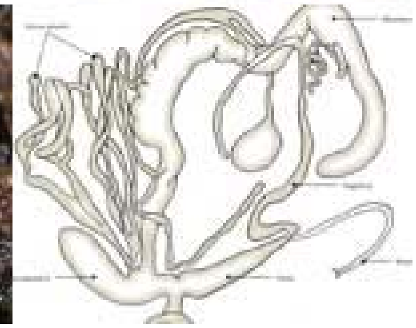
- *Helix subglobosa* A. Binney, 1837, Boston Journ. Nat. Hist., 1:485
- *Helix hortensis* Muller, 1774. Verm. Hist., 2: 52; A. Binney, 1851, Terr. Moll., 2:111, l8 Tachea hortensis W. G. Binney, 1878, Terr. Moll., 5: 378, figs. 262, 263

References

Anderson 2005; Boycott 1934; Horsak 2004; Kantoret al. 2009; Kerney et al. 1979; Pilsbry 1939





Cepaea nemoralis

Family

Helicidae

Species

Cepaea nemoralis (Linnaeus, 1758)

Common Name

Brown-lipped snail, Larger banded snail, Banded wood snail, Grove snail

Description

The heliciform shell of this snail ranges in width from 18-25 mm (rarely 32 mm), attaining a height of approximately 12-22 mm (rarely 28 mm). The height of the shell is usually less than the width of the aperture. The shell is dense and has a slight sheen with few growth lines. The shell may be brown, orange, red, yellow or olive in color and may posses one to five black or dark brown (cinnamon) spiral stripes which may coalesce or be absent. There are 4 1/2 to 5 1/2 whorls with the last descending in front the aperture. The lip is purple-brown, thickened and slightly curved. The umbilicus is absent in the adults and narrow in the juveniles. The body of the snail is cream colored; however, the tentacle and head are darker in color.

Cepaea nemoralis and *C. hortensis* can be separated by the their distinctly colored apertural lip. In adult specimens of *C. nemoralis* the lip is always brown, while that of *C. hortensis* is white. Also *C. nemoralis* is larger than *C. hortensis.*

Native Range

Western Europe

Distribution

North America:

- U.S.: Maine, Maryland, Massachusetts, New Jersey, New York, Ohio, Tennessee, Virginia, West Virginia
- Canada: Ontario

Europe: Central and Western

Ecology

This snail is commonly found in urban areas where it inhabits gardens or abandoned lots. This snail has frequently been observed aestivating on tree trunks. The diet of this snail includes dead and living plant material, carrion, fungi, moss and insects (thrips, aphids). In some cases it may take approximately three years for this animal to achieve maturity and longevity is approximately 5 years. Polymorphism observed in this snail is genetically determined.

Synonyms

- *Tachea nemoralis* L. Binney, 1878, Terr. Moll 5:379, fig. 264; 1885, Man. Amer. L. Sh., Bull. U.S. Nat Mus. No. 28, p.468, fig. 512
- *Helix nemoralis* Linnaeus, 1798. Syst. Nat., Ed. X, p. 773

References

Anderson 2005; Boycott 1934; Forsyth 2004; Kantor et al. 2009; Kerney et al. 1979; Orstan et al. 2011; Pilsbry 1939

Cernuella spp.

Family

Hygromiidae

Species

Cernuella neglecta (Draparnaud, 1805)

C. virgata (DaCosta, 1778)

Common Name

Cernuella neglecta: Dune snail

C. virgata: Maritime garden snail, Vineyard snail, White snail, Striped snail, Zoned snail

Description

Cernuella neglecta: The shell of the dune snail is 6-10 mm high and 9-18 mm wide, with 5-6 whorls. The shell has a white background with several brown-pink colored stripes. The aperture of the shell may have a pinkish lip on the inside. The shell of this species is smoother and more depressed than *C. virgata*.

C. virgata: This shell of this species may attain dimensions as large as 19 mm high and 25 mm wide, with 5-7 whorls. The color of this snail's shell is not uniform. The shell may have dark colored stripes that may or may not be continuous (may appear as spots or bands).

Native Range

C. neglecta: Mediterranean region

C. virgata: Mediterranean region and Western Europe

Distribution

Cernuella virgata:

North America:

- U.S.: North Carolina, Washington

Europe

Australia

Ecology

This group is known to be a pest of small grains and seedling production. This pest species has the potential to produce 60 eggs per clutch and as many as 40 clutches per year. This species is considered a significant agricultural contaminant of small grains due to sheer numbers of snails that occasionally aggregate on the crop. They cause significant economic losses to farmers as their aggregation on crops clog and damage machinery during harvest. The presence of large numbers of snails in harvested grain elevates the moisture content and promotes secondary infestation by fungal pathogens that produce toxin in the grain. Toxin contaminated grain is unmarketable, as it is not fit for animal and human consumption. Multiple countries have rejected shipments of grain from Australia due to contamination by this species.

Synonyms

Cernuella neglecta:

- *Helix neglecta* Draparnaud, 1805

C. virgata:

- *Cochlea virgata* Da Costa, 1778
- *Helix variabilis* Draparnaud, 1801
- *Xerophila euxina* Clessin, 1883

References

Anderson 2005; Barker 2002; Hitchcox and Zimmerman 2004; Kerney et al. 1979; Robinson and Slapcinsky 2005

Cochlicella spp.

Family

Cochlicellidae

Species

Cochlicella acuta (da Costa, 1778)

C. conoidea (Draparnaud. 1801)

C. ventricosa (Draparnaud, 1801)

Common Name

Cochlicella acuta: Pointed helicelid, Conical snail

C. conoidea: None reported

C. ventricosa: None reported

Description

Cochlicella acuta: The pointed helicellid's shell is approximately 10-20 mm high and 4-7 mm wide. It typically has a high spire, giving it an elongated appearance, hence its name. The color of this snail is very variable. It may range from being completely off-white to having regular brown-colored bands and stripes over the entire shell.

C. conoidea: This species is approximately 6-9 mm high and 5-6 mm wide, with 4.5-6 whorls. The shell is either pale grey or tan with brown spots or bands. There is also a brown-colored stripe at the base of the body whorl. The umbilicus (navel) is narrow. The body of the animal is apple yellow to tan with a lighter foot. The ocular (eye-bearing) tentacles are very long and the posterior tip of the foot is pointed.

Native Range

C. acuta: Mediterranean region and Atlantic

Distribution

Australasia: Australia

Europe: Spain, France, Belgium, Netherlands, British Isles, Turkey (*C. acuta*)

Mediterranean: Greece, Israel, Egypt

Ecology

This coastal species prefers sandy and calcareous soils where it is often found in grassy areas. Under unfavorable environmental conditions, this species will aestivate on vertical structures (e.g., posts, walls). This snail can lay on average 36 eggs per clutch. *Cochlicella acuta* has been reported as a pest of fodder crops (i.e. alfalfa, clover, lupine).

Synonyms

Cochlicella acuta:

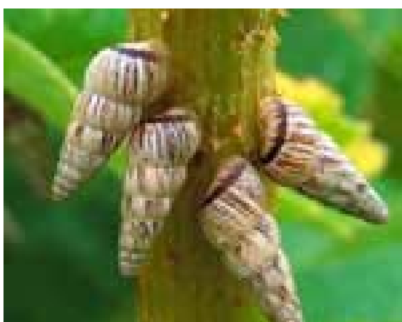
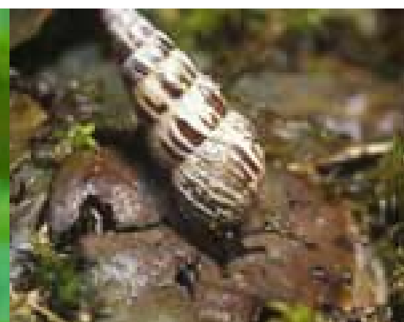
- *Bulimus acustus* . Zelebor, 1865. Mollusca. In: F. Unger and Th. Kotschy. Die Insel Cypern ihrer physischen und organischen Natur nanch mit Rucksicht auf ihre fruhere Geschichte geschildert: 593.
- *Cochlicella acuta*. Kerny and Cameron, 1979. A field guide to the land snails of Britain and North-west Europe: on pg. 183, pl.24 fig. 2a, b.

Cochlicella conoidea:

- *Cochlicella conoidea*, Kerney and Cameron (edition Gittenberger), 1980. Elseviers slakkengids: 1-310. Amsterdam & Brusessel. (on pg. 244. fig. 47).

References

Anderson 2005; Barker 2002; Cowie et al. 2009; Kerney et al. 1979; Gittenberger 1991; Godan 1983

Cochlicopa lubrica

Family

Cochliocopidae

Species

Cochlicopa lubrica (Muller, 1774)

Common Name

Glossy pillar

Description

This glossy shell ranges in length from 5.2-7 mm and is about 2.7 mm wide, with 5.5-6 whorls. The shell is off-white to brown in color and the body of the animal is dark blue-black. The tip of the lip of the shell may have a purplish tinge.

Native Range

Holarctic

Distribution

North America:

- U.S.: Alaska, California, Colorado, Iowa, Idaho, Illinois, Indiana, Kansas, Massachusetts, Maine, Michigan, Minnesota, Missouri, North Carolina, Nebraska, New Hampshire, New Jersey, New Mexico, New York, Ohio, Pennsylvania, Rhode Island, South Dakota, Tennessee, Utah, Virginia, Vermont, Washington, West Virginia, Wisconsin
- Canada: Alberta, British Columbia, New Brunswick, Ontario, Quebec, Newfoundland

Europe: Czech Republic, Netherlands, Poland, Slovakia, Great Britain, Ireland

Asia: Sri Lanka

Australasia: New Zealand

Ecology

The glossy snail inhabits forests, riverbanks and grassy areas in close proximity to human dwellings.

Synonyms

- *Cionella columna* Clessin, 1875
- *Bulimus nitidissimus* Krynicki, 1833
- *Cionella lubrica*
- *Helix lubrica* Muller, 1774

References

Anderson 2005; Georgiev 2008; Kantor et al. 2009; Kerney et al. 1979; Naggs et al. 2003; Perez and Cordeiro 2008; Quick 1954

Cornu aspersum

Family

Helicidae

Species

Cornu aspersum (Muller, 1774)

Common Name

Brown garden snail, Common snail, Garden snail

Description

Cornu aspersum is a moderately sized snail with a heliciform shell ranging in height from 20-35 mm and width from 25-40 mm (rarely 45 mm). The shell is yellow-brown and may possess darker brown spiral stripes interrupted by lighter, irregular markings and streaks, creating a banded appearance. There are irregular dimples on the shell. There are 4 1/2 to 5 whorls. The aperture (mouth) is large and rounded and has a lip that is white, faintly thickened and slightly recurved. In adults of this species, the umbilicus is normally absent or closed, though it may open to form a narrow slit in rare cases. The body of the animal is grey to pale brown-ochre and the tubercles are yellow. The mantle is somewhat black and speckled with grey-yellow.

Note: The surface sculpturing of the shell can be used to distinguish between Helix spp. and *Cornu aspersum*. The shell of *Cornu aspersum* is characteristically wrinkled, while the shell surface of *Helix* species lack wrinkles.

Native Range

Mediterranean region and Western Europe

Distribution

North America:

- U.S.: East and West Coast of the U.S., Southeastern States except Florida
- Canada: West Coast

South and Central America: Mexico, Chile, Argentina

Caribbean: Haiti

Pacific Islands: Hawaiian Islands

Atlantic Islands

Australasia: Australia, New Zealand

Asia

South Africa

Europe

Other: western Mediterranean region

Ecology

This edible snail lives in gardens and along roadsides and consumes both living and dead plant material. This species is recorded as a pest of citrus in California. In many parts of the world, *C. aspersum* attacks vegetables (carrot, cabbage, lettuce, onion, tomato), cereals (oats, wheat, barley), flowers (sweet-pea, lilies, carnation, aster, pansy), ornamental (California boxwood, hibiscus, rose) and fruit trees (peach, plum, apple, apricot). The garden snail can lay as many as 80 eggs per clutch. The juveniles of this species will achieve maturity in 1-2 years. Longevity is approximately 5 years.

Synonyms

- *Helix aspersa* Muller, 1774
- *Cantareus aspersus* (Muller)
- *Cryptomphalus aspersus* (Muller)

References

Anderson 2005; Boycott 1934; Cowie 2000; Cowie et al. 2008; Cowie et al. 2009; Forsyth 2004; Kerney et al. 1979

Deroceras agreste

Family

Agriolimacidae

Species

Deroceras agreste (Linnaeus, 1758)

Common Name

Field slug, Grey field slug, Milky slug

Description

This slug attains a maximum length of 50 mm when fully extended. It is pale brown to tan in color and does not have any conspicuous body markings. The head and tentacles are dark-brown. The tubercles of this species are not prominent. The sole is white and normally produces clear mucus, however the sole will produce milky white mucus when the animal is disturbed. In order to confirm the identity of this species, dissection and observation of the genitalia are required.

Deroceras agreste. The penis (p) of this species is broad with only a single appendix.

Deroceras caucasicum: The penis is broad and has two appendixes at the tip with the vas deferens emerges between them. The posterior edge of the penis is pigmented (dark-colored) and there is a hard "clam-shaped" shell-like plate inside the penis.

Deroceras laeve: The penis of this species is long, narrow and mostly twisted, with only a single appendix. It should be noted that a penis may be absent in some specimens.

Deroceras panormitanum: The penis in the species is broad and markedly bilobed with 4-6 appendixes.

Deroceras reticulatum: The penis (p) in the species is broad with only a single, irregularly branched appendix.

Native Range

Western Palaearctic

Distribution

Asia

Europe: North and Central including Scandinavia and Russia

Ecology

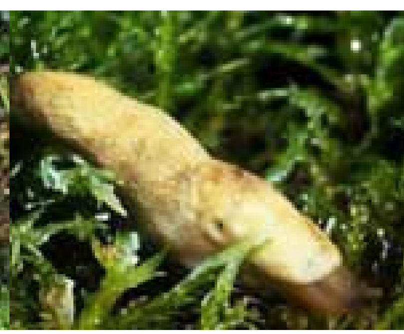
Habitats of this species include moist, natural and lightly disturbed grassy areas. It has also been noted to tolerate marshy habitats. This species has been reported as a common pest of agricultural crops (e.g., lettuce), seedlings and wild flowers. It also consumes dead vegetation, therefore allowing it to survive periods of fallow. It typically lives for a year. Upon maturity it will lay eggs approximately 10 days after mating. The incubation period of this slug is about 3 weeks.

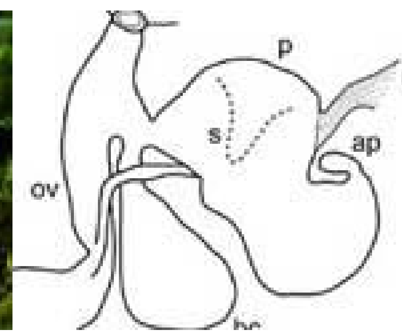
Synonyms

- *Limax agrestis* Linnaeus, 1758
- *Agriolimax agrestis* (Linnaeus)
- *Agriolimax fedschenkoi* Koch et Heynemann, 1874
- *Agriolimax transcaucasicus coeciger* Simroth, 1901

References

Anderson 2005; Kantor et al. 2009; Kerney et al. 1979; Niemela 1998; Wiktor 2000





Deroceras caucasicum

Family

Agriolimacidae

Species

Deroceras caucasicum (Simroth, 1901)

Common Name

None reported

Description

This slug has the potential to attain a length of 40 mm as fully mature adults. The adult color may range from whitish to dark brown. The head region and tentacles are dark brown to black in color. The mantle may be spotted in juveniles of this species. The sole is pale and the sole-mucus colorless. In order to confirm the identity of this species, dissection and observation of the genitalia are required.

Deroceras agreste. The penis (p) of this species is broad with only a single appendix.

Deroceras caucasicum: The penis is broad and has two appendixes at the tip with the vas deferens emerges between them. The posterior edge of the penis is pigmented (dark-colored) and there is a hard "clam-shaped" shell-like plate inside the penis.

Deroceras laeve: The penis of this species is long, narrow and mostly twisted, with only a single appendix. It should be noted that a penis may be absent in some specimens.

Deroceras panormitanum: The penis in the species is broad and markedly bilobed with 4-6 appendixes.

Deroceras reticulatum: The penis (p) in the species is broad with only a single, irregularly branched appendix.

Native Range

Caucasus Region: Northern Iran, Black Sea, Turkey and Crimea

Distribution

Asia: Central, Iran

Europe: Turkey, Ukraine

Ecology

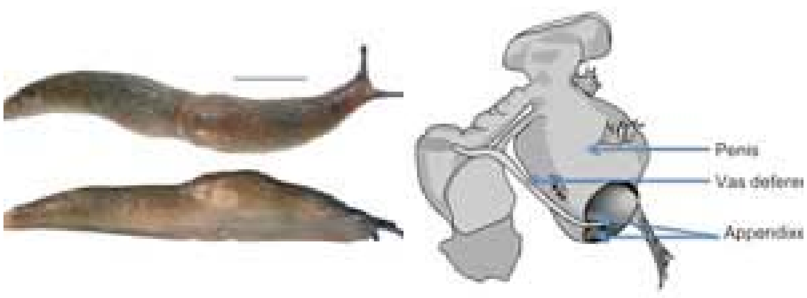
This slug species has been reported as a pest of strawberries, cabbage, cucumber, tomatoes, pepper and eggplant. This slug can survive in diverse habitats ranging from moist meadows to partial deserts. The number of generations per year may vary from one to three depending on the location.

Synonyms

- *Agriolimax dymczewiczi* sensu Simroth, 1901 non Kaleniczenko, 1851
- *Agriolimax caspius* Simroth, 1901
- *Lytopelte grusina* Simroth, 1901
- *Lytopelte caucasicus* Simroth, 1901
- *Lytopelte caucasica armenia* Akramowski, 1948
- *Deroceras hamatus* Skljar, 1975

References

Kantor et al. 2009; Son 2010; Uvalieva 1978; Wiktor 2000; Wiktor 2004



Deroceras laeve

Family

Agriolimacidae

Species

Deroceras laeve (O.F. Muller, 1774)

Common Name

Marsh slug, Meadow slug, Brown slug

Description

The meadow slug is a small slug approximately 25-35 mm long. It ranges in color from dark brown or yellowish to almost black, while the head and tentacles posses a characteristic smoky, bluish black color. The overall body shape of the slug is cylindrical, elongated and ends in a short keel. The mantle is oval in shape with fine concentric striations without spots or blotches. The back of the slug is covered with conspicuous elongated tubercles and furrows. The foot is narrow and whitish in color and produces mucus that is thin, watery, non-adhesive and colorless. It may be possible to distinguish this species from *D. panormitanum* by the slope of the tail. The tail of this species is bluntly rounded, while the tail of *D. panormitanum* gradually tapers to a point. In order to confirm the identity of this species, dissection and observation of the genitalia are required.

Deroceras agreste. The penis (p) of this species is broad with only a single appendix.

Deroceras caucasicum: The penis is broad and has two appendixes at the tip with the vas deferens emerges between them. The posterior edge of the penis is pigmented (dark-colored) and there is a hard "clam-shaped" shell-like plate inside the penis.

Deroceras laeve: The penis of this species is long, narrow and mostly twisted, with only a single appendix. It should be noted that a penis may be absent in some specimens.

Deroceras panormitanum: The penis in the species is broad and markedly bilobed with 4-6 appendixes.

Deroceras reticulatum: The penis (p) in the species is broad with only a single, irregularly branched appendix.

Native Range

Holarctic

Distribution

North America:

- U. S.: Alabama, Alaska, Arkansas, California, Delaware, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Michigan, Mississippi, Missouri, Nebraska, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Pennsylvania, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Washington, West Virginia, Wisconsin
- Canada: Newfoundland, British Columbia, Alberta, Nova Scotia, Ontario, Quebec

Caribbean: Jamaica

Europe

South America

Asia: Sri Lanka

Pacific Islands: Hawaii

Australasia: New Zealand

Ecology

This species primarily inhabits moist habitats such as wet marshes, woods and meadows, and sometimes found in greenhouses. This species has the potential to become a garden pest as it consumes living and dead plant material. *Deroceras laeve* reproduces year round, and generally becomes more active approximately three weeks before other species in the spring. The animal reproduces by self-fertilization although outcrossing has been recorded. The round to oval eggs are laid in clutches of approximately 33 (often times much fewer). They measure between 1-3 mm, and often hatch in 10-15 days. The translucent eggs are deposited in crevices in the soil or leaf litter. As the eggs mature, the color changes to a creamish color.

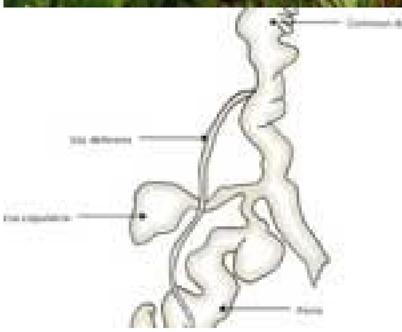
Synonyms

- *Limax laevis* Muller, 1774, Verm. Terr. Et fluv. Hist., 2: 2 (Denmark)
- *L. gracilis* Rafinesque, 1820, Ann. of Nat., 1: 10 (near Hendersonville, Kentucky, in woods).
- *L. campestris* A. Binney, 1842, Proc. Bost. Soc. N. H., 1:52 (New England States, New York, Ohio, Missouri): 1842, Bost. Jour. N. H., 4:169; 1851, Terr. Moll., 2:41, pl.64, fig. 3.
- *L. weinlandi* Heynemann, 1862, Zeits. F. Malak., 10: 212, pl. 3, fig. 1 (North America)
- *L. campestris* var*. occidentalis* Cooper, 1872, Proc. Acad. Nat. Sci. Phila., p.146, pl. 3, figs. C, 1-5 (California); Cf. W. G. binney, Terr. Moll., 5: 150, pl. 1, fig. L; 3d Suppl., Bull. Mus. Comp. Zool., 19: 206, pl. 8, fig. H (living animal).
- *L. montanus* Ingersoll, 1875, Bull. U. S. Geol. And Geogr. Surv. Terr., (2) no. 1: 130 (Hot Sulphur Springs, Colo.); W.G. Binney, 1878, Terr. Moll., 5:152, pl. xii, fig. B (genitalia). Not *Limax monotanus* Leydig, 1871.
- *L. costaneus* Ingersoll, 1875, 1.c., p. 131. (Blue River vally, Colorado)
- *L. ingersolli* W.G. Binney, 1875, Proc. Acad. Nat. Sci. Phila., p. 176; Ann. Lyc. N. H. of N. Y., 10: 169.
- *L. hyperboreus* [? Westerleund, 1876, Nachrbl. D. Malak. Ges., 8:97; 1877, K. Svenska Vet.-Akad. Handl., 14, no. 12, pl. 21
- *Agriolimax montanus* Ing., Cockerell, 1888, Jour. of Conch., 5: 358, with forms *typicus*, *intermedius* and t*ristis*, p. 359.
- *Limax hemphili* W.G. Binney, 1890, 3d Suppl., Bull. Mus. Comp. Zool., 19: 205, pl. viii, fig. E; pl I, fig. 13; pl. ii, fig. 3; 1892, 4th Suppl., Bull. M.C.Z. 22: 166, pl.3, fig. I. with var. pictus.
- *Agriolimax campestris zonatipes* Cockerell, 1892, The Conchologist. 2: 72.

- *Agriolimax hemphilli ashmuni* Pilsbry & Vanatta, in Pilsbry & Ferriss, 1910. Proc. Acad. Nat. Sci. Phil. For 1909, 61: 512, fig. 11 a-c (Huachuca Mts., Arizona, in Miller (type loc.), Brown and Tanner canyons and Nogales, Arizona; Pilsbry & Ferris, 1910 same Proc, 62: 130 (Chiricahua Mts., Arizona, at about 8000 ft.).
- *Agriolimax psudodioicus* Velitchkovsky, 1910.
- *Deroceras schulzi* Tzvetkov et Matyokin, 1946.

References

Anderson 2005; Branson 1959; Branson 1962; Branson 1980; Cowie 1997; Cowie et al. 2008; Forsyth 2004; Horsak 2004; Kantor et al. 2009; Kerney et al. 1979; Meyer and Cowie 2010; Naggs et al. 2003; Perez and Cordeiro 2008; Pilsbry 1939; Rosenberg and Muratov 2006; Wiktor 2000



Deroceras panormitanum

Family

Agriolimacidae

Species

Deroceras panormitanum (Lessona & Pollonera, 1891)

Common Name

Longneck fieldslug, Brown field slug

Description

Deroceras panormitanum is a chocolate-brown, grey-brown or almost black slug that ranges in length form 25-30 mm. The body of the slug is covered with dark brown speckles or flecks. The skin is very thin and almost completely translucent. The mantle is lighter in color over the lung and the sole is light grey. The mucus this slug produces is thin, colorless and not excessively gummy. It may be possible to distinguish this species from *D. laeve* by the slope of the tail. The tail of this species gradually tapers to a point, while the tail of *D. laeve* is bluntly rounded. In order to confirm the identity of this specimen, dissection and observation of the genitalia are required.

Deroceras agreste. The penis (p) of this species is broad with only a single appendix.

Deroceras caucasicum: The penis is broad and has two appendixes at the tip with the vas deferens emerges between them. The posterior edge of the penis is pigmented (dark-colored) and there is a hard "clam-shaped" shell-like plate inside the penis.

Deroceras laeve: The penis of this species is long, narrow and mostly twisted, with only a single appendix. It should be noted that a penis may be absent in some specimens.

Deroceras panormitanum: The penis in the species is broad and markedly bilobed with 4-6 appendixes.

Deroceras reticulatum: The penis (p) in the species is broad with only a single, irregularly branched appendix.

Native Range

Southwest Europe

Distribution

North America:

- U.S.: Western (Utah, Colorado, California)
- Canada

South America: Columbia

Atlantic Islands: Canary Islands, Tristan da Cunha

Australasia: Australia; New Zealand

Africa: South including Marion Island

Europe

Ecology

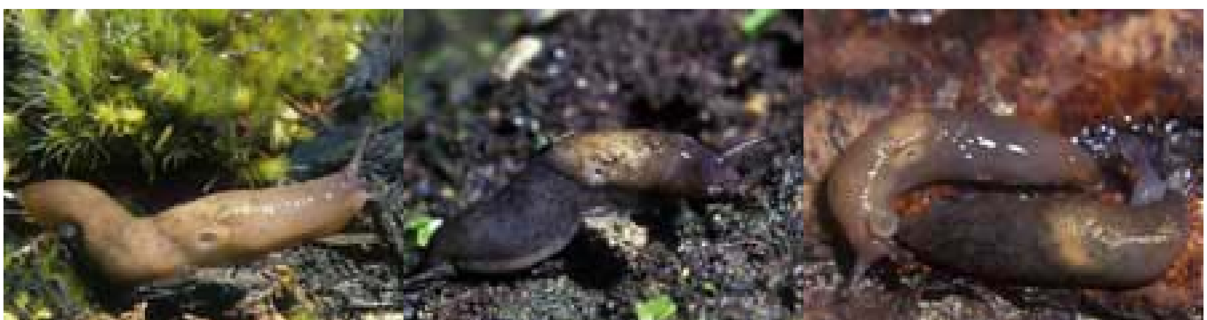
The longneck fieldslug is a fast moving slug, which is usually associated with human dwellings. It can be found in greenhouses, gardens, pastures, nurseries and commercial cropping systems. The diet includes living and dead plant material and this species has been reported as a pest of lettuce, asparagus, cereal and root crops. *Deroceras panormitanum* has been reported to display aggressive behavior involving tail lashing and biting and cannibalism. Eggs range from 1.5-1.75 mm in diameter and this species reproduce year-round.

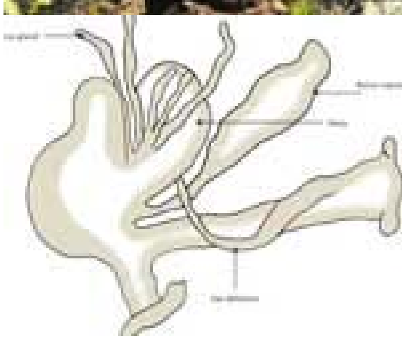
Synonyms

- *Agriolimax panormitanum* Lesson & Pollonera, 1882. Monografia dei Limacidi Italiani, Mem. R. Accad. Torino (2)35: 52. Type locality Sicily.
- *Limax panormitanum* Lessona & Pollonera, 1882
- *Limax queenslandicus* Hedley, 1888. Proc. R. Soc. Qld. 5(4): 150.
- *Agriolimax pollonerae* Simroth, 1889. Nachr. Deutsch. Malak. Ges. 21(11/12): 179-82.
- *Agriolimax caruanae* Pollonera, 1891. Boll. Mus. Zool. Anat. Comp. R. Univ. Torino 6(99): 3.
- *Agriolimax cecconii* Pollonera, 1896. Boll. Mus. Zool. Anat. Comp. R. Univ. Torino 11(264): 6.
- *Agriolimax ceccomii* var. *ilvatica* Pollonera, 1905. Boll. Mus. Zool. Anat. Comp. R. Univ. Torino 11(517): 3.
- *Agriolimax dubius* Hoffmann, 1941. Zool. Anzeiger 136: 254-7.
- *Deroceras meridionale* Reygrobellet, 1963. Bull. Soc. Zool. Fr. 88: 399.
- *Deroceras caruanae* (Pollonera, 1991).

References

Anderson 2005; Barker 1879; Forsyth 2004; Horsak et al. 2004; Hutchinson and Heike 2007; Kerney et al. 1979 ; Reise et al. 2006; Wiktor 2000





Deroceras reticulatum

Family

Agriolimacidae

Species

Deroceras reticulatum (O.F. Muller, 1774)

Common Name

Grey fieldslug, Field slug, Milky slug

Description

A mature grey fieldslug ranges in length from 35 to 50 mm. The stout body of this slug may be cream-colored, greyish or has a slight pink-grey color. The mantle has concentric striations and usually covers more than one-third the length of the slug. There are dark brown or grey flecks concentrated between the tubercles. The tentacles are dark in color. The thin, clear, sticky mucus of this slug often becomes a milky white when it is harassed. There is a short keel at the tail end. The sole of the foot is tripartite, whitish to grey-yellow in color with the median field grey. The pneumostome (breathing pore) having a raised, pale border is located in the posterior forth of the mantle. This species can easily be confused with *Deroceras agreste*. In order to confirm the identity of this species, dissection and observation of the genitalia are required.

Deroceras agreste. The penis (p) of this species is broad with only a single appendix.

Deroceras caucasicum: The penis is broad and has two appendixes at the tip with the vas deferens emerges between them. The posterior edge of the penis is pigmented (dark-colored) and there is a hard "clam-shaped" shell-like plate inside the penis.

Deroceras laeve: The penis of this species is long, narrow and mostly twisted, with only a single appendix. It should be noted that a penis may be absent in some specimens.

Deroceras panormitanum: The penis in the species is broad and markedly bilobed with 4-6 appendixes.

Deroceras reticulatum: The penis (p) in the species is broad with only a single, irregularly branched appendix.

Native Range

Western Europe

Distribution

North America:

- U.S.: Alabama, California, Colorado, Hawaii, Illinois, Kentucky, Michigan, Ohio, Oklahoma, Utah, Washington, Wisconsin, Wyoming
- Canada: Newfoundland, Quebec, Ontario, British Columbia

Asia: Sri Lanka

Australasia: New Zealand

Europe

Ecology

This slug prefers modified habitats, such as garden, greenhouses, roadsides and fields. The diet of *D. reticulatum* is primarilly constituted of living plant material but this slug is an omnivore and may consume mushrooms, dead slugs, earthworms and other animal matter. This species is especially destructive to seedlings and succulent plants. In northern Europe and North America this species damages grains, clover and vegetable crops. This slug has the potential to detect predatory carabid beetles through the use of olfactory cues. When attacked, the slug lashes its tail, secretes copious amounts of mucus and flees its attacker. The slug may also amputate the tip of its tail to evade predation. Reproduction is by cross-fertilization and occurs year round under favorable conditions. Mating occurs mainly at night and approximately 60-75 eggs (4 mm each) are produced per clutch totaling approximately 700 eggs per year per specimen. The animal's lifespan is generally one to two years.

Synonyms

- *Limax agrestis* Linnaeus, 1758. Syst. Nat. 1: 1082 (part).
- *Limax reticulatus* Muller, 1774 Verm. Terr. Et fluv. Hist., 2:10 (gardens of Rosenburg and Fridricksdal).
- *Limax canariensis* d'Orbigny, 1839. Hist. NAt. Iles Canaries (Webb and Berthelot) 2(2): 47.
- *Limax tunicata* Gould, 1841, Invert. of Mass. p. 3 (Massachusetts).
- *Krynickillus minutus* Kalenickzenko, 1851. Bull. Soc. Imp. Nat. Moscou 24: 224.
- *Limax agrestis* Leidy, 1851, in Binney, Terr. Moll., 1: 250, pl. 2, figs. 7-9 (anatomy); Binney, 1851, Terr. Mol. 2: 36, pl. 64, fig. 2.; W.G. Binney, 1878. Terr. Moll. 5:146. Not *Limax agrestis* Linnaeus, 1758, Syst. Nat. (10) p. 652, as restricted by Luther.

- *Limax molestus* Hutton, 1879. Trans. N.Z. Inst. 11: 331 (new synonymy).
- *Krynickillus niciensis* (Boettger) Nevill, 1880. Proc. Zool. Soc. Lond.: 103.
- *Agriolimax agrestis* L. of most authors in the last century; Cockerell , 1891, Nautilus, 5: 70 (named color-varieties); 11: 15, fig. 1 (monstrosity); 7:21 (in Jamaica)
- *Agriolimax reticulatus* Muller, Luther, 1915 Actes fauna et flora Fennica, 40, No. 2.; Ingram, 1943, Nautilus, 55:67.

References

Anderson 2005; Barker 1879; Branson 1959; Branson 1962; Branson 1980; Carrick 1942; Cowie 1997; Cowie et al. 2009; Forsyth 2004; Horsak 2004; Hutchinson and Heike 2007; Kerney et al. 1979; Naggs et al. 2003; Pilsbry 1939; Thomas et al. 2010; Wiktor 2000

Discus rotundatus

Family

Discidae

Species

Discus rotundatus (Muller, 1774)

Common Name

Rotund disc

Description

The rotund disc snail is very small. It is approximately 2.5 mm in height and ranges in width from 5.5-7.2 mm, with about 4.5-6 whorls. This flattened shell is almost disc-shaped and can either be grey or light yellow-brown in color, with prominent uniformly arranged reddish brown blemishes. The body of the animal is blue-grey or blue-black, but pale on the sides of the foot.

Native Range

Western and Central Europe

Distribution

North America:

- U.S.: California, New Jersey, New York, Massachusetts, Washington State
- Canada

Atlantic Islands

Europe: Southern Scandinavia, Northern Scotland to Algeria, Spain, Ireland to Ukraine, Turkey, Denmark, Norway

Ecology

This snail inhabits forests, greenhouses, wasteland and gardens. They often lay fewer than 5 eggs per clutch.

Synonyms

- *Helix rotundatus* Muller, 1774

References

Anderson 2005; Grimm et al. 2009; Forsyth 2004; Horsak 2004; Kerney et al. 1979



Elasmias apertum

Family

Tornatellinidae

Species

Elasmias apertum (Pease, 1864)

Common Name

None reported

Description

This snail is very small, approximately 4.5 mm in length and 2.5 mm in diameter, with a total of 3-4.5 whorls. The shell is globose-ovate in shape. The snail has a pale brown color and may appear glossy. In some specimens a slight discoloration of the apex of the spire may be observed. The body of the animal is pale with dark tentacles. The foot of the animal is almost as long as the shell.

Native Range

Polynesia

Distribution

Indian Ocean islands

Pacific Islands

Australia

Ecology

This species is generally found on foliage, as they are tree dwellers.

Synonyms

- *Tornatellina aperta* Pease, Proc. Zool. Soc. Lond., 1864, p.673; 1871, p.473.

References

Pilsbry and Cooke 1915; Sloem 1964

Eobania vermiculata

Family

Helicidae

Species

Eobania vermiculata (Muller, 1774)

Common Name

Chocolate-band snail

Description

This snail's shell is whitish (with yellow to grey-brown tinge) in color with four or five chestnut-brown to chocolate stripes that are more or less spotted or speckled with white. Albino variants do exist (i.e. they do not have stripes). The peristome is also white. The thick-walled shell of this species has 5-6 whorls and may attain a height of 14-27 mm and a diameter of 22-30 mm although specimens have been reported to measure 35 mm. The umbilicus (navel) is inconspicuous.

Native Range

Mediterranean region

Distribution

North America:

- U.S.

Other: Mediterranean region

Ecology

This species inhabits fields, gardens and vineyards. During the day, the animal aestivates on vertical structures (e.g., trees, palms, bushes, fences).

Synonyms

- *Helix vermiculata* Muller, 1774

References

Cowie et al. 2009; Pilsbry 1939; Kerney et al. 1979; Yildirim et al. 2004

Euconulidae

Family

Euconulidae

Species

Euconulus spp.

Common Name

Brown hive, Hives

E. alderi: Shiny hive

E. chersinus: Wild hive

E. dentatus: Toothed hive

E. fulvus: Brown hive

E. polygyratus: Fat hive

E. trochulus: Silk hive

Description

This small group of snails only attains a maximum width of 3.5 mm. They are generally dome or bee hive-shaped, pale brown and glossy. The aperture is crescent shaped. There are approximately 25 species in the genus *Euconulus*, with six species currently occurring in the eastern U.S.:

E. alderi: 2.1 mm high, 2.3-2.8 mm wide, 5.2 whorls

E. chersinus: 2.35 mm high, 2.5 mm wide, 6.6 whorls

E. dentatus: 2.75 mm high, 2.5 mm wide, 6.9 whorls

E. fulvus: 3.2 mm high, 3.4 mm wide, 6.5 whorls

E. polygyratus: 2.4 mm high, 2.75 mm wide, 6.8 whorls

E. trochulus: 2.4 mm high, 2.45 mm wide, 5.9 whorls

Native Range

Holarctic

Distribution

North America:

- U.S.: Central and Eastern
- Canada

Europe

Australasia: New Zealand

Ecology

This snail genus inhabits cool, calcareous wetlands, lowland conifer, coastal dune/beaches or grassy meadows. *E. alderi* is a protected species in Michigan.

References

Grimm 2009; Forsyth 2004; Kerney et al. 1979; Michigan Natural Features Inventory 2007; Perez and Cordeiro 2008



Granodomus lima

Family

Camaenidae

Species

Granodomus lima (Ferussac, 1821)

Common Name

Rasping nipple snail

Description

The shell size is 25-35 mm, with 4-5 whorls. The heliciform shell has regularly spaced, small raised bumps that are more prominent on the body whorl. The shell is light brown in color and there are no color markings present. The shell is dull in appearance (not glossy). It has a low spire and the animal is capable of retracting completely into its shell. Only dextral individuals exist. The body of the animal is dark brown with a pale brown foot and blue-black tentacles.

Distribution

Caribbean: Puerto Rico

Ecology

This pest species is mainly a contaminant. It has been intercepted many times on crushed automobiles from Puerto Rico.

Synonyms

- *Polydontes lima*

References

Wade et al. 2006

Guppya gundlachi

Family

Helicarionidae

Species

Guppya gundlachi (Pfeiffer, 1839)

Common Name

Glossy granule

Description

The shell of this snail is approximately 1.75 mm in height and 3 mm in diameter. It has 4 2/3 whorls and is generally glossy in appearance. The growth lines on the shell are inconspicuous; however, after the smooth apical half whorl, there are minute, moderately spaced spiral lines. The pale brown shell of the glossy granule snail is minutely perforated. The depressed shell has a low dome-like appearance from above. The aperture of the shell is lunate (half moon-shaped).

Native Range

Central America

Distribution

North America:

- U. S.: Florida, Texas

South and Central America

Caribbean: Trinidad, Puerto Rico, Cuba, Jamaica

Asia: Thailand

Ecology

This species is commonly intercepted in shipments of ornamental crops from Thailand to the U.S.

Synonyms

- *Helix pusilla* Pfeiffer, 1839, Archiv. F. Naturg., 1: 351. Not of Lowe, 1833.
- *Helix gundlachi* Pfeiffer, 1840, Archiv. F. Naturg., 1: 250; substitute for H. pusilla; 1848, Mon. Hel. Viv., 1: 50.
- *Helix simulans* C.B. Adams, 1849, Contrib. to Conch., No. 3, p.35 (Jamaica).
- *Helix egena* Gould inBinney, 1851, Terr. Moll., 2: 245, pl. 22a, fig. 3. Not of Say.

- *Guppya gundlachi* Pfeiffer, Von Martens, 1892, Biol. Centr.-Amer., Moll., p. 122.; H.B. Baker, 1922, Occas. Pap. Mus. Zool. Univ. Mich., 106: 45, pl. 17, figs. 1,3, jaw and teeth.
- *Zonites gundlachi* Pfeiffer, W. G. Binney, 1978, Terr. Moll., 5: 127, pl. 22a, fig. 3; pl.2, fig. D, teeth.
- *Guppya orosciana*

References

Baker 1928; Pilsbry 1946; Rosenberg and Muratov 2006

Helicarionidae

Family

Helicarionidae

Species

Mariaella dussumieri Gray, 1855

Parmarion martensi Simroth, 1893

Parmarion reticulates Hasselt, 1824

Common Name

Mariaella dussumieri: None reported

Parmarion martensi: Yellow-shelled semi-slug

Parmarion reticulates: None reported

Description

Mariaella dussumieri: Mature specimens of this slug will measure up to 200 mm in length. Its body color ranges from yellow-brown to olive, with black colored blotches that may coalesce in some individuals giving the animal a completely black appearance. The mantle of this animal extends 2/3 the length of the body. There is a small, internal shell that is flat and beak-like in this species. The shell is partially visible through an external pore in the mantle. There are two elevated ridges on the very large mantle of this species. The left ridge runs from the anterior portion of the mantle to the posterior edge. The other ridge on the right side of the animal runs from the breathing pore to the opening of the shell. There is a prominent keel that extends from the posterior edge of the mantle to the tip of the tail where it ends in the mucus pore. The foot is tripartite and has bands.

Parmarion martensi: This species is brown in color and is capable of attaining a length of up to 50 mm. The animal is generally called a semi-slug because of a small, soft shell that covers the back. The shell is not large enough to cover the mantle, therefore leaving it partially exposed. The animal has the capability to cover its shell with the mantle flaps adjacent to it (the entire structure looks like a 'bag' hanging over the tail of the animal). There is a very prominent, pale colored keel that extends from the base of the posterior edge of the mantle to the mucus pore. The tentacles bearing the eyes are dark-brown to black, while the lower pair is tan/cream colored.

Parmarion reticulates: This species is similar to *P. martensi*. The mantle in this species also appears sac-like with an opening in the middle through which the shell can be seen. The sole is tripartite and the foot has a mucus pore.

Distribution

Mariaella dussumieri:

Asia: India, Sri Lanka

Parmarion martensi:

Pacific Islands: Hawaiian Islands, Samoa, American Samoa

Asia: Japan, Taiwan, Vietnam, Malay Peninsula, Sumatra, Java, Singapore, Borneo

Ecology

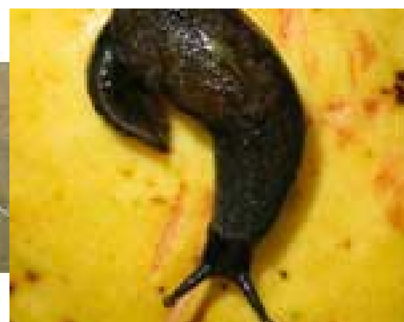
Mariaella dussumieri: This species has been documented as a pest of cabbage, young rubber plants and legumes. The incubation period of eggs 4-46 days.

Parmarion martensi: This species has been intercepted on lettuce, fennel, sweet potato, banana, passion fruit, lemon grass and *Heliconia* sp. It has also been observed feeding on fallen fruits of avocado, guava, citrus, papaya and mango. This species is commonly found around human dwellings and is reported as a reservoir host of the human rat lungworm parasite (*Angiostrongylus cantonensis*). This increases the probability of the slug transmitting this potentially fatal disease-causing organism to humans.

Parmarion reticulates: This species has also been reported to feed on young plants of the rubber tree.

References

Gupta and Oli 1998; Hollingsworth et al. 2007; Mead 1961; Naggs et al. 2003; Tandon et al. 1975



Helicella itala

Family

Helicidae

Species

Helicella itala (Linnaeus, 1758)

Common Name

Heath snail

Description

This species has white, tan or pale yellow shells that are approximately 5-12 mm high and 9-25 mm wide, with 5.5-6.5 whorls. There may also be dark brown stripes on the conical shell of this group. The shell has a wide umbilicus.

Native Range

Western Europe

Distribution

Europe: Great Britain, Ireland, Germany, France, Belgium, Netherlands, Denmark, Austria, Poland

Australia

Ecology

This species occupies open habitats, including grasslands. It can also be found in disturbed habitats (e.g. roadsides, railways and forested dunes). The heath snail aestivates on vertical objects (e.g., blades of grass). This species is generally considered a contaminant; however, in agricultural setting this species may achieve pest status when there is a high population density. Large numbers of heath snails can clog machinery and add moisture to harvested crops. This added moisture often leads to spoilage and in some cases infestation by secondary pathogens. Some secondary pathogens are capable of producing toxins which may be harmful to humans and cattle. They produce a maximum of 90 eggs per clutch and can live up to 3 years, reproducing twice per year.

Synonyms

- *Helicella ericetorum* O.F. Muller

References

Anderson 2005; Kerney et al. 1979




Helix spp.

Family

Helicidae

Species

Helix pomatia Linnaeus, 1758

H. lucorum Linnaeus, 1758

H. aperta Born, 1778

Common Name

Roman snail, Edible snail, Vineyard snail

Helix aperta: Burrowing snail, Green snail

Description

H. pomatia: *Helix pomatia* has a large shell that can attain a height of 30-50 mm and a width of 32-50 mm. There are a total of 5-6 whorls. The thin shell of this snail is globose with a wrinkled surface, giving the appearance of faint spiral lines. The shell has a brownish color often classified as chamois. This chamois color is often interrupted by wide cinnamon-brown stripes. The stripes may be either distinct or ill-defined. The aperture is large with a slightly expanded pecan brown lip that is broadly reflected at the collumela, partially covering the umbilicus.

H. lucorum: The thick shell of this species will get as high as 55 mm, with 4.5-5 rapidly increasing whorls. The compressed, spherical shell has a distinct apex. The shell has a white background with dark-brown, irregular, vertical bands.

H. aperta: This species has a diameter of approximate 31 mm, with 4 rapidly increasing whorls. This species is not banded or striped. The base color is olive-brown to greenish. The shell is thin-walled and translucent.

Note: The surface sculpturing of the shell can be used to distinguish between Helix spp. and *Cornu aspersum*. The shell of *Cornu aspersum* is characteristically wrinkled, while the shell surface of *Helix* species lack wrinkles.

Native Range

Central and Southeastern Europe, and the Mediterranean region

Distribution

North America:

- U.S.: Michigan, Wisconsin

Europe

Other: Mediterranean region

Ecology

This group of species can be found in greenhouses, grassy areas, forests, gardens and orchards where they may attain pest status. Their longevity is approximately 5 years, although specimens of *H. pomatia* have been documented to live for over 20 years.

Synonyms

Helix aperta:

- *Cantareus apertus* (Born, 1778)

H. lucorum:

- *Helix taurica* Krynicki, 1833

- *Helix radiosa* Rossmassler, 1838
- *Helix taurica* mut. *martensi* O. Boettger, 1883
- *Helix ancyrensis haussknechti* Kobelt, 1906

References

Anderson 2005; Boycott 1934; Horsak 2004; Kantor et al. 2009; Kerney et al. 1979; Pilsbry 1939; Yildirim et al. 2004

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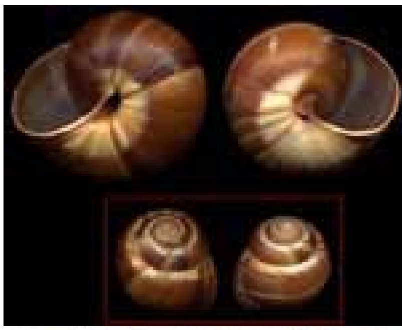
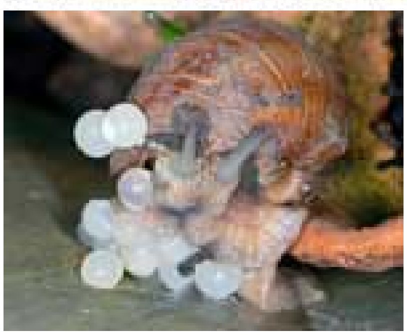








Hygromia cinctella

Family

Hygromidae

Species

Hygromia cinctella (Draparnaud, 1801)

Common Name

Girdled snail

Description

The shell of the girdled snail is 6-7 mm high and 10-14 mm wide, with 5-6 whorls. The shell is tan to light brown, with pale colored blotches. The outer rim of the body whorl of the shell is very pale when compared to the rest of the whorl. The aperture (mouth) is oval and the umbilicus (navel) is small and narrow.

Native Range

Mediterranean region

Distribution

Europe

Other: Mediterranean region

Ecology

Found on hedges and in gardens where they aggregate in large numbers.

References

Anderson 2005; Kerney et al. 1979



Lauria cylindracea

Family

Pupillidae

Species

Lauria cylindracea (da Costa, 1778)

Common Name

Moss snail

Description

The shell of this species is 3-4 mm high and 1.8 mm wide with 5-6 whorls. The brown shell of this species is transparent and glossy. It is pupa-shaped with a low spire. The aperture (mouth) may have a papery mucus membrane and may or may not have a tooth. The apertural margin is white, sharp and reflected. The umbilicus (navel) is open and narrow. The body of the animal is dark with pale sides and foot. The animal characteristically moves with the shell held in an almost vertical position.

Native Range

Western Europe and Mediterranean region

Distribution

Caribbean: Jamaica

Europe

Ecology

This species never lay eggs; instead, it produces living young (ovoviviparous). The juveniles have 2-2.5 whorls. This species occurs in forests, meadows and gardens, but never where the humidity is high.

Synonyms

- *Turbo cylindraceus* Da Costa, 1778
- *Pupa umbilicata* Draparnaud, 1801
- *Pupa sempronii* Charpentier, 1837
- *Pupa dilucida* Rossmassler, 1837

- *Lauria cymmetrica* Puzanov, 1925

References

Anderson 2005; Hausdorf 2007; Kantor et al. 2009; Kerney et al. 1979; Rosenberg and Muratov 2006

Lehmannia marginata

Family

Limacidae

Species

Lehmannia marginata (Muller, 1774)

Common Name

Tree slug

Description

The tree slug is variable in color, ranging from grey to reddish. There is a short keel at the tip of the tail. The mantle is very large in relation to the size of the animal (1/3 the length of the body). There are 2 dark-colored stripes on each side of the animal. The lower stripe often branches and may be difficult to see. On the other hand, the mantle has three stripes, with the middle stripe being paler than the other two. The pale area between the bands on the mantle forms a lyre shape (horseshoe-shaped). The pneumostome (breathing pore) is located on the right, in the posterior third of the mantle. The sole is tripartite (grey with a darker center). The mucus is clear and watery. There is a characteristic pale stripe running down the midline of *Lehmannia marginata,* and this character is very useful to distinguish this species from *L. valentiana.* However if there is any doubt, the genitalia should be used to confirm the identity of the specimen. There is a European species called *Lehmannia nyctelia* that can be confused with this species. Genitalic characters are provided below for species determination.

The following species can be separated by dissection and observation of their genitalia:

Lehmannia marginata: The appendix on the penis of this species tapers to a point. It should be noted that the appendix might be inverted in this species.

L. valentiana: The appendix on the penis of this species is somewhat tubular or the apex may appear expanded.

L. nyctelia: The appendix is lacking in this species.

Native Range

Europe

Distribution

North America:

- U.S.: Oklahoma

Australasia: New Zealand

Europe

Ecology

This species inhabits gardens, forests, and open habitat but are rarely encountered in intensively cultivated lowland areas. *Lehmannia marginata* consusumes algae, lichen and mushroom. In the absence of prefered food material this species is reported to consume other mollusc species that are already dead, but are not known to attack other gastropods. Clutches of between 8-30 eggs are deposited in the soil and depending on temperature may incubate for approximately 35-130 days. Maturity is achieved in 8-10 months and longevity is approximately 2.5-3 years.

Synonyms

- *Limax arborum* Bouchard-Chantereaux, 1838
- *Limax livonicus* Schrenk, 1848
- *Limax marginatus* Muller, 1774

References

Abbes 2010; Anderson 2005; Branson 1980; Cowie 1997; Forsyth 2004; Horsak 2004; Kantor et al. 2009; Kerney et al. 1979; McDonnell et al. 2009; Thomas et al. 2010

Lehmannia valentiana

Family

Limacidae

Species

Lehmannia valentiana (Ferussac, 1821)

Common Name

Three-band gardenslug, Greenhouse slug

Description

Mature adults of this slug can attain a length of about 50-75 mm. The three-band gardenslug appears translucent and has a yellow-grey or yellow-violet color. The slug generally has a two pairs of dark bands on either side of the body's midline. The lower pair of bands may be faint in some individuals. The sole of the slug is pale grey in color. The keel of this slug is short and does not extend out to the mantle. The mantle has multiple ridges with what appears to be a fingerprint-like pattern. The pneumostome (breathing pore) is located on the right, in the posterior third of the mantle. The non-sticky, colorless mucus produced by this slug is very watery.

The following species can be separated by dissection and observation of their genitalia:

Lehmannia marginata: The appendix on the penis of this species tapers to a point.

L. valentiana: The appendix on the penis of this species is somewhat tubular or the apex may appear expanded.

Native Range

Iberian Peninsula

Distribution

North America

South America

Europe

Asia: Japan

Africa

Oceania

Ecology

The three-band gardenslug is nocturnal in nature and is often dispersed by human activity. This species inhabits moist habitats and generally comsumes decaying wood and living plant material and is often considered a serious pest in greenhouses. This slug produces copious amounts of slime as a defense mechanism. The oval eggs produced by this species are yellow and measures 2.25 mm wide. There may be as many as 60 eggs per clutch.

Synonyms

- *Limax valentianus* Ferussac, 1821
- *Limax valentiana* Ferussac, 1822
- *L. poirieri* Mabille, 1883
- *L. marginatus* of authors, not Muller, 1774.

References

Anderson 2005; Horsak et al. 2004; Kerney et al. 1979; Roth and Sadeghian 2006; Udaka and Numata 2008

Leptinaria unilamellata

Family

Subulinidae

Species

Leptinaria unilamellata (D'Orbigny, 1835)

Common Name

None reported

Description

This species measures a maximum of 20.6 mm in height, with approximately 6 whorls. The shell ranges from tan to pale brown in color. The aperture (mouth) has denticles (teeth).

Distribution

Pacific Islands: Hawaii

Central and South America: Mexico

Caribbean

Ecology

Leptinaria unilamellata is capable of self-fertilization and has been documented to occur in large numbers wherever it inhabits (e.g., greenhouses). This species is reported to achieve sexual maturity in approximately 104 days and on average will lay as many as 22 eggs per clutch.

Synonyms

- *Achatina lamellata*
- *Tornatellina (Leptinaria) lamellata* Potiez and Michaud

References

Almeida and Bessa 2001; Cowie 1997; Cowie et al. 2008; Jurickova 2006; Robinson et al. 2009; Rosenberg and Muratov 2006

Limacus flavus

Family

Limacidae

Species

Limacus flavus (Linnaeus, 1758)

Common Name

Yellow gardenslug, Cellar slug, Tawny garden slug

Description

As the common name suggests, this slug is yellow in appearance with grayish-green mottling covering the entire body. In contrast, the tentacles are pale bluish or bluish black in color. Adults of the slug range in length from 75 to 115 mm or more. The oval mantle has ridges that appear to have a fingerprint-like pattern. The base color of the mantle is black or dark gray, and the reticulations are yellow-white in color. The pneumostome is located behind the midline of the mantle and is surrounded by a halo. The keel only appears close to the end of the slug's tail. Interestingly, the body mucus is yellowish and very adhesive, while the foot mucus is colorless. The sole of the foot is yellow-white.

Native Range

Southern and Western Europe

Distribution

North America:

- U.S.: California, Kansas, Kentucky, Oklahoma, Wisconsin

Pacific Islands: Hawaii

Australasia: New Zealand

Europe

Ecology

Limacus flavus prefers dark, moist habitats, where it can lay between 12 to 32 eggs per clutch, totaling 60-138 per individual, with each egg measuring 5.0-6.3 mm. This species can be found in diverse habitats ranging from compost piles, gardens and woodlands to greenhouses. The diet includes lichen, fungi and plant material. This species has been reported as an occasional pest in gardens. It has been recorded that *Limacus flavus* display food aversions when the food is suspected to be noxious. This sensitization can be displayed for up to 3 weeks without error.

Synonyms

- *Limax flavus* Linnaeus, 1758. Systema Naturae, Edito decima, reformata 1: 692. Type locality Sweden.
- *Limax variegatus* Draparnaud, 1801. Tabl. Moll. 103.
- *Limacella ungicula* Brard, 1815. Hist. terr. fluv. Environs Paris: 115.
- *Limax megaldontes* Quoy and Gaimard, 1824. Voyage l'Uranie et la Physic. Zool.: 428.
- *Limax umbrosus* Philippi, 1844. Enum. Moll. Siciliae: 102.
- *Krynickillus maculatus* Kaleniczenko, 1851. Bull. Soc. Imp. Nat. Moscou 24: 226.
- *Limax olivacius* Gould, 1852. U.S. Expl. Exped. XII: 4.
- *Limax erenbergii* Bourguignat, 1853. Cat. Moll. Saulcy: 3.
- *Krynickia maculata* P. Fischer, 1856. J. Conchyliol. 5: 69.
- *Limax deshayesi* Bourguignat, 1861. Rev. Mag. Zool. (2)13: 302.
- *Limax companyoi* Bourguignat, 1863. Rev. Mag. Zool. (2)15: 179.
- *Limax breckworthianus* Lehmann, 1864. Malakozool. Bl. 12: 105.
- *Limax beaticus* Mabille, 1868. Rev. Mag. Zool. (2)20: 145.

References

Anderson 2005; Barker 1979; Branson 1962; Branson 1980; Cowie 1997; Forsyth 2004; Kantor et al. 2009; Kerney et al. 1979; Landauer and Cardullo 1983; McDonnell et al. 2009; Roth and Sadeghian 2006; Thomas et al. 2010

Limax cinereoniger

Family

Limacidae

Species

Limax cinereoniger Wolf, 1803

Common Name

Ash-grey slug, Black keel-back slug

Description

This species can attain a length of 300 mm when fully mature. The color of this species is variable. It may be pale grey or light brown to jet-black, except for the tan to white stripe that runs from the posterior edge of the mantle to the tip of the tail. The pneumostome (breathing pore) is located in the posterior half of the mantle. The keel also occurs near the tip of this species.

Note: *L. cinereoniger* has an obvious tripartite sole (the center of the foot is pale and the margins dark) whereas; *L. maximus* has a uniformly white sole. Also, a pale tan to white stripe runs down the back of *L. cinereoniger*, but it is absent in *L. maximus*. Also, juveniles of *L. cinereoniger* may be confused with adult *L. maximus* due to their uniformly colored sole*.*

Native Range

Northern Europe and the Mediterranean region

Distribution

Europe

Ecology

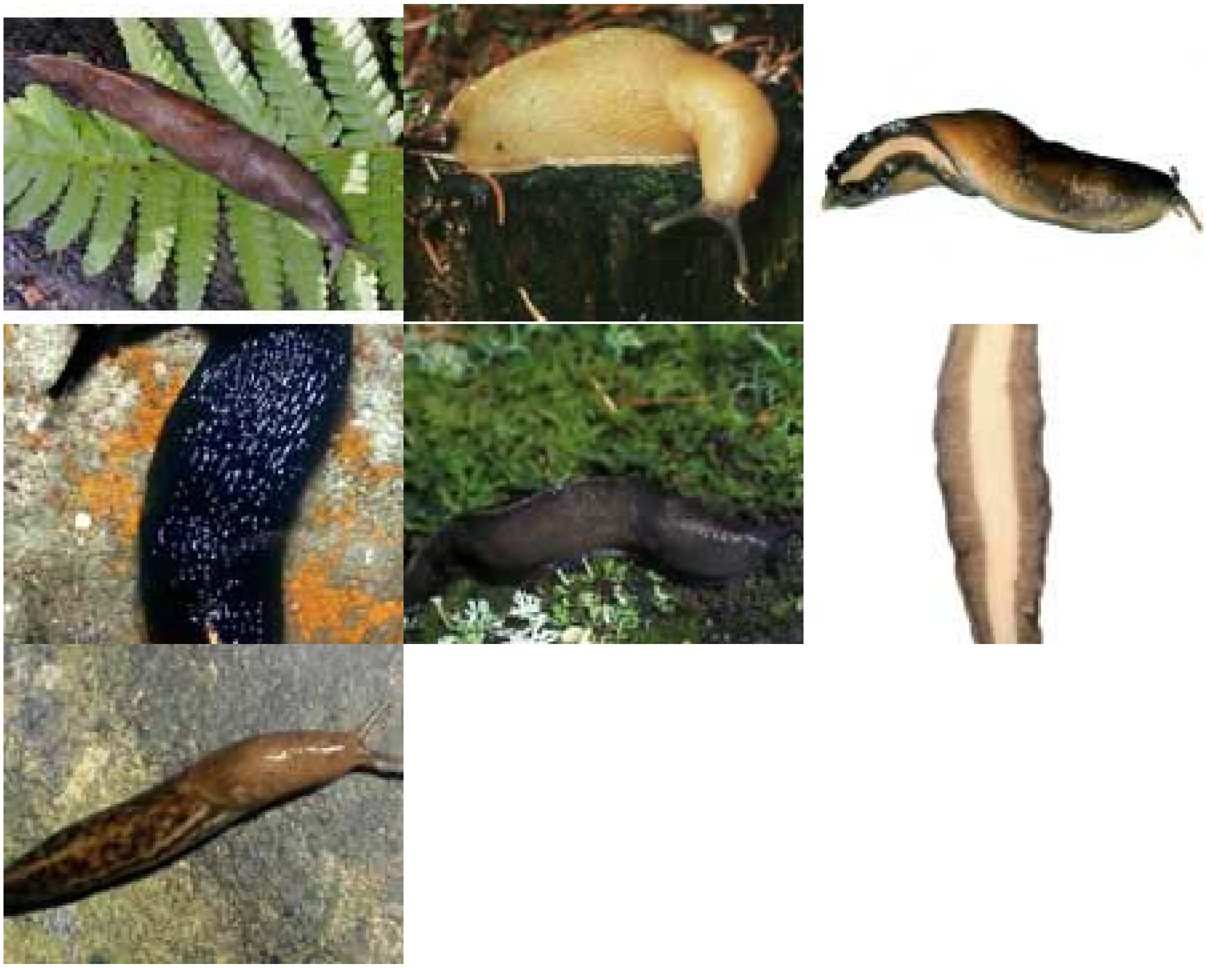
This species generally comsumes algae and mushrooms and should not be considered a pest. This species occurs in woodlands and is not commonly intercepted.

Synonyms

- *Limax antiquorum* Ferussac, 1819 (part)

References

Anderson 2005; Kerney et al. 1979; Quick 1960



Limax maximus

Family

Limacidae

Species

Limax maximus Linnaeus, 1758

Common Name

Giant gardenslug, Great slug, Tiger slug, Spotted leopard slug

Description

This is one of the larger garden slugs, with the potential to grow up to 150 mm or more in length. The body of this slug is yellow-grey or brown in color. It usually has black markings that may resemble spots or stripes. These markings may sometimes coalesce into two or three pairs of stripes that run the length of the body, but never forming a continuous line. The tentacles are red-brown in color. The mantle has a yellow or white base color and it is also patterned with a brown color; however, it never has bands or stripes; instead it is irregularly spotted or mottled. Albino variants of this species do exist. The ridges on the mantle appear to have a fingerprint-like pattern. The pneumostome (breathing pore) is located in the right, posterior margin of the mantle. The keel only occurs near the tip of the tail, and the sole of the foot is creamy white and produces colorless mucus.

Note: *L. cinereoniger* has an obvious tripartite sole (the center of the foot is pale and the margins dark); whereas, *L. maximus* has a uniformly white sole. Also, a pale tan to white stripe runs down the back of *L. cinereoniger*, but it is absent in *L. maximus*. Also, juveniles of *L. cinereoniger* may be confused with adult *L. maximus* due to their uniformly colored sole.

Native Range

Europe, North Africa and Asia Minor

Distribution

North America:

- U.S.: California, Illinois, Kentucky, Oklahoma, Wisconsin

Pacific Islands: Hawaii

Australasia: New Zealand

Europe

Ecology

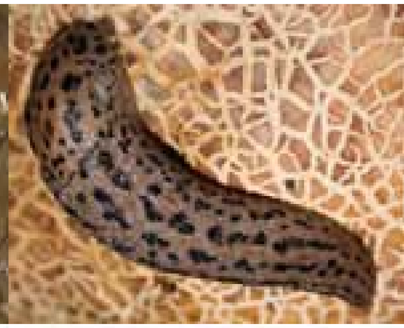
The giant gardenslug prefers habitats modified by humans such as gardens, greenhouses or wooded areas. They prefer damp, shaded places such as beneath rocks or vegetation. They are nocturnal in nature and have a very developed homing behavior. The diet includes fungi, decaying plant material and green plants. They are able to mate while suspended on a thread of mucus and generally produces oval eggs, in clusters (50-130) that are approximately 5-5.5 mm in diameter. The total number of eggs laid by this species throughout its lifetime is roughly 650-850. Mating occurs in spring and autumn. They have a lifespan of approximately three to four years.

Synonyms

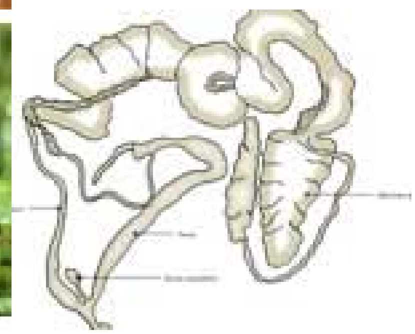
- *Limax maximus* Linnaeus, 1758. Systema Naturae, Edito decima, reformata 1: 652. Type locality Sweden.
- *Limax cinereus* Muller, 1774. Verm. HIst. 2: 5.
- *Limacella parma* Brard, 1815. Hist. terr. fluv. Environs. Paris: 110.
- *Limax antiquorum* Ferussac, 1819. Hist. nat. Moll. II: 68 (part).
- *Limax maculatus* Nunneley, 1837. Trans. Phil. Soc. Leeds I: 46.
- *Limax cellarius* (d'Argenville) Lessona & Pollonera, 1882. Monogr. Limacidae Ital. 1: 23.

References

Anderson 2005; Barker 1979; Branson 1959; Branson 1962; Branson 1980; Cowie 1997; Forsyth 2004; Horsak 2004; Kantor et al. 2009; Kerney et al. 1979; Niemela et al. 1988; Meyer and Cowie 2010; McDonnell et al. 2009; Roth and Sadeghian 2006; Stephenson 1968, Thomas et al. 2010





Limicolaria aurora

Family

Achatinidae

Species

Limicolaria aurora (Jay, 1839)

Common Name

escargot Geant d'Afrique, Nigerian land snail

Description

This snail generally attains a height of 60 mm and a width of 28 mm, with 9-9.5 whorls at maturity. The shell is smooth, dull, oblong-ovate and displays a wide range of colors. The umbilicus (navel) is narrow.

Native Range

East Africa

Distribution

North America: Currently not present, though it is commonly intercepted at U.S. ports

Caribbean: Martinique

Africa: West: Guinea to Nigeria, Cameroun and Gabon

Ecology

Achatinids are generally nocturnal forest dwellers but have the potential to adapt to disturbed habitats. Concealed habitats are generally preferred; however, individuals may colonize more open habitats in the event of overcrowding. Achatinids often become more active during periods of high humidity (e.g., after rainfall); however, the occurrence of large numbers of individuals especially during daylight may indicate high population density.

Achatinids are hermaphroditic and there the introduction of a single mature specimen, into a new habitat, can initiate a new population. Achatinids normally lay their calcareous eggs in the soil, but they may be deposited under leaf litter or rocks. They feed on both living and dead plant material. In addition to being agricultural pests, achatinids can be a threat to public health as they act as a reservoir host of the rat lung parasites (*Angiostrongylus cantonensis* and *A. costaricensis*), which causes eosinophilic meningoencephalitis in humans. They can also be an unsightly public nuisance during periods of population explosion.

This species of Achatinid (*Limicolaria aurora)* has the potential to reproduce in much drier conditions than other species. The eggs are often laid in the soil and have an incubation period of approximately 30 days. This species has been reported to consume the following plants: oil palm, yam (*Dioscorea alata*), black pepper, Jerusalem artichoke, cucumber, okra, rose-mallow, sweet potato and legumes.

Synonyms

References

Abbott 1989; Barker 2002; Ebenso 2006; Cowie et al. 2009; Udoh et al. 1995

Lissachatina fulica

Family

Achatinidae

Species

Lissachatina fulica (Bowdich, 1822)

Common Name

Giant African snail, Achatine, Escargot geant, Caramujo

Description

The shell of this species is generally narrowly conic with 7-10 whorls and may attain a length of 200 mm (averaging 50-100 mm) and a width of 120 mm when fully mature. The color pattern of the shell will vary widely depending on the diet of the animal but will most often consist of alternating bands of brown and tan. The body of the animal is brown-gray in color and it may be able to extend up to 300 mm in length.

Native Range

East Africa

Distribution

North America: Currently not present, though it is commonly intercepted at U.S. ports.

South and Central America: Argentina, Brazil (Sao Paulo, Rio de Janeiro, Minas Gerais), Ecuador, Venezuela

Indian Ocean: Madagascar, Mauritius, Seychelles

Pacific Islands: Hawaiian Islands, Marianas, Bonin, Caroline Islands, Guam, Wake, Society Islands, Vanuatu, Cook Islands, American Samoa, Western Samoa, Micronesia

Caribbean: Guadeloupe, Martinique, St. Lucia, Barbados

Australasia: Bougainville, New Guinea, New Ireland, New Britain, Papua, New Caledonia, Australia (Queensland)

Asia: India, Ceylon, Bangladesh, Malaya, Taiwan, Vietnam, Surinam, Java, Bali, Sulawesi, Moluccas, Flores, Timor, Iran, Jaya, Thailand, Japan, Hong Kong, China

Africa: Ethiopia, Somalia, Mozambique, Morocco, Ivory Coast, Ghana, Annobon, Equatorial Guinea, Sao Thome, Madagascar

Ecology

Achatinids are generally nocturnal forest dwellers but have the potential to adapt to disturbed habitats. Concealed habitats are generally preferred; however, individuals may colonize more open habitats in the event of overcrowding. Achatinids often become more active during periods of high humidity (e.g., after rainfall); however, the occurrence of large numbers of individuals especially during daylight may indicate high population density.

Achatinids normally lay their calcareous eggs in the soil, but they may be deposited under leaf litter or rocks. They feed on both living and dead plant material. In addition to being agricultural pests, achatinids can be a threat to public health as they act as a reservoir host of the rat lung parasites (*Angiostrongylus cantonensis* and *A. costaricensis*), which cause eosinophilic meningoencephalitis in humans. They can also be an unsightly public nuisance during periods of population explosion.

References

Abbott 1989; Barker 2002; Cowie et al. 2008; Cowie et al. 2009; Meyer and Cowie 2010

Lymnaeidae

Family

Lymnaeidae

Species

Radix auricularia (Linnaeus, 1758)

R. peregra (Muller, 1774)

Lymnaea stagnalis (Linnaeus, 1758)

Common Name

Radix auricularia: Big-ear Radix, Ear pond snail

R. peregra: Wandering pond snail

Lymnaea stagnalis: The great pond snail, Stagnant pond snail, Swamp lymnaea

Description

The shells of this freshwater-dwelling group are not patterned and they do not posses an operculum. They will attain a maximum height of 70 mm. The tentacles of these species are characteristically triangular in shape with the small eyes located at the base.

Radix auricularia: The big-ear Radix may be as large as 14-30 mm high and 12-25 mm wide, with 4-5 whorls. The whorls of this species rapidly increase towards the very large body whorl. The shell is slightly glossy and smooth. The thin shell of this species is generally tan to pale yellow. The aperture is ear-shaped and the umbilicus (navel) may be slightly open or closed altogether. The body of the animal may have small white spots on the head and tentacles.

R. peregra: The wandering snail is between 18-20 mm high and 12-13 mm wide. The shell of this species is tan to brown and may possess a blackish cover. The body of the animal is greenish with black and dirty-yellow spots covering it.

Lymnaea stagnalis: This species is very large when compared to the other 2 species in this group. It can attain a height of 45-70 mm and a width of 20-34 mm. The shell is also tan colored and does not have any obvious markings.

Distribution

Radix auricularia

North America:

- U.S.: Massachusetts, New Jersey, New York, Nevada, Pennsylvania, Vermont

Europe: Croatia, Czech Republic, Germany, British Isles, Netherlands, Poland, Slovakia, Ireland (and possibly other countries)

Asia

R. peregra

North America:

- U.S.: Massachusetts, New Jersey, New York, Pennsylvania, Vermont

Europe: Croatia, Czech Republic, Germany, British Isles, Netherlands, Poland, Slovakia, Ireland (and possibly other countries)

Asia

Lymnaea stagnalis

North America:

- U.S.: Illinois, Massachusetts, Michigan, New Jersey, New York, Pennsylvania, Vermont, Wisconsin,

Europe: Croatia, Czech Republic, Germany, British Isles, Netherlands, Poland, Slovakia, Ireland (and possibly other countries)

Asia

Ecology

The species in this group prefers stagnant or very slow moving water with dense vegetation. *R. auricularia* is an intermediate host for a human pharyngeal parasite (*Clinostomum complanatum*).

Synonyms

Radix auricularia:

- *Helix auricularia* Linnaeus, 1758
- *Limnaea auricularia*
- *Lymnaea auricularia* (Linnaeus, 1758)
- *Radix auriculatus* Montfort, 1810

R. peregra:

- *Buccinum peregrum* Muller, 1774
- *Radix labiata* (Rossmassler, 1835)
- *Lymnaea peregra* (Muller, 1774)
- *Lymnaea pereger*

Lymnaea stagnalis:

- *Helix stagnalis* Linnaeus, 1758
- *Limnaea vulgaris* Locard, 1840
- *Limnaea turgida* Locard, 1882
- *Lymnaea stagnalis* var. *ssorensiana* W. Dybowski, 1912
- *Lymnaea stagnalis* var. *subulata angarensis* B. Dybowski, 1912

References

Anderson 2005; Chung et al. 1998; Kantor et al. 2009

Marisa cornuarietis

Family

Ampullariidae

Species

Marisa cornuarietis (Linnaeus, 1758)

Common Name

Giant ramshorn snail, apple snail

Description

The shell of this species on average measures 50 mm wide, with 3.5-4 whorls. The shell of adults generally appears flattened, as the apex does not extend above the body whorl. The juveniles' shell, on the other hand, have a more globose shape and the apex is well above the body whorl. The shell often appears to be bicolored with different color patterns on the dorsal and ventral surfaces. They almost always have 3-6 dark colored stripes; however, an unusual morph exists that is completely yellow. The body of this snail is yellow to grey with black blotches covering the entire body. The rigid structure that is used to block the opening of the shell (operculum) is very small and can be retracted entirely into the shell.

Native Range

Southern and Central America

Distribution

North America:

- U.S.: Alabama, Alaska, Arizona, California, Florida, Georgia, Idaho, Texas

South America

Pacific Islands: Hawaii

Caribbean

Ecology

This omnivorous snail can be found in standing or slow-moving water. The adults lay their orange-colored eggs, measuring 2-3 mm, below the surface of the water. The eggs are often deposited on vegetation in a gelatinous matrix. Clutch size average 210 eggs with an incubation period of approximately 8-24 days. The snail is not hermaphroditic (both sexes exist). There has been evidence of sexual dimorphism, where the males have a more rounded aperture (mouth) and a thicker shell, while the females have an oval-shaped aperture (mouth) and thinner shells. This snail is of concern because of its ability to completely decimate the vegetation in its habitat. They also are capable of outcompeting native species through direct competition and predation on their eggs and young.

References

Barker 2002; Rawlings et al. 2007

Megalobulimus oblongus

Family

Megabulimidae

Species

Megalobulimus oblongus (Muller, 1774)

Common Name

Giant South American snail

Description

The shell of this species will vary in color from brown, to tan, to pinkish. There are no color markings on the shell. It may grow as high as 70-100 mm, with 5.5-6 whorls. The apertural (mouth) lip in adults of this species is pink. The umbilicus (navel) is covered by the columella (lip of mouth). This species is very similar in appearance to the giant African snails; however, obvious differences include:

- The whorl just above the body whorl has a characteristic bulge.
- The body of the animal has a softer, gelatinous texture, when compared to the more leathery feeling of the acahtinids.
- They produce less slime.

Native Range

South America

Distribution

Caribbean: Barbados, Jamaica

South America: Uraguay, Brazil, Argentina

Synonyms

- *Strophocheilus oblongus*

References

Abbott 1989; Rosenberg and Muratov 2006

Microxeromagna lowei

Family

Hygromiidae

Species

Microxeromagna lowei (Potiez and Michaud, 1852)

Common Name

Small brown snail, Citrus snail

Description

The shell of this species is 3-5 mm high and 5.5-8.5 mm wide, with 4.5 whorls. The shell is tan with numerous brown spots of various shades. The lower portion of the shell has narrow stripes that are not continuous. There may be short hairs covering the shells (0.05 mm long). In many empty shells, the hair may be absent due to abrasion of the surface, leaving hair scars. It has a narrow umbilicus. The body of the animal is white with a brown spot at the margin of the mantle.

Native Range

Western Mediterranean region

Distribution

Australasia: Australia

Africa: Canary Islands to Israel and Lebanon

Europe: Italy; Spain; Mediterranean

Ecology

The small brown snail occupies terrestrial and arboreal habitats. It is generally a contaminant of citrus exports from Australia. Shipments to the U.S. have been rejected due to contamination by this species. Both adults and juveniles of this species may be found in citrus trees on the leaves and fruit as well as in the leaf litter below the trees. This complicates management strategies for this species. The small brown snail is also a pest of cereals as they generally aggregate on the leaves and seed head. They contaminate cereal grains and increase the moisture content. This allows for the introduction of secondary fungal pathogens which may produce toxins. The toxins produced by these secondary fungal pathogens may cause fatality and reproductive disorders in humans and cattle. The snail density may attain 4000 snails/m^2. This self-fertile species can mature within 6 weeks and will lay on average 500 eggs per year in the soil.

Synonyms

- *Microxeromagna arrouxi*
- *Microxeromagna vestita*
- *Microxeromagna armillata* (Lowe)
- *Helix lowei* Potiez & Michaud, 1838
- *Helix* (*Xerophila*) *armillata* Lowe, 1852
- *Helix vestita* Rambur, 1868
- *Helix subsecta* Tate, 1879
- *Helicella* (*Candidula*) *mayeri* Gude, 1914

References

Zhao 2004

Milax gagates

Family

Milacidae

Species

Milax gagates (Draparnaud, 1801)

Common Name

Greenhouse slug, Keeled slug

Description

Fully mature adults of this species may be as long as 70 mm. The body of the animal may be grey-brown to black, gradually becoming lighter in color towards the foot. There are no obvious markings on the body of neither the adults nor juveniles. The mantle is large and may be slightly granular with a horseshoe-shaped groove in the center. There may also be 16-17 grooves between the keel and the pneumostome (breathing pore). The breathing pore is located in the posterior half of the mantle. There is a very prominent keel on the back of the animal, extending from the posterior edge of the mantle to the tip of the tail. The sole is tripartite: blackish with a pale median. There are "v"-shaped grooves along the median line of the sole. The mucus produced by this slug is clear.

Native Range

Western Mediterranean, Western Europe and the Canary Islands

Distribution

North America:

- U.S.: eastern North America, Pacific Northwest, California

South America

Australasia: New Zealand, Australia

Asia: Japan, Sri Lanka

South Africa

Europe: Britain, Mediterranean region

Ecology

Milax gagates has been reported to be very destructive in Hawaii where it is decimating rare, native plants in Haleakala National Park (Hawaiian Islands). The keeled slug is known to cause yield reduction in soybean, sunflower and oilseed rape, by causing damage to seeds and seedlings. This pest species is capable of burrowing and often damages the roots and lower stems of plants (e.g., carrot, potato). The eggs are laid in tunnels made below the soil surface. Clutch size may be as few as 16. The incubation period for the eggs is approximately 25 days, juvenile mature within about 4-5 months.

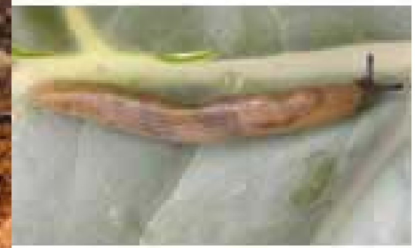
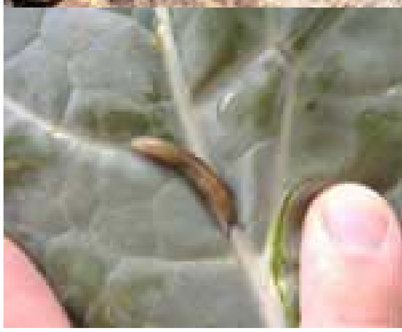
Synonyms

- *Limax gagtes* Draparnaud, 1801. Tableau des mollusques terrestres et fluviatiles de la France: 100. Type locality? Montpellier.
- *Limax maurus* Quoy and Gaimard, 1824. Voyage L'Uranie et la Physic. Zool.: 427.
- *Limax fulginosus* Gould, 1852. U.S. Expl. Exped. XII: 5.
- *Milax antipodarum* Gray. 1855. Cat. Pulmonata Brit. Mus. 1: 177.
- *Limax pectinatus* Selenka, 1865. Mal. Blatt.: 105.
- *Milax hewstoni* Cooper, 1872. Proc. Acad. Nat. Sci. Philad.: 147.
- *Milax emarginata* Hutton, 1879. Trans. N.Z. Inst. 11: 331.
- *Milax tasmanicus* Tate, 1881. Pap. Proc. R. Soc. Tas.: 16.
- *Milax nigricolus* Tate, 1881. Pap. Proc. R. Soc. Tas.: 17.
- *Amalia antipodarum* var. *pallida* Cockerell, 1891. Ann. Mag. Nat. Hist. VII: 340.
- *Amalia parryi* Collinge, 1895. J. Malac. 4(1): 7.
- *Amalia babori* Collinge, 1897. Proc. Malac. Soc. Lond. 2(6): 294.

References

Anderson 2005; Barker 1979; Barker 1999; Clemente et al. 2010; Cowie et al. 2009; Kerney et al. 1979; Naggs et al. 2003



Monacha spp.

Family

Hygromiidae

Species

Monacha cantiana (Montagu, 1803)

M. cartusiana (Muller, 1774)

M. syriaca (Ehrenberg, 1831)

Common Name

Monacha cantiana: Kentish snail, Kentish garden snail

Monacha cartusiana: Carthusian snail, Chartreuse snail

Monacha syriaca: None reported

Description

Monacha cantiana: The medium sized shell of this snail is 10.5 to 14 mm high and 15.5 to 20 mm wide with 5 1/2 - 6 whorls. The shell has a narrow umbilicus (navel-like opening at the base of the shell), is globosely depressed, and slightly transparent. The top of the shell is somewhat whitish in color and becomes progressively brownish toward the base. This thin shell is glossy in appearance and possess fine, weak, irregular lines and courser growth wrinkles. The aperture of the shell is broadly lunate while the lip is slightly expanded and shortly dilated at the columellar insertion. A narrow white or brown rib strengthens this insertion.

Monacha cartusiana: This species is smaller than *C. cantiana*. It has a shell that is approximately 6-10 mm high and 9-17 mm wide with 5.5-6.5 whorls. The shell is pale white or pale yellow in color and may have brown stripes. The aperture of the shell may be darker than the rest of the body.

Monacha syriaca: The shell of this species is 7-9 mm high and 8-13.5 mm wide, with 4.5-5.5 whorls. The brown shell has a white spiral stripe and a white lip. The apertural lip (mouth) may be red-brown and the umbilicus (navel) is closed. The body of the animal is tan to pale yellow with brown antennae.

Native Range

M. cantiana: Mediterranean region and Northwestern Europe

M. cartusiana: Mediterranean region and Southeastern Europe

M. syriaca: Mediterranean region

Distribution

North America:

- U.S.: Delaware (*M. cartusiana*), North Carolina (*M. syriaca*)
- Canada: Quebec, Ontario

Europe: Netherlands, West Germany, France, England

Ecology

This group of snails prefers dry, grassy areas (e.g. road sides, pastures). *Monacha cartusiana* is an intermediate host for livestock parasites including that of the sheep lungworm disease. *Monacha syriaca* is a pest of ornamental plants in shade houses in Israel (e.g., Butcher's broom/ horse-tongue (*Ruscus hypoglossum*), cast-iron plant (*Apidistra elatior*). Both plant species are used in gardens elsewhere.

Synonyms

Monacha cantiana:

- *Helix cantiana* Montagu, 1803, Testace Britannica p. 422, Suppl. Pl. 23, fig. 1.; F. R. Latchford, 1885, Amer. Nat. 19: 1111.; A. W. Hanham, 1896, Nautilus, 10: 99.
- *Fruticicola cantiana* Montagu, W. G. Binney, 1886. 2nd Suppl. Terr. Moll., Bull. Mus.Comp. Zool., 13: 23, pl. 1, fig. 13.
- *Helix cantiana* var. *minor* Moq., Cockerell, 1889, Nautilus 3: 87.
- *Theba cantiana* (Montagu) , Taylor, 1917, Monogr. L. & Freshw. Moll. Brit. Is., pt. 23, p. 78.

Monacha cartusiana:

- *Helix cartusiana* Muller, 1774

Monacha syriaca:

- *Helix syriaca* (Ehrenberg, 1831)

References

Anderson 2005; Kantor et al. 2009; Kerney et al. 1979; Pislbry 1939; Robinson 1999; Robinson and Slapcinsky 2005

Otala spp.

Family

Helicidae

Species

Otala lactea (Muller, 1774)

O. punctata (Muller, 1774)

Common Name

Otala lactea: Milk snail, Milky snail

Otala punctata: Spanish snail

Description

Otala lactea: The diameter of *Otala lactea's* shell ranges from 27.5 to 36 mm and the height ranges from 16 to 25 mm. The non-globular, slightly depressed shell is whitish or brownish and has darker stripes that are speckled. These white specks are very close to each other. The discoloration on the shell may also be either uniformly distributed or it may posses darker fine or gray mottling in the stripes. The surface of the shell is minutely dented or punctuated and has very fine, partly indistinct spiral striations. This species has a distinct apertural lip. The aperture and peristome are liver-brown to black in color. The umbilicus (navel) is inconspicuous. The body of the animal is tan to grey-brown.

Otala punctata: This species is morphologically similar to *O. lactea* ; however, *O. punctata* shell ranges from 33 to 39 mm wide and 20 to 24 mm high.

These species can be separated by:

- *O. lactea: A* denticular tooth is present on the columella of the shell. The entire apertural lip of the opening (mouth) is very dark brown.
- *O. punctata: D*enticular tooth absent. The upper region of the apertural lip of the opening (mouth) is very pale (tan to white), with the remainder being brown.

Native Range

O. lactea: Northern Africa and Spain

O. punctata: Spain and Southern France

Distribution

North America:

- U.S.: Arizona, California, Florida, Georgia, Louisiana, Mississippi, Texas

South America: Argentina

Caribbean: Bermuda, Cuba, Jamaica

Australia

Africa

Europe: Spain

Other: Mediterranean region

Ecology

Otala spp. are noctural foliage feeders. *Otala lactea* has been reported to feed on papaya, lily, anise, broccoli, cabbage, cauliflower, celery, lettuce and yucca plants. This edible snail is often consumed in the Mediterranean region. The milk snail generally exists in rocky heath lands and steppes. The Spanish snail prefers agricultural areas and coastal plains.

Synonyms

Otala lactea:

- *Helix canariensis* Mousson, 1872
- *Helix ahmarina* Mabille, 1883
- *Helix jacquemetana* Mabille, 1883

Otala punctata:

- Helix *punctata* (Muller, 1774)

References

Abbott 1989; Cowie et al. 2009; Pilsbry 1939

Ovachlamys fulgens

Family

Chronidae

Species

Ovachlamys fulgens (Gude, 1900)

Common Name

Jumping snail

Description

The jumping snail's shell is 5-7 mm wide, with 4-5 whorls. The foot of the snail is tripartite. It also has a characteristic horn near the tip of its tail that it often uses to catapult itself away from perceived danger.

Native Range

Japan

Distribution

North America:

- U.S.: Florida

South and Central America: Costa Rica

Pacific Islands: Hawaiian Islands

Caribbean: Trinidad

Asia: Japan

Ecology

This snail has been recorded to be a pest of ornamental plants such as orchids, *Heliconia* sp. and *Dracaena* sp. The jumping snail can live for as long as 9 months. It has the potential to self-fertilize and begin oviposition as soon as 42 days post hatching, with a total clutch size of 165 eggs throughout its life.

References

Barrientos 1998; Barrientos 2000; Cowie et al. 2008; Cowie et al. 2009; Robinson and Slapcinsky 2005; Stange 2004




Oxychilus spp.

Family

Zonitidae

Species

Oxychilus alliarius (Miller, 1822)

O. cellarius (Muller, 1774)

Common Name

Oxychilus alliarius: Garlic glass-snail

O. cellarius: Cellar glass-snail

Description

Oxychilus alliarius: This species is approximate 3.4-4 mm high and 5-8 mm wide with 4-4 1/2 whorls. The shell is smooth, glossy and has wide umbilicus (navel). The shell is reddish brown and living animals emit a garlic odor when disturbed. The body color of the animal is blue-black.

Oxychilus cellarius: The narrowly umbilicate shell of this snail has a height of approximately 4.2 mm and a width of 9-14 mm. The nearly smooth shell is depressed and heliciform. As its common name suggests, the shell has a translucent pale yellow-brown color with the umbilicus being even paler and more opaque. The smooth, glossy umbilicus is approximately 1/6th the width of the shell and the shell has a total of 5 1/2-6 whorls. The entire body of the snail, including the tentacles, is grey, with the sides and the sole being paler. The pneumostome has small brown freckles around it. There is a groove that runs parallel to the edge of the foot. The groove on each side of the animal has a row of small brown specks running alongside it. Characteristically, this snail does not emit a garlic odor and its body is much paler than other species in the genus (*Oxychilus*).

These species may be confused with a similar species (*Oxychilus draparnaudi*) that is carnivorous. The cellar glass-snail (*Oxychilus cellarius*) shell is much larger than that of *O. alliarius* and smaller than that of *O. draparnaudi*. Also, the convex spire of *O. cellarius* is flatter than that of *O. alliarius*.

Native Range

Western Europe

Distribution

Oxychilus cellarius:

North America:

- U. S.: California, Colorado, Connecticut, Delaware, District of Columbia, Illinois, Indiana, Maine, Massachusetts, Michigan, Missouri, New Hampshire, New York, New Jersey, Oregon, Pennsylvania, Rhode Island, South Carolina, Utah, Virginia, Wisconsin

Australasia: New Zealand

Canada: Nova Scotia, Quebec, Ontario

Asia

North Africa

Europe

Oxychilus alliarius:

North America: Canada: Nova Scotia, Quebec, Ontario

Australasia: New Zealand

South America: Columbia

Asia

North Africa

Europe

Ecology

Oxychilus alliarius: This gregarious species can be found in humid habitats (e.g., meadows, cultivated areas, greenhouses). It consumes living and dead plant material as well as small snails and their eggs.

Oxychilus cellarius: This species prefer to live in association with human activities and can be found in parks, gardens, under rocks, rubbish, wood, cellars, plant material an around greenhouses. This animal can be found year round with peak breeding activities occurring in autumn and they may be found in abundance. They often produce small white eggs that are roughly 1.5 mm in diameter. In addition to vegetation, this species will feed on the eggs of other snails, slugs, and earthworms.

Synonyms

Oxychilus alliarius:

- *Helix alliarius* Miller, 1822

Oxychilus cellarius:

- *Helix cellaria* Muller, 1774, Hist. Verm., 2: 28 (wine cellars of Copenhagen).
- *Helix glaphyra* Say, 1816 [Nicholson's] Amer. Edit. British Encycl., art Conchology, No. 5, pl. 1, fig. 3 (garden in Philadelphia).
- *Zonites cellarius* Muller, Leidy, 1851, Terr. Moll., 1: 233, pl. 7, fig. 1; W. G. Binney, 1878, Terr. Moll., 5: 112, pl. 2, fig. G (teeth); 1885, Man. Amer. Land Sh., p. 448:, figs. 493, 494.
- *Oxychilus cellarius* Muller, Ellis, 1926, British Snails, p. 245, pl. 12, figs. 10-12.
- *Oxychilus pulchro-striatum* MacMillan, 1940, Amer. Midland Nat., 23: 731, figs. 2-4 (Duquesne Bluff, Pittsburg, Pa.)

References

Anderson 2005; Hutchinson and Heike 2007; Kerney et al. 1979; Meyer and Cowie 2010; Naggs et al. 2003

Pallifera costaricensis

Family

Philomycidae

Species

Pallifera costaricensis (Morch, 1857)

Common Name

Costa Rica mantleslug

Description

This species can attain a length of 45 mm. It is pale tan to brown in color, with dark colored markings on the sides. Towards the head of the animal, there is a band (running the width of the body) that is jet-black and thick. The sole is undivided, but the edge is dark gray. The tentacles also are dark gray. It should be noted that this species has an extensive mantle that covers the entire back (excluding the head) of the animal.

Native Range

Central America

Distribution

South and Central America

Ecology

This species has been intercepted in cut flowers.

References

Baker 1930

Parmacella ibera

Family

Parmacellidae

Species

Parmacella ibera Eichwald, 1841

Common Name

Melon slug, Vine slug

Description

This slug is often mistaken for a snail as the shell is often exposed. This thick-walled shell is very narrow with a smooth apex. The shell of this species does not coil (possess whorls). It typically has a brownish yellow color with many tubercles and wrinkles in the aperture (opening). The body of the animal is brown with dark brown bands running the length of the mantle. The animal is generally 32 mm long. The mantle covers most of the body and can measure up to 20 mm.

Native Range

Mediterranean region (Iberian peninsula)

Distribution

Europe

Asia: Georgia, Armenia, Iran

Africa: Egypt, Libya

Ecology

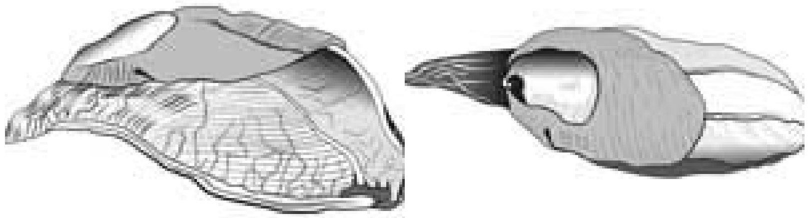
This slug is a serious pest of citrus in Iran. It may also cause damage to field-grown tomatoes, cabbage, melons, pumpkins and cucumber. This species will go into diapause during the warm season and will deposit eggs as deep as 50 mm below the soil surface.

Synonyms

- *Parmacella olivieri* var. *ibera* Eichwald, 1841
- *Parmacella olivieri* sensu Simroth, 1883 non Cuvier, 1804
- *Parmacella simrothi* Germain, 1912
- *Clathropodium vitrinaeformis* Westerlund, 1897

References

Kantor et al. 2009



Physella acuta

Family

Physidae

Species

Physella acuta (Draparnaud, 1805)

Common Name

European physa, Left-handed pondsnail, Acute baldder snail, Ashy physa, Lateritic physa, Pewter physa, Tadpole snail, Pewter physa

Description

The European physa has a sinistral (left-handed) shell that is 7-12 mm high and 7-10 mm wide, with 5-6 whorls. This snail has a very large body whorl, relative to the rest of the shell. The height of the body whorl accounts for approximately 75 % of the total height of the shell. The vacant shell has a tan color, but in living specimens the body whorls appears mottled (black and tan spots and blotches). The aperture (mouth) is oval and may have a white rib. The opaque shell has a pointed spire and does not have a rigid structure blocking the opening of the shell (operculum). The body of the animal is blue-grey in color with innumerable dark spots.

Distribution

North America:

- U.S.: Wyoming

Australasia: Australia, New Zealand

Asia: Hong Kong

Europe: Croatia, Germany, Netherlands, Czech Republic, Britain, Ireland

Other: Mediterranean region

Ecology

This species inhabits shallow, warm, standing fresh water in very high densities. It is able to withstand polluted water and is often introduced inadvertently into new habitats by humans. This species is very adaptable and is recorded as a serious pest of both economic plants in greenhouses and filtering vegetation in sewage treatment plants.

Synonyms

- *Haitia acuta*
- *Physella heterostropha* (Say, 1817)
- *Physa globosa* Haldeman, 1841
- *Physella integra* (Haldeman, 1841)

References

Albrecht et al. 2009; Anderson 2003; Anderson 2005; Cope and Winterbourn 2004; Semenchenko et al. 2008




Polygyra cereolus

Family

Polygyridae

Species

Polygyra cereolus (Muhlfeld, 1816)

Common Name

Southern flatcone snail

Description

There is considerable variation in the shell size of *Polygyra cereolus*. The height ranges from 3.5-4.6 mm and the diameter ranges from 11.5-18.2 mm. The number of whorls for this species also varies from 7-9. The discoidal shell is white with radial streaks or spots of gray or light brown on the base, giving the shell a uniform wood-brown or fawn-colored appearance. The upper surface of the shell may be completely flat or it may be slightly raised (conical) with obliquely regular rib striations. The lower side of the shell is nearly flat or slightly concave with a vortex-like umbilicus (navel). The last whorl is swollen at the end (near the aperture). The keel is weak or completely absent. The outer and basal margins of the peristome (margin/edge of the mouth) is reflected and thickened on the inside, giving it a heart-shaped appearance. The parietal margin is slightly raised, free and possesses a short, oblique tooth.

Native Range

Florida

Distribution

North America:

- U.S.: Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Texas, Wisconsin

South America: Mexico

Pacific Islands: Hawaii

Atlantic Islands: Bermuda

Caribbean: Cuba

Ecology

This species is reported to feed on red and white clover (*Trifolium* spp.) and alfalfa (*Medicago sativa*).

Synonyms

- *Helix cereolus* J. C. Megerle von Muhlfeld, 1818, Gesellschaft naturforschender Freunde zu Berlin, Magazin etc., 8: 11, pl. 2, fig. 18a, b; Binney, 1959, Terr. Moll., 4: 90, pl. 77, fig. 23 (copy from Muhfeld); Bland, 1860, Ann. Lyc. Nat. Hist. N.Y., 7: 137, fig. 2.
- *Hellix cereolus* var. *laminifera*, W. G. Binney, 1858, Proc Acad. Nat. Sci. Phila. P. 200, nude name; cf. Bland, 1860 and Binney, 1869.
- *Helix microdonta* Desh., W. G. Binney, 1859, Terr. Moll., 4: 91, in part.
- *Helix carpenteriana* Bland, 1860, Ann. Lyc. Nat. His. N.Y., 7: 138.
- *Polygyra carpenteriana* Bland, W. G. Binney, 1878, Terr. Moll., 5: 284, fig. 182, pl. vi, fig. m (teeth).
- *Polygyra cereolus* Muhlfeld, W. G. Binney, 1878, Terr. Moll., 5: 283, fig. 181; Rhoads, 1899, Nautilus, 13: 44.

References

Abbott 1989; Cowie 1997; Kalmbacher et al. 1979; Pilsbry 1940; Perez and Cordeiro 2008; Pilsbry 1940

Pomacea spp.

Family

Ampullariidae

Species

Pomacea canaliculata (Lamarck, 1822)

P. glauca (Linnaeus, 1758)

P. insularum (d'Orbigny, 1835)

P. lineata (Spix, 1827)

P. haustrum (Reeve, 1856)

P. diffusa (Blume, 1957)

Common Name

Apple snails

Pomacea canaliculata: Golden applesnail, South American ampullarid, Channeled applesnail, Miracle snail

P. insularum: Island applesnail

Description

Pomacea spp.

Traditionally, apple snails have been diagnosed by characters of the shell, operculum and siphon. In recent years, these characters have been proven to be unreliable in differentiating species. As such, molecular techniques have been developed to distinguish between species.

The globose shell of this group of snails ranges from 45-75 mm in height and 40-60 mm in width, with 4-6 whorls, depending on the species. The aperture is oval to round. The color of this species also varies: yellow to green to brown. There may or may not be brown-black spiral bands on the shell.

There is a single native species of apple snail in the U.S, *Pomacea paludosa*. It can be found in wetlands in Florida, Georgia and more recently, Alabama. This should not be confused with the introduced species. A species comparison follows:

Pomacea paludosa: Clutch size: up to 30; Egg Color: freshly laid eggs are salmon colored in a gelatinous matrix then they become pink-white and calcified; Incubation Period: 15-28 days; Time to Maturity: undocumented; Longevity: undocumented.

P. canaliculata: Clutch size: 25-1000; Egg Color: bright pink; Incubation Period: 7 days - 6 weeks; Time to Maturity: 55 days to 12 months; Longevity: up to 5 years.

P. glauca: Clutch size: 30-90; Egg Color: green; Incubation Period: 14-17 days - 6 weeks; Time to Maturity: 8-13.5 months; Longevity: up to 3 years.

P. insularum: Clutch size: undocumented; Egg Color: pink-red; Incubation Period: undocumented; Time to Maturity: undocumented; Longevity: undocumented.

P. lineata: Clutch size: 100; Egg Color: pink-red; Incubation Period: 15 days; Time to Maturity: undocumented; Longevity: undocumented.

P. haustrum: Clutch size: 236; Egg Color: bright green and polygon-shaped; Incubation Period: 9-30 days; Time to Maturity: approximately 1 year; Longevity: undocumented.

P. diffusa: Clutch size: undocumented; Egg Color: tan to salmon (white when just laid) and honey-comb shaped; Incubation Period: undocumented; Time to Maturity: undocumented; Longevity: undocumented.

Native Range

South America

Distribution

North America:

- U.S.: Alabama, Arizona, California, Florida, Georgia, Texas

South and Central America

Pacific Islands: Hawaii, Guam

Caribbean: Dominican Republic

Australasia: Papua New Guinea

S.E. Asia: China, Singapore, Sri Lanka

Africa

Ecology

Apple snails are serious pests of aquatic ecosystems. They are generally found in fresh water habitats, though these species are known to tolerate low levels of salinity. This group is often dispersed by human activity through the pet trade or through their use as a food source. These snails are a threat to wetland ecosystems as they are generalist feeders and as such they have the potential to outcompete and displace other snail species. These snails are omnivorous and will consume vegetation, and all life stages of other snail species. Apple snails are known to be amphibious; however they will spend considerable periods in terrestrial habitats. This behavior facilitates disperal in both terrestrial and aquatic habitats. *Pomacea canaliculata* species is of concern to the U.S. as they may pose a risk to the rice producing area of the U.S. (e.g., Texas and Louisiana).They often are pest of rice and taro in other regions of the world.

Generally *Pomacea* species prefer standing or slow moving water (e.g., marshes, lakes and rivers). It has been reported that *Pomacea canaliculata* inhabits standing water, but P*. insularum* prefers faster moving water (e.g., rivers). Also, both species may be separated by egg characteristics: the eggs of *P. canaliculata* are larger and fewer than *P. insularum* (which lays more than 1000 eggs per clutch). Apple snails are diecious, meaning that both sexes occur separately. Sexual dimorphism has also been documented in some species; in the females the shells are often larger than that of males. *Pomacea* spp. prefer to lay their eggs above the water line on vegetation or on other substrates like rocks.

Synonyms

Pomacea canaliculata:

- *Ampullaria canaliculata* Lamarck, 1822.

References

Barker 2002; Barnes et al. 2008; Cowie 2000; Cowie 2001; Cowie et al. 2009; Pain 1960; Peebles et al. 1972; Rawlings et al. 2007; Thiengo 1987

Praticolella griseola

Family

Polygyridae

Species

Praticolella griseola (Pfeiffer, 1841)

Common Name

Vagrant scrubsnail, Vera cruz shrubsnail

Description

The tan to brown-gray, umbilicate (possess a navel-like opening), flattened shell of this species varies in height 6-11 mm and diameter 8-13.7 mm. There are 4-5 1/2 whorls. The shell may be glossy in color with faint oblique striations. There are several pale tawny stripes that have a white color on each margin. The spire is short. The umbilicus (navel) is very narrow and the aperture (mouth) lunate. The peristome (edge of the mouth) is simple, white and a little reflected, with the columellar margin slightly extended.

Native Range

Northern and Central America

Distribution

North America:

- U.S.: Florida, Texas

Central America: Mexico

Caribbean: Cuba, Dominican Republic, Jamaica

Ecology

This species has been intercepted on shipments from the Dominican Republic to the U.S on the leguminous plant, guar gum (*Cyamopsis tetragonolobus*) .

Synonyms

- *Bradybaena pisum* Beck, 1837, Index, p. 18, not described, Pfeiffer, 1. c. in synonymn.
- *Helix griseola* Pfeiffer, 1841, Symbolae HIst. Hel., 1: 41, Conchyl. Cab., *Helix,* p.342, pl. 60, figs. 17, 18; Monogr. Hel. Viv., 1: 337.
- *Helix cicercula* Ferussac, in coll., = griseola according to Pfeiffer, Monogr. Hel. Viv., 1: 337.
- *Helix albocincta* A. Binney, 1851 Terr. Moll., 1: 109, 128, name only.
- *H. albolineata* "Binney", Gould 1857, Terr. Moll, 3: 34 (referring to Terr. Moll. 3, pl. 49, fig. 2), as var of berlandieriana.
- *H. albo-zonata* A. Binney, 1857, Terr. Moll., 3, pl. 49, fig. 2
- *Dorcasia griseola* Pfeiffer, W. G. Binney, 1878, Terr. Moll., 5: 348, fig. 231(jaw), pl. vii, fig. v (teeth).
- *H. berlandieriana* var. *griseola* Pfeiffer, Von Martensis, 1892., Biol. Centr.-Amer., Moll., p. 140, pl. 7, figs. 15-17.

References

Abbott 1989; Perez and Cordeiro 2008; Pilsbry 1940; Rosenberg and Muratov 2006

Prietocella barbara

Family

Cochlicellidae

Species

Prietocella barbara (Linnaeus, 1758)

Common Name

Scrubsnail, Banded conical snail, Small pointed snail, Potbellied helicellid

Description

The shell of this species is generally 8-12 mm high and 5-8 mm wide, with 7-8 whorls. The shell color is also variable, ranging from off-white to grey to pale yellow. Dark-colored spots or stripes may also be present.

Native Range

Mediterranean region

Distribution

North America:

- U.S.: may be in California (verification required)

Australasia: New Zealand, Australia

Atlantic Islands: Bermuda

South Africa

Europe: southwest Britain, Belgium, coastal areas of France

Other: Mediterranean Basin

Ecology

This snail will cause severe damage to small grain and seedling production. It is also a pest in legume-based pastures in Australia and is especially damaging to annual medics, alfalfa and clovers.

Synonyms

- *Cochlicella barbara* (Linneaus, 1758)

References

Barker 2002; Hitchcox and Zimmerman 2004; Kerney et al. 1979

Prophysaon andersonii

Family

Anadenidae

Species

Prophysaon andersonii (Cooper, 1872)

Common Name

Reticulate taildropper

Description

A mature, adult slug can attain a length of approximately 64 mm. The pale brown, red-grey or yellow body of the slug is usually clouded with darker shades. The tentacles are usually dark brown. This slug has a characteristic diamond-mesh pattern on the dorsal surface of its body, due to the arrangement of the tubercles. The pale, finely granulated mantle often has two, dark lateral lines running its length. The pneumostome (breathing pore) is anteriorly or medially located on the mantle. The fringe of the foot is pale and does not possess any dark bands; however, faint lines may be observed. The sole is brilliant white to dirty white with a highly contrasting mucus color (lemon yellow to orange). The tail is acute in shape. When contracted, the body of the slug is tadpole-shaped.

The genus *Prophysaon* has nine recognized species. According to Pilsbry's (1948), there are two species groups (subgenera) in this genus:

1. *Prophysaon*: In this group, the epiphallus is extremely long and slender except it enlarges abruptly near the insertion in the penis.

- *P. boreale* (Northern taildropper): Body finely reticulate, with pale dorsal line. Penis not much shorter than muscular body of the epiphallus.

- *P. foliolatum* (Yellow-bordered taildropper): Body finely reticulate, with pale dorsal line. Penis much shorter than muscular body of the epiphallus. Large species (~ 90 mm).
- *P. andersonii* (Reticulate taildropper): Body finely reticulate, with pale dorsal line. Penis much shorter than muscular body of the epiphallus. Small species (~ 64 mm).
- *P. coeruleum* (Blue-gray taildropper): Body not finely reticulate, no pale dorsal line. Muscular body of the epiphallus very short. Uniform blue-gray slug.
- *P. dubium* (Papillose taildropper): Body not finely reticulate, no pale dorsal line. Muscular body of the epiphallus long. Purple-gray slug.

2. *Mimetarion*: In this group, the epiphallus is of moderate length and slender. Initially, the epiphallus is much wider than the vas deferns, but tapers where both structures meet.

- *P. fasciatum* (Banded taildropper): Vagina and spermathecal duct slender and very long. Penis sac broad.
- *P. obscurum* (Mottled taildropper): Vagina and spermathecal duct slender and very long. Penis sac narrow.
- *P. vanattae* (Scarlet-backed taildropper): Vagina and spermathecal duct stout and very short. Cavity of epiphallus possess two longitudinal ridges.
- *P. humile* (Smoky taildropper): Vagina and spermathecal duct stout and very short. Cavity of epiphallus possess one longitudinal ridge.

Native Range

North America

Distribution

North America:

- U.S.: Alaska to California and east to Idaho
- Canada: British Columbia

Ecology

This slug will occur in wooded areas, gardens and disturbed habitats. It has the ability to self-amputate and regenerate its tail. The site of potential amputation characteristically has a diagonal constriction and a may appear as a dark line on the sole of the foot.

Synonyms

- *Arion andersonii*, Cooper, 1872, Proc. Acad. Nat. Sci. Phila., p148, pl. 3, figs. F1-5.

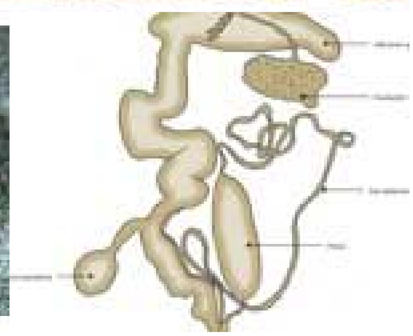
- *Prophysaon hemphilli* Bland & Binney, 1873, Ann Lyc. N.H. of N.Y., 10: 295, pl. 13, figs. 2, 4, 6-8; W.G. Binney, 1878, Terr. Moll., 5: 238, figs. 137-139, pl. v, fig. 1 (teeth), pl. xiii, fig. h (genitalia), "specimens from Mendocino county" excluded.
- *P. pacificum* Cockerell, 1890, Nautilus 3: 111., 1891, Nautilus, 5: 31; 1897, 11: 77; W.G. Binney, 1890, Third Suppl., Bull. M.C.Z., 19: 210, pl. 7. Figs. B,F,H.
- *P. flavum* Cockerell, 1890
- *P. andersonii var pallidum* Cockerell, 1891, Nautilus, 5:31
- *P. andersonii* var. *marmoratum* Cockerell, 1892, The Conchologist, 2: 72
- *P. andersonii* var *suffusum* Cockerell, 1893, The Conchologist, 2: 118; 1897, Nautilus, 11: 79

References

Forsyth 2004; Ovaska et al. 2004; Pilsbry 1948







Pupisoma dioscoricola

Family

Valloniidae

Species

Pupisoma dioscoricola (Adams, 1845)

Common Name

Yam babybody

Description

The small, subglobose shell of this species is approximately 1.95 mm high and 1.8 mm wide with 2.5-3.25 whorls. The upper whorls are granulated. The cinnamon-colored shell is thin, slightly translucent, smooth and glossy. This species can be separated from other species in this genus by the presence of distinct spiral striations on the shell and the first couple of whorls are large.

Native Range

Asia

Distribution

North America:

- U.S.: Florida, Texas

South and Central America

Pacific Islands: Galapagos Islands

Caribbean: Cuba, Jamaica, Haiti, Trinidad

Synonyms

- *Helix dioscoricola* Adams, 1845. Proc. Boston Soc. N. H., ii. p. 16
- *Helix punctum* Morelet, 1851. Von Martens, Biol. Centr. Amer., Moll., p. 131, pl. 7, f. 3-3b
- *H. caeca* Guppy, 1868. Proc. Sci. Asso. Trinidad, p. 241.; Amer. Journal. Conch., vi, p. 307
- *Microphysa dioscoricola* Binney, 1890
- *Pupisoma americanum* Moellendorff, 1899
- *Pupisoma dioscoricola insigne* Pilsbry, 1920
- *Pupisoma puella* Hylton Scott, 1960
- *Helix dioscoricola* Pfriffer, 1848
- *Helix (Conulus) dioscoricola* Tryton, 1886
- *Thysanophora dioscoricola* Pilsbry, 1894
- *Pupisoma dioscoricola* Pilsbry, 1920
- *Pupisoma (Ptychopatula) dioscoriicola* Haas 1937
- *Ptychopatula dioscoricola* Paul and Donovan, 2005

- *Helix punctum* Fischer and Crosse, 1872
- *Helix (Microconus) punctum* Tryon, 1887
- *Thysanophora punctum* Pilsbry 1894
- *Helix caeca* Dall 1889
- *Helix (Acanthinula) caeca* Tryon 1887
- *Patula (Ptychopatula) caeca* Pilsbry, 1889
- *Thysanophora dioscoricola* caeca Rhoads, 1899
- *Pupisoma dioscoricola insigne* Baker, 1925
- *Ptychopatula dioscoricola insigne* Tillier, 1980
- *Pupisoma puella* Quintana, 1982
- *Pupisoma (subgenus?) minus* Hass, 1960
- *Pupisoma minus* Oliveira and Almeida, 1999

References

Abbott 1989; Anderson 2005; Hausdorf 2007; Kantor et al. 2009; Pilsbry 1920; Rosenberg and Muratov 2006

Rumina decollata

Family

Subulinidae

Species

Rumina decollata (Linnaeus, 1758)

Common Name

Decollate snail

Description

The shell of mature specimens can attain a maximum length of 45 mm and a width of 14 mm. It is reasonably easy to detect mature specimens of this species, as they are characteristically "decollate-shaped". Upon maturity, adult specimens intentionally break off the tip of the shell, leaving it with a blunt end. There are generally 4-7 whorls in adult specimens. An additional 3-4 whorls may be observed in juveniles of this species.

Native Range

Mediterranean region

Distribution

North America:

- U.S.: Arizona, California, Florida, Georgia, North Carolina, South Carolina, Texas

Central and South America: Mexico

Europe

Caribbean: Bermuda, Cuba

Other: Mediterranean Region

Ecology

The decollate snail has been employed as biological control for pestiferous snail and slugs for many years. This species will rarely consume plant material. This generalist predator will feed indiscriminately and has been implicated in the decimation of native gastropods (including non-pest species) and beneficial annelids. Sexual maturity occurs at approximately 10 months. Each adult is capable of laying 500 eggs throughout its lifetime. The eggs are deposited singly in the soil and will hatch between 10-45 days.

Synonyms

- *Bulimus decollatus* Draparnaud, 1805
- *Helix decollata* Linnaeus, 1758
- *Orbitina incomparabilis* Germain, 1930
- *Orbitana truncatella* (Germain, 1930)

References

Abbott 1989; Anderson 2005; Burch 1962

Subulina octona

Family

Subulinidae

Species

Subulina octona (Bruguière, 1798)

Common Name

Thumbnail awlsnail, Miniature awlsnail

Description

This species measures 14-17 mm high, with 8-9 whorls. The shell is long and narrow with a small, ovate aperture (mouth). The shell of this species is thin, translucent and glossy. The color ranges from colorless to pale yellow-brown. The body of the animal is pale yellow. This species may be confused with *Allopeas gracile;* however, *Subulina octona* is larger and has a truncated columella.

Native Range

Tropical America

Distribution

Pacific Islands: Hawaii

Central and South America: Mexico

Europe

Asia: Sri Lanka

Caribbean

Ecology

This species have been documented to occur in large numbers wherever it inhabits, and often occur in greenhouses.

References

Almeida and Bessa 2001; Burch 1962; Anderson 2005; Cowie 1997; Cowie et al. 2008; Juricková 2006; Kerney et al. 1979; Naggs et al. 2003; Robinson et al. 2009; Rosenberg and Muratov 2006

Succineidae

Family

Succineidae

Species

Succinea campestris Say, 1818

S. costaricana von Martens, 1898

S. horticola Reinhardt, 1877

S. putris (Linnaeus, 1758)

Indosuccinea tenella (Morelet, 1865)

Calcisuccinea luteola Gould, 1848

C. dominicensis (Pfeiffer)

Oxyloma elegans (Risso, 1826)

Common Name

Ambersnails

Succinea campestris: Crinkled ambersnail

S. costaricana: None reported.

S. horticola: None reported.

S. putris: Large ambersnail

Indosuccinea tenella: None reported

Calcisuccinea luteola: Mexico ambersnail

C. dominicensis: Dominican ambersnail

Oxyloma elegans: Pfeiffer's ambersnail

Description

Ambersnails are very difficult to distinguish. Morphological and molecular techniques are usually required to separate the different species. A common species in this group is *Succinea campestris*. The shell of this snail has a dull appearance due to the faint, irregular microscopic granulation present on the exterior surface. The height of the shell ranges from 9.4 -17 mm and the width 6.8-11.5 mm totaling 3 1/3-3 1/2 whorls. The shell is very compact at the top as a result of a very short spire. The overall shape of the shell is oval and the base of the shell is wide as a result of the very large aperture (mouth). The whitish shell has gray streaks. In some cases the shell may be gray in color with light yellow streaks or tint. The wrinkles on the shell are low and wide. The sutures on the shell are deeply prominent. The interior surface of the shell cream colored or white.

Calcisuccinea luteola: Shell succiniform, averaging a height of 12.5 mm and a width of 6 mm, with 4 whorls. The shell of juveniles may be yellow-green to tan in color. In adults it is gray to white, with the inside of the shell sometimes having a yellow color. Aperture (mouth) ovate.

C. dominicensis: The succiniform shell of this species can attain a height of 10 mm and a width of 7 mm, with 3.25 whorls. The shell is generally tan to pale brown in color, smooth and glossy. This species has a thicker shell than other species.

Oxyloma elegans: The shell of this species may be 9-12 mm high, occasionally 18 mm, with 3 whorls. The color of the shell varies from light brown to black. The pale morphs generally have a dark-colored markings on the shell.

Native Range

S. campestris: North America

S. putris: Europe and Siberia

O. elegans: Holarctic

Distribution

Succinea spp.:

North America*:*

- U.S.
- Canada

Pacific Islands: Hawaii

Europe

Calcisuccinea luteola:

North America:

- U.S.: from Louisiana west to Arizona

South and Central America

Caribbean: Haiti, Dominican Republic

C. dominicensis:

Caribbean: Haiti

Oxyloma elegans:

Europe: Britain, Ireland

Ecology

In general, *Succinea* spp. and *Indosuccinea* spp. consume algae and moss, and occasionally higher plants. *Succinea costricana* colonize leaf litter and other moist microhabitats. Additionally this species is attracted to lights, which is highly unusual for snails. This species has been noted as a quarantine pest of ornamentals (*Dracaena* species) because of its propensity to remain attached to leaves. It can reproduce by self-fertilization and lays few eggs; however, it lays year round.

Calcisuccinea spp. are considered significant pests of fruit and horticultural crops. They have been detected in greenhouse and nursery production of fruit and ornamental crops, on the other hand *Indosuccinea* spp. are typically found in wetlands (e.g., marshes). These species are prolific and can rapidly achieve pest status.

Synonyms

Succinea campestris:

- *Succinea campestris* Say 1817, Jour. Acad. Nat. Sci. Phila., 1:281 (Sea Islands of Georgia and Cumberland Island; Amelia Island, N.E. Florida; Binney, 1851, Terr. Moll., 2: 67, pl. 67b, fig. 1.
- *Succinea inflata* Linnaeus 1844, Trans. Amer. Philos. Soc., 9: 5; Obs. Genus Unio, 4: 5 (South Carolina)

S. putris:

- *Helix putris* Linnaeus, 1758
- *Succinea amphibia* Draparnaud, 1801

Calcisuccinea luteola:

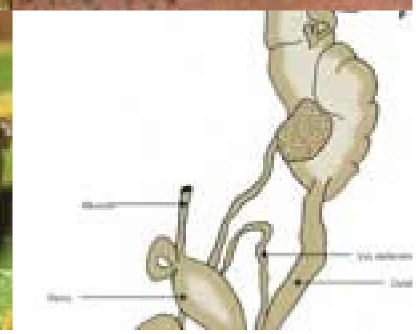
- *Succinea (Calcisuccinea) luteola luteola* Gould, 1848
- *Succinea luteola* Gould, 1848
- *Succinea texasiana* Pfeiffer, 1848
- *Succinea citrina* Shuttleworth

References

Anderson 2005; Cowie et al. 2008; Cowie et al. 2009; Kantor et al. 2009; Villalobos et al. 1995; Perez and Cordeiro 2008; Pilsbry 1948






Tandonia spp.

Family

Milacidae

Species

Tandonia budapestensis (Hazay, 1881)

T. sowerbyi (Ferussac, 1823)

T. rustica (Millet, 1843)

Common Name

Tandonia budapestensis: Keeled slug, Budapest slug

Tandonia sowerbyi: None reported.

Tandonia rustica: Bulb-eating slug, Root-eating slug

Description

Tandonia budapestensis: Mature, fully extended members of this species will be between 50-70 mm long. The body color of this species is variable. Typically the animals appears black at fist glance; however, it has a pale cream or orange background with very dense, dark-colored speckling. This species has a distinct olive or pale orange-colored keel that extends from the tip of the tail to the posterior margin of the mantle. The pneumostome is located in the posterior half of the mantle and has a grey border. There is also a horseshoe-shaped groove in the center of the mantle. The sole is tripartite: dark in the middle and pale on either side. The foot mucus is colorless. This slender slug often coils into a 'C' shape when it is not active. Other species in this family will contract their bodies into a dome-shape at rest.

Tandonia sowerbyi: Fully extended specimens of this species will be approximately 60-75 mm. The body of the animal is pale or dark brown. Unlike *T. budapestensis* this species has dark blotches all over its body. The keel is pale in color, and the grooves between the tubercles are pigmented. The breathing pore has a pale border. The pale sole of this animal produces a contrasting yellow mucus.

Tandonia rustica: This slug can measure up to 100 mm long when fully extended. The color of the bulb-eating slug is variable ranging from off-white to dirty yellow to reddish. All color morphs have multiple black flecks. Similar to the other two species describe in this fact sheet. Typical of the *Tandonia* genus, this species also has a pale colored (yellowish to white) keel. The very large mantle occupies approximately 40 % of the animal's body length. There is a lateral, black streak in the horseshoe-shaped groove in the mantle. The cream-colored sole of this species produces colorless mucus. When disturbed, this species produces thick, milky mucus.

Native Range

Tandonia budapestensis: Eastern Europe

T. sowerbyi: Western Europe and the Mediterranean region

T. rustica: Central and Southern Europe

Distribution

North America:

- U.S.: Pennsylvania, Washington D.C.

Australasia: New Zealand (except *Tandonia budapestensis*)

Europe

Ecology

These species commonly occurs in greenhouses, gardens, ploughed fields and woods. They have the capability to burrow into the soil at depths of 37 cm. All species are known to eat living plant material. *Tandonia budapestensis* has been recorded to be a pest of potatoes, other root crops and ornamental plants.

Synonyms

Tandonia budapestensis:

- *Milax gracilis* (Leydig, 1876)
- *Limax gracilis* Leydig, 1876. Arch. Naturgesch. 62(1): 276 (not Rafinesque, 1820).
- *Amalia budapestensis* Hazay, 1881. Die Mollusken-fauna von Budapest, Malakozool. Bl. (n.s.) 3: 37. Type locality Budapest.
- *Amalia cibiniensis* Kimakowicz, 1884. Verh. Mitth. siebenb. Ver. Naturwiss. 33: 220.

Tandonia sowerbyi:

- *Milax sowerbyi* (Ferussac, 1823)
- *Limax sowerbyi* Ferussac, 1823. Histoire nayurelle generale et particuliere des mollusques terrestres et fluviatiles (Nouvelle division de pulmones sans opercule) 2: 96. Type locality London.
- *Limax carinatus* Risso, 1826. Nat. Hist. Moll. Medit.: 56.
- *Limax marginatus* Jefferies, 1862. Brit. Conchol. I: 132 (not Muller, 1774; not Draparnaud, 1805).
- *Amalia marginata* (not Muller, not Draparnaud) var *mongianensis* Paulucci, 1879. Esc. Scient. Calabria: 23.
- *Amalia tyrrena* Lessona & Pollonera, 1882. Monogr. Limacidae Ital.: 56.
- *Amalia maculata* Collinge, 1895. Proc. Malac. Soc. Lond. 1(7): 336.
- *Amalia collingei* Hesse, 1926. Abh. Arch. Moll. 2(1): 139.

Tandonia rustica:

- *Limax rustica* Millet 1843
- *Limax marginatus* Draparnaud 1805

References

Anderson 2005; Barker 1979; Cowie et al. 2009; Horsak 2004; Reise et al, 2006; Wiktor 1996

Testacella haliotidea

Family

Testacellidae

Species

Testacella haliotidea Draparnaud, 1801

Common Name

Shelled slug, Earshell slug

Description

The length of this semi-slug ranges from 80-120 mm. The body of this animal is light grayish-brown (sometimes yellowish), with a pale foot fringe and sole. The small (approx. 7-8 x 5-6 mm) external shell of this animal is located on the dorso-posterior tip of the tail. Members of this group (Testacellidae) characteristically have two distinct, lateral (branched) grooves that originate from the anterior margin of the much-reduced shell.

Two addition species in this group have been reported from Europe and may be distinguished by the following characters:

T. haliotidea: Morphology-the dorsal lateral grooves are approximately 2 mm apart at the point of origin. Genitalia-the penis has a flagellum and the spermathecal duct is short and thick.

T. maugei: Morphology-shell larger than both species (12-16 mm long by 6-7 mm wide) and the dorsal lateral grooves are approximately 5 mm apart at the point of origin. Genitalia-the penis does not have a flagellum, and the spermathecal duct is long and thin.

T. scutulum: Morphology-the shell is of similar size to that of *T. haliotidea* and the dorsal lateral grooves join (just under the shell) before reaching the the point of origin. Genitalia-the penis does not have a flagellum and the spermathecal duct is intermediate between those of *T. haliotidea* and *T. maugei*.

Native Range

Western Europe and Western Mediterranean region

Distribution

North America:

- U.S.: California
- Canada

Australia: Australia, New Zealand

Europe

Caribbean: Cuba

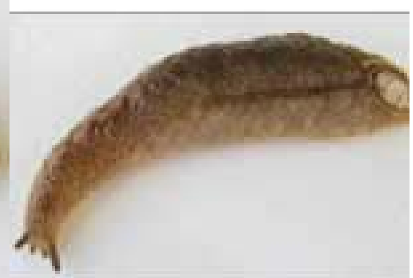
Ecology

This carnivorous semi-slug spends most of its time underground, where it hunts and consumes earthworms, snails and slugs. The shelled slug is commonly found in disturbed habitats like gardens, parks and agricultural fields. This slug is able to burrow to depths of up to one meter during periods of aestivation. This animal has not been reported to feed on plant material and as such should not pose a threat to agricultural produce. The ecological impact that this species may have on other terrestrial mollusc species has not been documented.

Synonyms

References

Anderson 2005; Barker 1979; Barker 1999; Kerney et al. 1979; McDonnell et al. 2009

Theba pisana

Family

Helicidae

Species

Theba pisana (Muller, 1774)

Common Name

White garden snail, Mediterranean sandsnail, Sandhill snail, White snail

Description

The tough, opaque shell of this species is slightly flattened (low spire). The height of the shell is 13 mm and width 18 mm with 4 1/2 whorls. However, some specimens may be smaller. The ivory yellow shell may be uniform or it may possess unequal brown stripes. These stripes or lines may be interrupted forming dots or dashes. The dull surface has fine growth lines. However, the embryonic 1 1/2 whorls are smooth.

Native Range

Mediterranean region and Western Europe

Distribution

North America:

- U.S.: California

Atlantic Islands: Bermuda, Canary Islands

Australia

Europe: Western France, Southwestern England and Wales, Ireland

Asia: Iran

Africa: South Africa, Somaliland

Other: Mediterranean region

Ecology

Typically this snail is found in coastal, sandy areas. *Theba pisana* has the potential to increase in number rapidly. This species has been deemed a serious pest and and may be a nuisance because of its ability to aggregate in large numbers. It may occur in numbers of up to 3000 in one tree. This snail possesses the ability to defoliate large trees, including citrus and ornamentals. It also consumes garden crops, seedlings and cereal grains (e.g., wheat, barley, oil seeds, seed carrot and legumes). In grain producing areas this species will cause direct and indirect losses. Direct losses include clogging machinery and directly consuming the crop. Indirect losses include contaminating the grain and allowing for the infestation of the grain by secondary fungal pathogens, due to the added moisture they provide.

Theba pisana generally lays its eggs several inches below the soil surface with an average of 70 eggs per clutch. It takes approximately 20 days for the eggs to incubate; however, it may take longer in dry weather. This snail typically does not seek cool, dark places to aestivate. They preferentially attach to plants, fences, under stones or other vertical, physical structures. Longevity: 2 years.

Synonyms

- *Helix pisana* Muller, 1774, Verm. Hist., 2: 60; Taylor, 1911, Monogr. L. & Freshw. Moll. Brit. Is., 3:360, pl. 30, 31; Orcutt, 1919, Nautilus, 33:63.

References

Anderson 2005; Barker 2002; Cowie et al. 2009; Hitchcox and Zimmerman 2004; Pilsbry 1939; Mead 1971; Rumi and Sanchez 2010; Yildirim et al. 2004

Trochoidea pyramidata

Family

Hygromidae

Species

Trochoidea pyramidata (Draparnaud, 1805)

Common Name

Pyramid snail

Description

The shell of this species ranges from 6-9 mm high and 8-11 mm wide with 4.5-7 whorls. The slightly glossy, white shell may have brown stripes or spots. The aperture (mouth) of the shell has a white lip inside. The umbilicus (navel) is narrow in this species. The body of the animal is tan to grey.

Native Range

Western Palearctic region

Distribution

North America:

- U.S.: North Carolina

Europe

Synonyms

- *Helix nova* Paulucci, 1879
- *Helix radiata* Retowski, 1889
- *Helix platiensis* Sturany, 1902
- *Helix vernicata* Westerlund, 1902
- *Helicella subplatiensis* Germain, 1936

References

Abbott 1989; Robinson and Slapcinsky 2005

Trochulus hispidus

Family

Hygromiidae

Species

Trochulus hispidus (Linnaeus, 1758)

Common Name

Hairy snail

Description

The shell of this small snail is 4-6 mm high and 5-12 mm wide, with 6-7 whorls. The slightly translucent shell is tan to brown. It is also covered with a dense mat of short, curved hairs. The hairs may be absent in vacant shells (due to abrasion); however, hairs will remain attached and visible in the open umbilicus (navel). The body of the animal is tan to grey-black.

Native Range

Europe

Distribution

North America: Canada

Europe: Czech republic, Netherlands, Poland, Slovakia, Great Britain, Ireland

Ecology

This species can occur in a wide variety of habitats.

Synonyms

- *Trichia hispida*

References

Anderson 2005; Kerney at al. 1979



Trochulus striolatus

Family

Hygromiidae

Species

Trochulus striolatus (Pfeiffer, 1828)

Common Name

Strawberry snail

Description

The somewhat flattened (low spire) shell of the strawberry snail measures 6.5-9 mm high and 11-15 mm wide, with 6 convex whorls. The growth ridges of this species are very prominent. The shell is dark brown or red-brown. Light brown spots/flecks may be present. The umbilicus (navel) is obvious. The shells of juveniles of this species are hairy, but the shells of adults lack hair.

Native Range

Northwestern Europe

Distribution

Europe: England, Scotland, Wales, Ireland, Netherlands, Slovakia

Ecology

This species is often associated with human dwellings (e.g., in gardens, on buildings/hedges). As its common name suggests, this species is a pest of strawberries.

Synonyms

- *Trichia striolata*

References

Anderson 2005; Daw and Ivison; Kerney et al. 1979

Urocyclus flavescens

Family

Urocyclidae

Species

Urocyclus flavescens (Keferstein, 1866)

Common Name

African banana slug

Description

The color of this slug is variable, ranging from pale yellow, lemon-yellow, green-yellow, yellow-brown to gray. The mantle is typically greenish, and generally covers the anterior third of the dorsum. The dorsal surface is typically uniform in color, except for two faint lateral stripes. In rare cases, there may exist a third stripe medially. A mixture of color variants typically exists in a single population. This slender slug will attain a maximum length of 60 mm. The body of the African banana slug quickly tapers from front to back, giving an unusually angular appearance to the posterior section of the animal. A keel is absent. There are also minute longitudinal grooves on the dorsum. These grooves are transected by shorter transverse grooves. There is a prominent caudal pore at the posterior end of the animal. The middle of the animal is characteristically vaulted (humped), causing the tail to appear narrower than the body. The sole of the foot is tripartite with the middle appearing narrower than the sides. The foot fringe is typically uniform (no vertical bands).

Native Range

East Africa

Distribution

Africa: Southern

Ecology

The African banana slug has been documented as a pest of banana. This slug will damage the fruit by rasping at the peel. This results in necrotic scaring which reduces the marketability (reduced sales and outright rejection of the fruit) of the fruit. Entire bunches can be lost, and losses of greater than 10 % is not atypical. It can be found in banana plantations, forests (inside and at the edge), dune forest and gardens. The slugs do not seem to have microhabitat preferences, and they can be found out in the open, in grass, under logs and buried between the hands on banana bunches. This species colonize habitats ranging from sea level up to an altitude of 1400 m. This species is nocturnal and lays its eggs during spring. The eggs can be found buried in the soil or under plant material. Hatching commences during spring rains if favorable conditions prevail. The juveniles then proceed up banana plants where they would feed. The juveniles of *Urocyclus flavescens* are drought resistant. During periods of drought, they have the ability to survive several months in aestivation, both in the soil and under plant material on the ground.

Synonyms

- *Parmarion flavescens* Keferstein, 1866. Malak. Bl., 13: 70, pl. 2 figs. 1-8.
- *Elisolimax rufescens* Simroth

References

Barker 2002; Forcart 1967; Hausdrof 2000; Van Bruggen and Appleton 1977


Veronicellidae: Belocaulus angustipes

Family

Veronicellidae

Species

Belocaulus angustipes Heynemann, 1885

Common Name

Black-velvet leatherleaf, Paraguayan black-velvet leatherleaf

Description

This slug can measure up to 55 mm when fully extended. It is jet black in color with similarly colored tentacles. There is a pale, inconspicuous tan stripe down the center of the back, which may not be visible. The mantle extends over the entire length of the body. The dorsal surface of the mantle may appear velvety or wrinkled. The pneumostome (breathing pore) and anus is located posteriorly. The foot appears tripartite because the mantle of this species has black flecks along the margins.

Native Range

South America

Distribution

North America:

- U.S.: Alabama, Florida, Louisiana, Mississippi

South America

Ecology

This nocturnal pest species consumes a wide variety of plants. It can inhabit greenhouses, grassy fields and nurseries. It is also known to be an intermediate host for the nematode *Angiostrongylus costaricensis*, causative agent of the rat lung disease, oesinophilic meningoencephalitis. It is commonly found in St. Augustine grass. This species can live up to 5 years.

Synonyms

- *Veronicella ameghini* Gambetta

References

Neck 1976; Thome 1989; Walls 2009

Veronicellidae: Diplosolenodes occidentalis

Family

Veronicellidae

Species

Diplosolenodes occidentalis Guilding, 1825

Common Name

Spotted leatherleaf slug

Description

Mature specimens of *Diplosolenodes occidentalis* have the potential to extend up to 60 mm. This species characteristically have black speckling on the dorsal surface of its grey-colored body; however, juveniles lack this pigmentation. In rare cases adult specimens may also lack the characteristic speckling. The ocular tentacles are dark colored and the sole is pale grey.

Native Range

Lesser Antilles

Distribution

North America:

- U.S.: Introduced to greenhouses in Oklahoma, but apparently not established in the U.S.

South and Central America

Caribbean: Lesser Antilles, Greater Antilles

Ecology

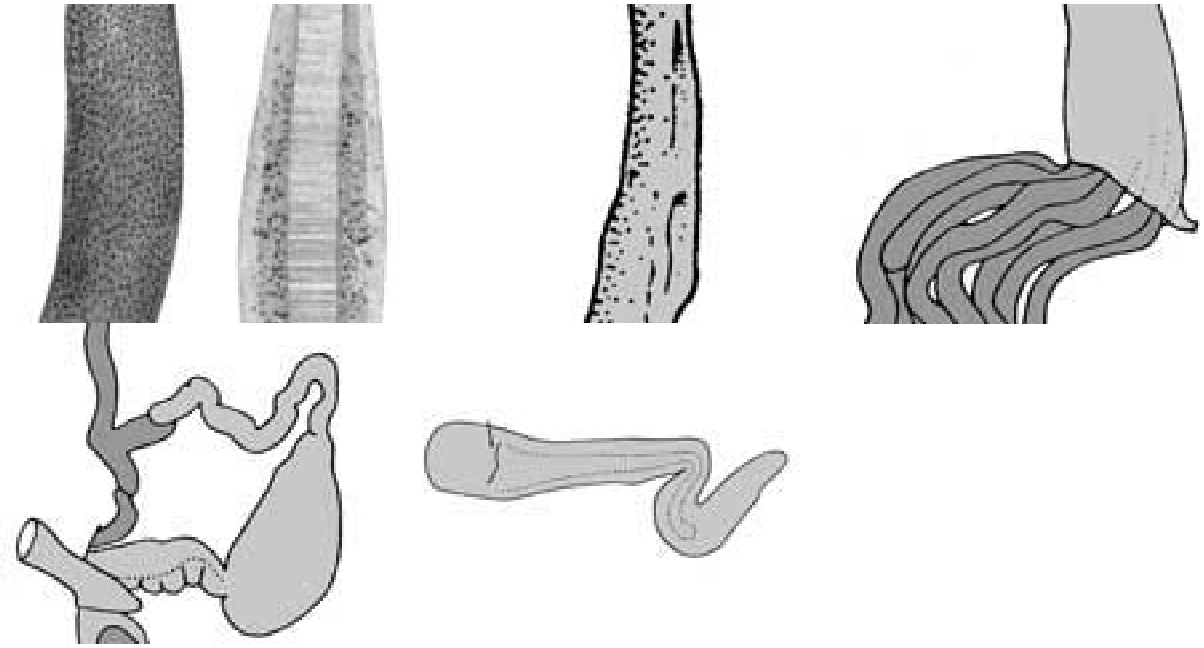
The spotted leatherleaf slug prefers undisturbed environments; however, it may be observed in agricultural areas where it is generally a minor pest of perennial crops. Crop species eaten include Brassicaceae (e.g., cabbage), pepper, lettuce, tomato and beans.

Synonyms

- *Vaginula occidentalis* Angas, 1884
- *Vaginulus occidentalis*
- *Vaginula punctatissima* (Semper) Pilsbry 1892
- *Diplosolenodes occidentalis* Thome, 1997.
- *Veronicella occidentalis* Guildingm, 1825
- *Veronicella lavis* (Ferussac)

References

Branson 1962; Cowie et al. 2009; Robinson et al. 2009; Rosenberg and Muratov 2006; Thome 1989



Veronicellidae: Phyllocaulis gayi

Family

Veronicellidae

Species

Phyllocaulis gayi (Fischer, 1871)

Common Name

None reported.

Description

This pale, tan-colored slug can get as large as 100 mm long and 20 mm wide. It typically has a cream colored-colored line running the entire length of the body. There may be grey speckling on its dorsum, creating a greyish-colored animal. The tentacles appear blue or silver in color.

Native Range

South America

Distribution

South and Central America: Mexico, Chile

Ecology

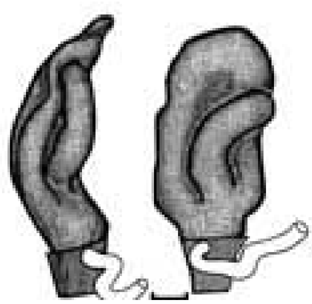
This granivorous (seed eating) species has been observed feeding on the seeds of the peanut plant (*Arachis hypogea*), and that of the trees *Cryptocarya alba* and *Aetoxicum punctatum*. This species may be considered an ecological pest, especially in forest regeneration.

Synonyms

- *Vaginula gayi* Fischer, 1871 in Fischer, 1871. Revision des especes du genere *Vaginula* Ferussac. Nouvelles Archives du Museum d'Historie Naturelle. Paris. 7: 147-175.
- *Vaginula* (*Phyllocaulis*) *gayi* Fischer, 1871 in Baker, 1925. North American Veronicellidae. Proceedings of the Academy of Natural Sciences of Philadelphia. 77: 157-184.
- *Phyllocaulus gayi* (Fischer, 1871) in Thome, 1971. Redescricao dos tipos de Veronicellidae (Mollusca, Gastropod) neotropicais: VII especies depositadas no Museum National d'Histoire Naturelle, Paris, Franca. Iheringia (Zool.) 40: 27-52.

References

Naranjo-García et al. 2007; Rodrigues Gomes et al. 2009; Simonetti et al. 2003; Thome 1989



Veronicellidae: Sarasinula spp.

Family

Veronicellidae

Species

Sarasinula plebeia (Fischer, 1871)

S. dubia (Semper, 1885)

S. marginata (Semper, 1885)

Common Name

Sarasinula plebeia: Caribbean leatherleaf slug, Bean slug

S. dubia: None reported.

S. marginata: None reported.

Description

Sarasinula plebeia: This species is grey-brown with small black markings. It can attain a maximum length of 70 mm. The Caribbean leatherleaf slug can be mistaken for the Florida leatherleaf slug (*Veronicella* aff. *floridana*), but *S. plebeia* can be distinguished by the location of the female genital pore (away from the foot) and the absence of the pale median line down the back of the animal.

Native Range

Sarasinula plebeia: Brazil and the West Indies

Distribution

Sarasinula plebeia:

North America:

- U.S.: Florida

South and Central America

Pacific Islands: New Caledonia

Caribbean: Dominica, Jamaica, Grenadines (Canouan)

S. marginata:

South America: Brazil, Peru, Columbia

Caribbean: Dominica, Guadeloupe

Ecology

Sarasinula plebeia: This is a serious pest of agriculture in Central America. In South America this slug consumes legume pods and flowers, as well as the foliage of beans, sweet potato, cabbage, *Cucurbita* sp., tomato, coffee, weedy species in the genus *Borreria*, and the fruit of papaya. In many cases, this pest species has been known to eat young plants to the ground on farms. Plant nurseries that grow tree species like mahogany and red cedar have also been affected by this species. This slug can transmit the nematode *Angiostrongylus costaricensis*, which is pathogenic to humans.

*Sarasinula ple*beia can bury itself in the soil to a depth of up to 100 cm in order to protect itself from desiccation during the dry season. In Texas it has shown the potential to survive sub-freezing temperatures. This hermaphroditic slugs can reproduce by self-fertilization. It can lay up to 80 eggs per clutch. The oval, translucent eggs have an incubation time of 20-24 days at 27 degrees Celsius. Adulthood can be attained in 2-5 months and the adults can live for more than a year.

S. marginata: This species has been reported to feed on dasheen (*Colocasia esculenta*) in the field. This slug is a minor pest of agriculture in Dominica. The genitalia may be used to distinguish this species from *Sarasinula plebeia* and *S. dubia*.

Synonyms

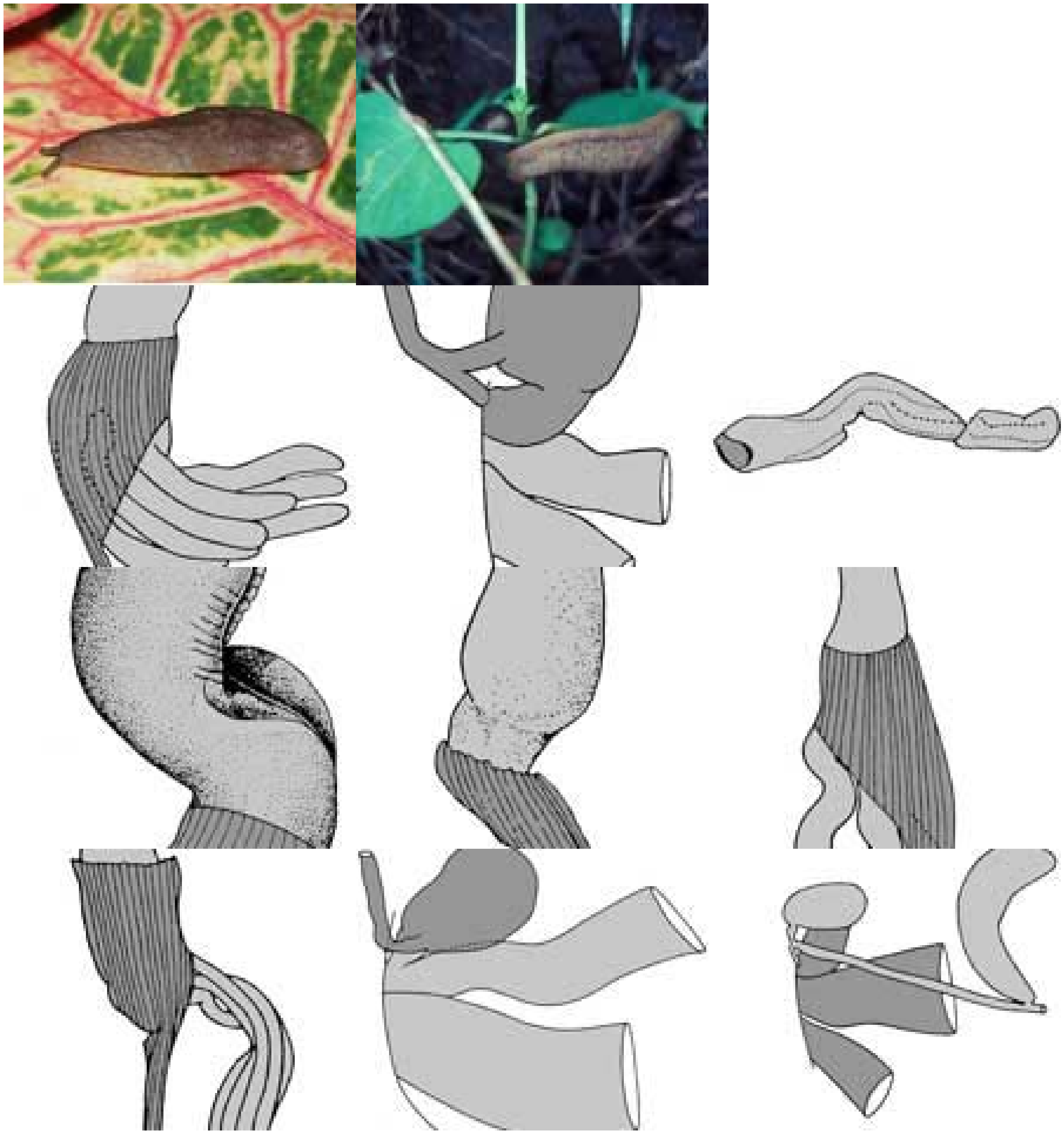
Sarasinula plebeia:

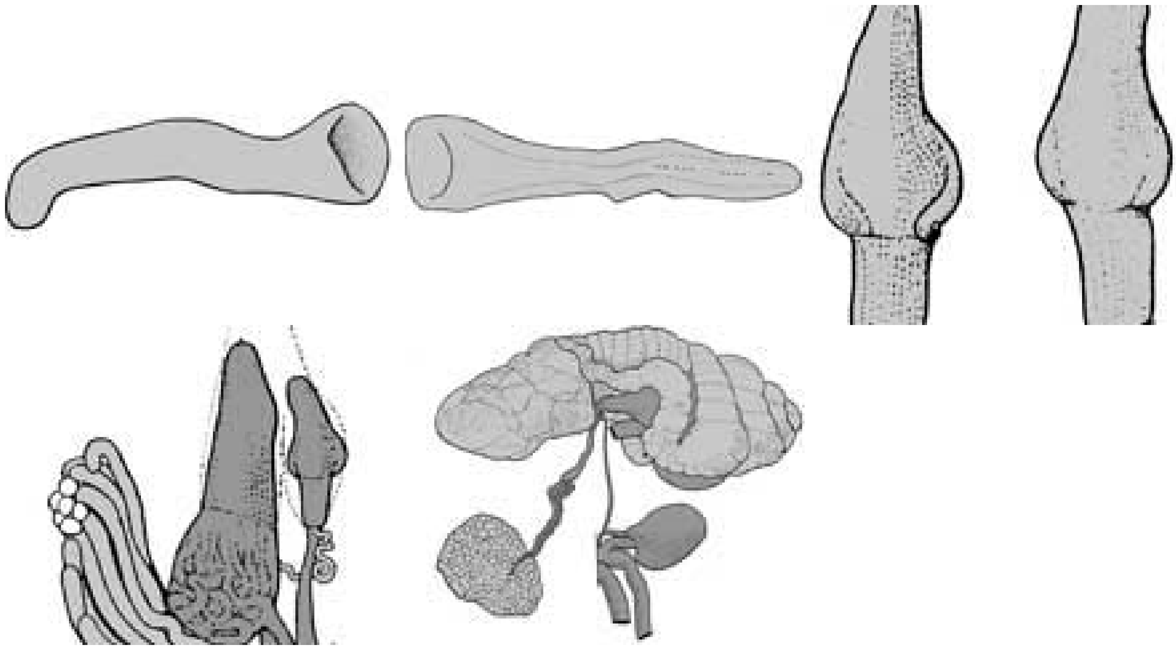
- *Sarasinula dubia* (Semper)
- *Vaginulus plebeius* Fischer, 1868 in Fischer, 1868. Diagnoses de deux Limaciens de la Nouvelle Caledonie. Journal de Conchyliologie, Paris. 16: 145-146.
- *Vaginula plebeja* Fischer, 1868 in Aguayo, 1964. Notas sobre la distribucion de la babosa *Vaginulus plebejus*, Mollusca: Veronicellidae. Caribbean Journal of Science. 4: 549-551.
- *Sarsinula plebeja* Grimpe and Hoffmn, 1925 in Thome, 1971. Redescricao dos tipos de Veronicellidae (Mollusca, Gastropod) neotropicais: VII especies depositadas no Museum National d'Histoire Naturelle, Paris, Franca. Iheringia (Zool.) 40: 27-52.

- *Vaginula behni* Semper, 1885 in Thome, 1989. Annotated and illustrated preliminary list of the Veronicellidae (Mollusca: Gastropod) of the Antilles, and Central and North America. Journal of Medical and Applied Malacology. 1: 11-28.
- *Sarasinula lemei* Thome, 1967 inThome, 1989. Annotated and illustrated preliminary list of the Veronicellidae (Mollusca: Gastropod) of the Antilles, and Central and North America. Journal of Medical and Applied Malacology. 1: 11-28.
- *Sarasinula plebeia* Thome, 1993 in Thome, et al. 1997, Annotataed list of Veronicellidae from the collections of the Academy of Natural Sciences of Philadelphia and the National Museum of Natural History, Smithsonian Institution, Washington, D.C., U.S.A. (Mollusca: Gatropoda: Soleolifera). Proceedings of the Biological Society of Washington. 110: 520-536.
- *Angustipes dubia*
- *Angustipes dubius*
- *Angustipes plebeius*
- *Imerimia plebeja*
- *Sarasomia plebeia*
- *Vaginula dubia*
- *Vaginula moerchi*
- *Vaginula plebeius*
- *Vaginulus dubius*
- *Vaginulus plebejus*
- *Vernicella plebeius*
- *Viginula dubia*
- *Viginula moerchi*

References

Cowie et al. 2008; Naranjo-García et al. 2007; Robinson et al. 2009; Rosenberg and Muratov 2006; Rueda et al. 2004; Solem 1964; Thome 1989





Veronicellidae: Vaginulus alte

Family

Veronicellidae

Species

Vaginulus alte (Ferussac, 1822)

Common Name

Black slug, Tropical leatherleaf

Description

The tropical leatherleaf slug measures 70-80 mm long. It is dark-colored (grayish) with raised pustules/tubercles and a characteristically narrow foot. A pale brown line spans the length of its dorsum. The foot is 4-5 mm wide in adults and 1 mm wide in juveniles. The keel is tan colored. The tentacles are 2-3 mm long, and rarely extend beyond the tip of the mantle.

Native Range

Cental Africa

Distribution

Pacific Islands: Hawaii

Islands of the Indian and Pacific Oceans

Australasia: Australia, New Zealand

Asia: Southern

Africa: South and Central

Ecology

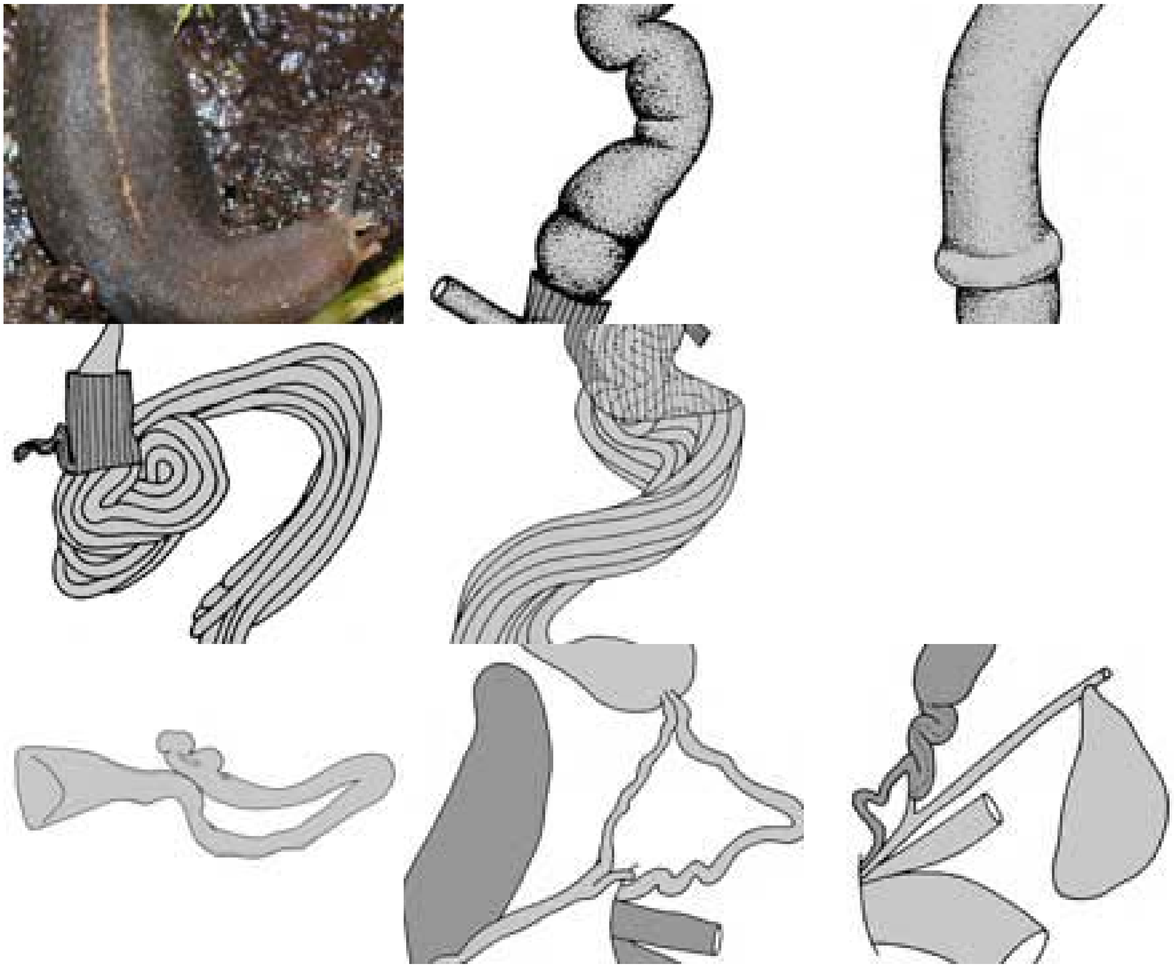
This pest species consumes vegetable crops, fruits and weeds. This species is an intermediate host for *Angiostrongylus cantonensis*, the rat lung parasite of humans. It occupies dry areas at low altitudes and feed during periods of high humidity (late evening/early morning). The adults of this slug will deposit its eggs in any depression in the soil. The eggs are often observed in a cluster with a thread-like material surrounding it. Fecal matter is also deposited on the eggs to maintain the eggs' high moisture content. The oval, translucent eggs will measure up to 8 mm. Clutch size may be as much as 100 eggs. The eggs often hatch in about a month. The juveniles will measure close to 8 mm upon eclosion (hatching). Although maturity is often attained after 5 months, breeding only commences during favorable conditions (warm and rainy weather).

Synonyms

- *Laevicaulis alte* (Ferussac, 1822)
- *Vaginulus alte* Ferussac, 1822
- *Vaginula leydigi* Simroth, 1889

References

Cowie 1997; Cowie et al. 2008; Cowie et al. 2009; Naggs et al. 2003; Solem 1964; Thome 1989



Veronicellidae: Veronicella spp.

Family

Veronicellidae

Species

Veronicella floridana (Leidy, 1868)

V. cubensis (Pfeiffer, 1840)

V. sloanei (Cuvier, 1817)

V. moreleti (Crosse & Fischer, 1872)

Common Name

Veronicella aff*. floridana*: Florida leatherleaf slug

V. cubensis: Cuban slug

V. sloanei: Sloan slug, Jamaican slug, Pancake slug

V. moreleti: Tan leatherleaf, Morelet slug

Description

Veronicellid species can only be reliably distinguished from each other through dissections and observation of the genitalia.

Veronicella aff. *floridana*: This species may be distinguished from *Veronicella cubensis* by the genitalia.

V. cubensis: The body color of this slug is variable. There may be multiple shades of brown with two dark stripes running down the length of its back. The lines may be solid or broken up into spots. There may also be an albino form. Another thin, pale white stripe also runs down the midline of the animal. The body texture also varies, where, the body may appear smooth or granular. This slug can usually be distinguished from other species of Veronicellids by the presence its blue-gray eye tentacles. There is also a pale brown area around the eyespots. Adults will measure between 50-70 mm in length, although lengths of up to 120 mm have been recorded.

V. sloanei: Similarly to the other species of this genus, this animal has variable body color, ranging from albino, to tan to grey with varying degrees of grey markings. It has the potential to attain a maximum length of 120 mm. The tentacles of this species are typically blue-grey with pale brown tips.

V. moreleti: This brown-colored species usually does not have a dorso-median stripe. Genitalia: The basal section of the penis is cylindrical. The apex is twisted and the entire region is a hardened mass.

Native Range

Veronicella floridana: Southern Florida and Greater Antilles

V. cubensis: Greater Antilles (Cuba)

V. sloanei: Greater Antilles (Jamaica)

V. moreleti: South America

Distribution

Veronicella aff*. floridana*:

North America:

- U.S.: Alabama, Florida; Louisiana, Texas

Central America: Mexico

Caribbean: Puerto Rico, Cuba, Dominica, Jamaica

V. cubensis:

North America:

- U.S.: California

Pacific Islands

Caribbean: Cuba, Hispaniola, Puerto Rico, Saint Kitts, Nevis, Dominica, Barbados

V. sloanei:

Caribbean: Jamaica, Bermuda, Dominican Republic, Grand Cayman, Guadeloupe, Dominica, Barbados, Saint Vincent, Saint Lucia, Cuba

V. moreleti:

North America:

- U.S.: This species has been intercepted in Vermont

Central and South America

Ecology

Pest species have been known to consume both ornamental and agricultural crops: melon, pumpkin, pepper, eggplant, cabbage, cassava, taro, sweet potato, yam, papaya, banana, star fruit, mango, noni, citrus and coffee.

Veronicella aff*. floridana*: This slug is known as a pest of potatoes in Cuba and that of beans, tomatoes and ornamental plants elsewhere.

V. cubensis: This animal is a serious pest of agricultural and ornamental crops (e.g., papaya production in Hawaii) especially in the Pacific Basin. Crops include but are not limited to the following: banana, cabbage, cassava, citrus, coffee, eggplant, mango, noni, papaya, pepper, pumpkin, satar fruit, sweet potato, taro, yam. It can be found in very moist habitats (e.g., near water bodies).

V. sloanei: This opportunistic pest is quite aggressive and consumes a wide variety of ornamental and agricultural crops. Crops consumed by this pest includes but is not limited to the following: leafy vegetables (e.g., spinach, cabbage, lettuce), dasheen, banana, plantain, tannia, papaya, citrus, bean, peanut, *Hibiscus* sp. and *Bougainvillea* sp. This pest can also remove the bark of several plants (e.g., *Datura* sp. and gardenia), therefore girdling the plant. It will lay clutches of 10-12 eggs in a chain.

V. moreleti: This slug has been described from multiple habitats from lowland jungles to open savannas. It is viviparous; therefore, eggs of this species are never intercepted. It has been recorded as a pest of coffee and cacao in Mexico.

Synonyms

Veronicella aff*. floridana* (Leidy, 1868):

- *Leidyula floridana* (Leidy & Binney, 1851), Thome, et al. 1997, Annotataed list of Veronicellidae from the collections of the Academy of Natural Sciences of Philadelphia and the National Museum of Natural History, Smithsonian Institution, Washington, D.C., U.S.A. (Mollusca: Gatropoda: Soleolifera). Proceedings of the Biological Society of Washington. 110: 520-536.
- *Vaginulus floridanus* Leidy & Binney, Binney 1851, The terrestrial air-breathing mollusks of the United States and the adjacent territories of North America. Vol. I. A.A. Gould (ed.) Charles Little and James Brown, Boston, MA. pp. 198, 251, pl. IV.
- *Veronicella floridana* (Binney, 1851) in Binney, 1885. A manual of American land shells. Bulletin No. 28 of the United States National Museum, p. 528.

V. cubensis (Pfeiffer, 1840):

- *Onchidium cubense* Pfeiffer, 1840.
- *O. cubensis*
- *Veronicella cubensis* Thome, 1975.

V. sloanei (Cuvier, 1817):

- *Vaginulus sloanei* Ferussac
- *V. laevis* Blainville, 1817

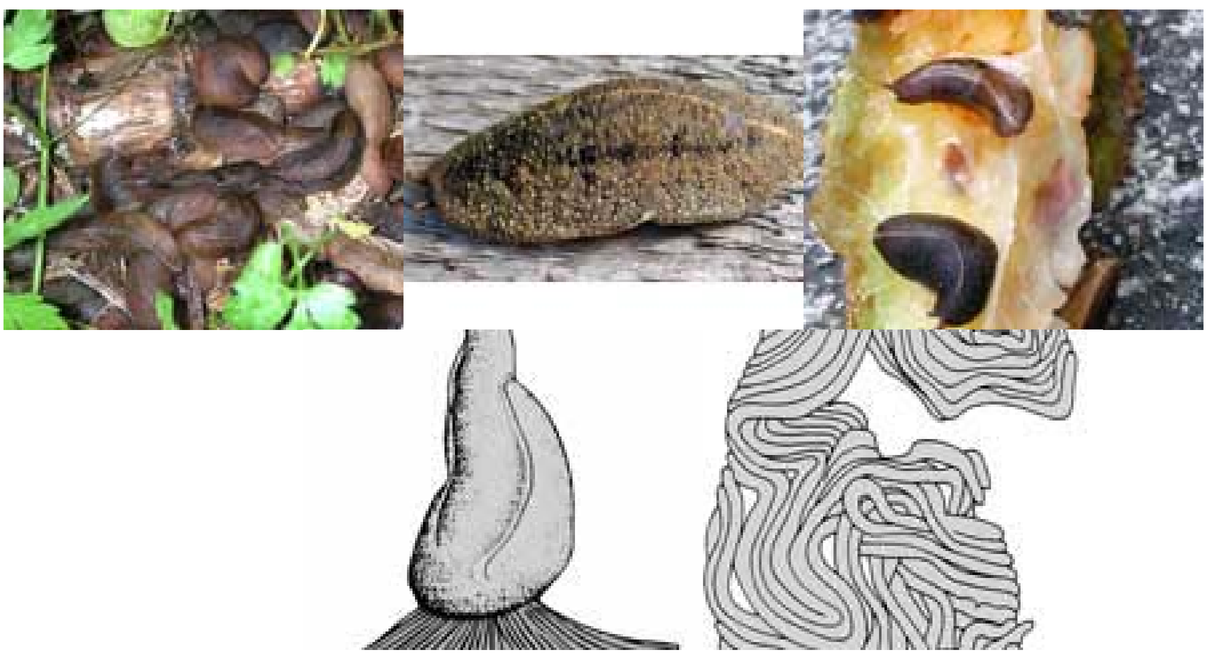
V. moreleti (Crosse & Fischer, 1872):

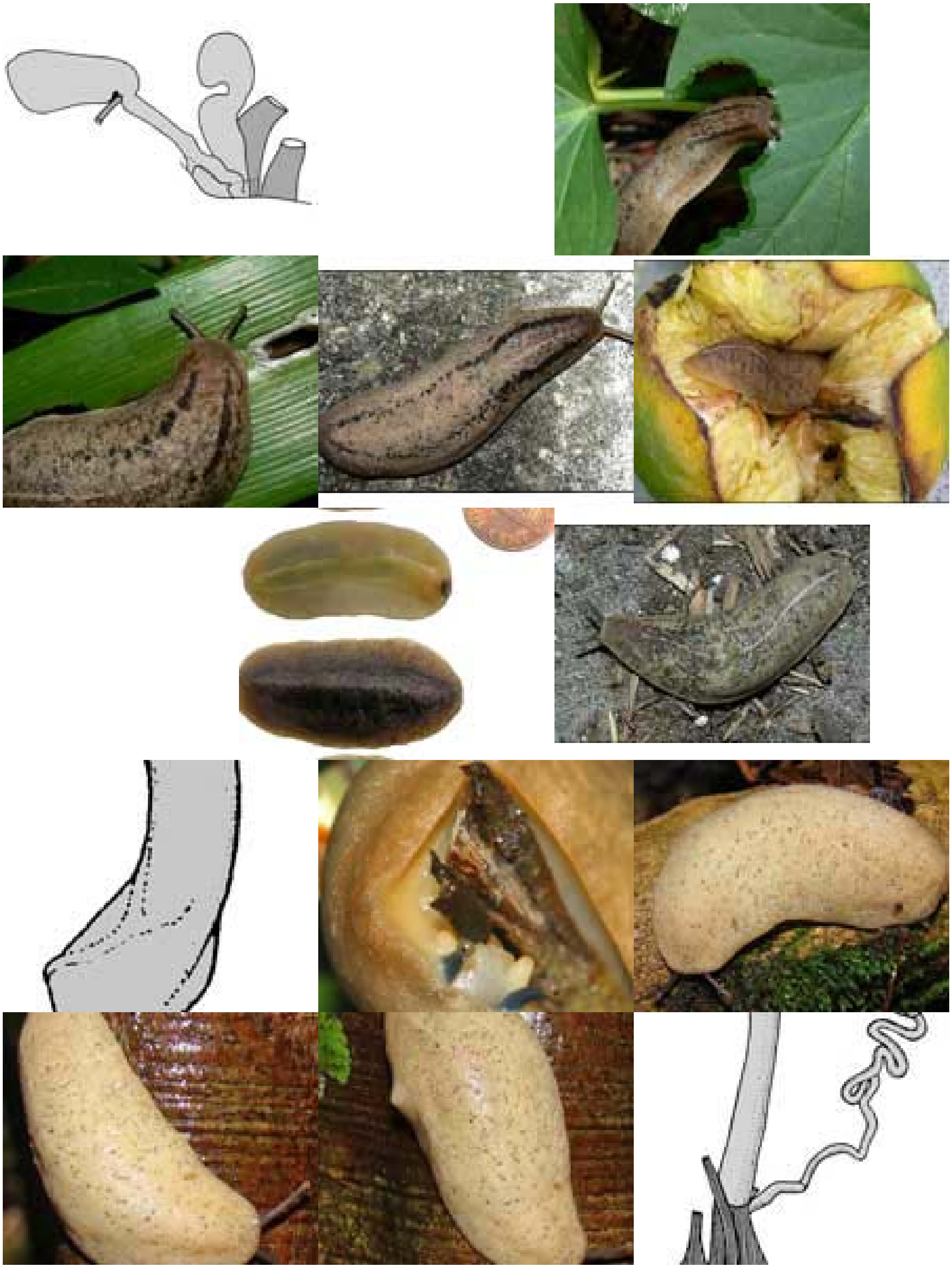
- *Leidyula moreleti* (Crosse & Fischer, 1872)

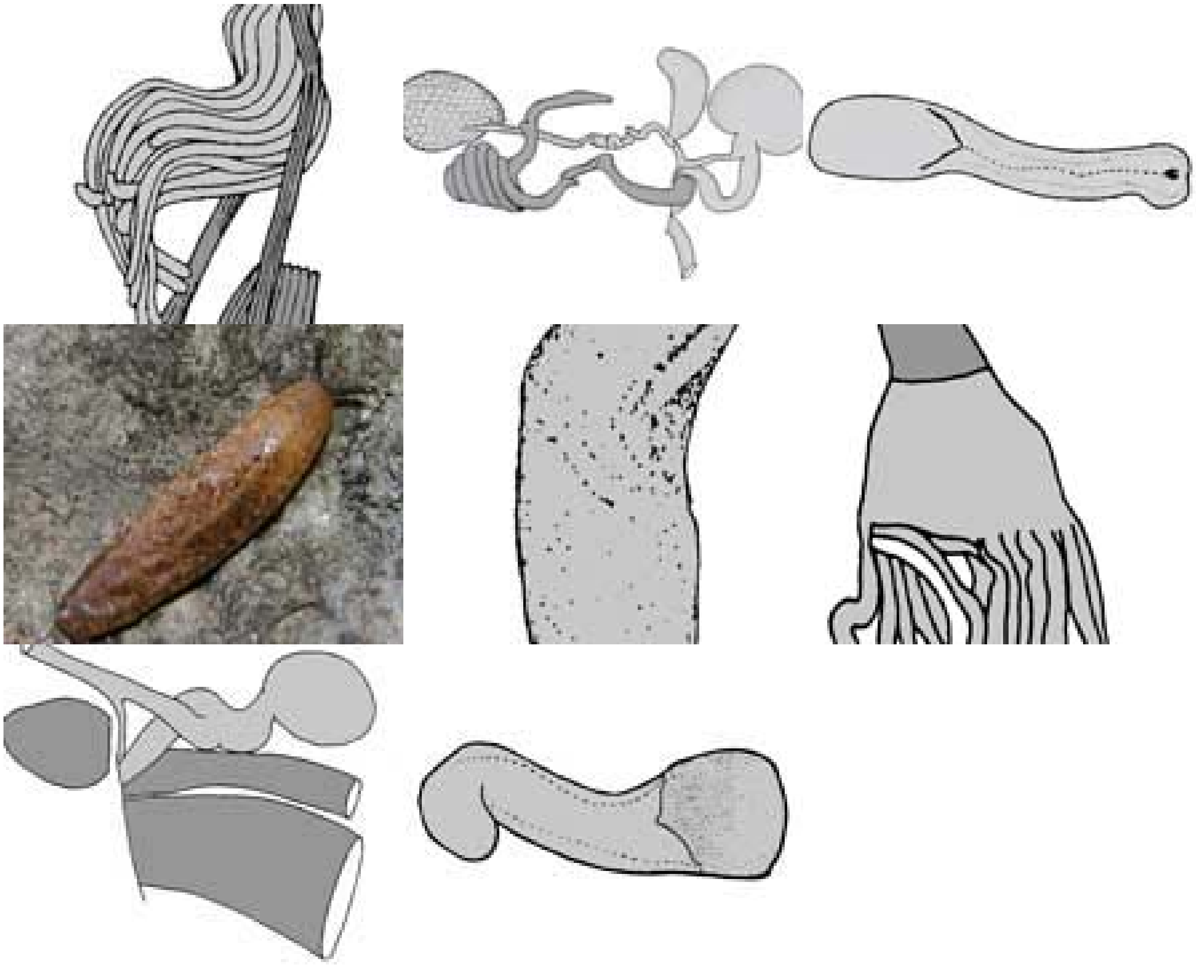
- *Vaginulus moreleti* Fischer, 1871 in Fischer, P. 1871. Revision des especes du genere Vaginula Ferussac. Nouvelles Archives du Museum d'Historie Naturelle. Paris. 7: 147-175.
- *Vaginulus kreideli* Semper, 1885 in Thome, 1971. Redescricao dos tipos de Veronicellidae (Mollusca, Gastropod) neotropicais: VII especies depositadas no Museum National d'Histoire Naturelle, Paris, Franca. Iheringia (Zool.) 40: 27-52.
- *Veronicella (Leidyula) moreleti* (Crosse and Fischer, 1872) in Baker, 1925. North American Veronicellidae. Proceedings of the Academy of Natural Sciences of Philadelphia. 77: 157-184.
- *Vaginulus mexicanus* Strebel and Pfieffer, 1882 in Thome, 1989. Annotated and illustrated preliminary list of the Veronicellidae (Mollusca: Gastropod) of the Antilles, and Central and North America. Journal of Medical and Applied Malacology. 1: 11-28.

References

Cowie 1997; Cowie et al. 2008; Cowie et al. 2009; Fields and Robinson 2004; Lechmere Guppy 1866; McDonnell et al. 2008; Naranjo-García et al. 2007; Neck 1976; Perez and Cordeiro 2008; Robinson et al. 2009; Rosenberg and Muratov 2006; Stange 2004; Thome 1989; Thome 1993; Whitney et al. 2004







Viviparus viviparus

Family

Viviparidae

Species

Viviparus viviparus (Linnaeus, 1758)

Common Name

River snail, Common river snail

Description

This species will attain a maximum height of 40 mm, with 5-6 whorls. The shell is yellow-green with three distinct brown spiral stripes (that follow the direction of the whorls). The shell of this operculate snail opaque and slightly glossy. The umbilicus (navel) is inconspicuous, occurirng only as a groove or notch. This species is not hermaphroditic, both sexes exist. They are ovoviviparous.

Distribution

North America: Eastern

Europe

Synonyms

- *Helix vivipara* Linnaeus, 1758
- *Nerita fasciata* Muller, 1774 (part.)
- *Nerita vivipara* Muller, 1774 (part.)
- *Cyclostoma achatinum* Draparnaud, 1801
- *Viviparus fluviorum* Montfort, 1810
- *Cyclostoma achatinum* Lamarck, 1812
- *Viviparus vulgaris* Gray,1850
- *Paludina duboisiana* Mousson, 1863
- *Vivipara subfasciata* Bourguignat, 1870
- *Vivipara subfasciata* var. *sequanica* Bourguignat, 1870
- *Paludina okaensis* Clessin, 1875
- *Vivipara forbesi* Bourguignat, 1880
- *Vivipara nevilli* Bourguignat, 1880
- *Vivipara imperialis* Bourguignat, 1884
- *Vivipara penthica* var. *albisiana* Servain, 1884
- *Vivipara bourguignati* Servain, 1884
- *Vivipara paeteliana* Servain, 1884
- *Vivipara penthica* Servain, 1884
- *Vivipara strongyla* Servain, 1884
- *Paludina duboisiana* var. *concis* Westerlund, 1886
- *Paludina penthica* var. *porphyrea* Westerlund, 1886

References

Anderson 2005; Jakubik 2006; Kantor et al. 2009

Xerolenta obvia

Family

Hygromiidae

Species

Xerolenta obvia (Menke, 1828)

Common Name

Heath snail

Description

This heath snail will attain a maximum height of 16 mm and a diameter of 22 mm, with 5-6 whorls. This opaque shell is very flattened for a helicid-shaped shell. The body whorl of this species turns downwards. The aperture (mouth) is oval in shape and is very thin and brittle, often incomplete in vacant shells as it generally breaks. The background color is white with dark brown spiral stripes. The most obvious and consistent stripe can be found at the periphery. Subsequent stripes may be faint, inconsistent and broken. The umbilicus is open and obvious. In some species the coiling of the shell when observed through the umbilicus may appear haphazard.

Native Range

Southeastern Europe

Distribution

North America:

- U.S.: Michigan

Europe: England, Ireland, Germany, Bulgaria, Italy, Turkey

Ecology

This species is known to feed on fodder crops (e.g., alfalfa, clover, lupine, sanfion, seradella) in southern Germany. It is also a pest in Italy and Bulgaria where it is often intercepted in shipments of fruits and vegetables to other European countries. *Xerolenta obvia* is a vector of fungal pathogens (e.g., *Alternaria* sp. *Fusarium* sp., *Phytophthora* sp.). It also vectors the sheep and goat parasites, *Protostrongylus rufescens*, *Davainea proglottina* and *Dicrocoelium dendriticum*.

Synonyms

- *Helicella obvia* (Menke, 1828)

References

Kerney et al. 1979; Robinson and Slapcinsky 2005


Xeropicta krynickii

Family

Hygromidae

Species

Xeropicta krynickii (Krynicki, 1833)

Common Name

Desert snail

Description

This species has a shell diameter of 12-18 mm, with 5-6 whorls. The shell has a white base color with varying shades of brown spots and bands. This glossy shell has uneven sculpturing and an open umbilicus (navel).

Native Range

Mediterranean region

Distribution

Middle East: Turkey to Jordon, Egypt, Israel

Ecology

This species prefers open habits, with little vegetation (e.g., gardens, road medians). *Xeropicta krynickii* may occur in vineyards and orchards where it will cause damage to the crop. This species is often inadvertently harvested with agricultural produce and is generally considered a contaminant pest. In Israel, this species often invades ornamental cropping systems in search of a place to aestivate. Shipments of these ornamental plants are often rejected by trading partners due to contamination by this species.

Synonyms

- *Xeropicta vestalis* (Pfeiffer, 1841)
- *Helix vestalis* Pfeiffer, 1841

References

Abbott 1989; Cowie et al. 2009; Kostyukovsky and Shaaya 2001; Moran et al. 2004

Xerotricha conspurcata

Family

Hygromiidae

Species

Xerotricha conspurcata Draparnaud, 1801

Common Name

None reported.

Description

The shell of this species ranges in height from 3.3-4.5 mm and a width of 4.8-6.8 mm, with 4-5 whorls. The shell is light brown with tan or darker brown spots and short stripes randomly distributed over the entire shell. There generally are long hairs covering the shell, approximately 0.2-0.3 mm long in the juveniles. The hairs are often absent in the adults.

Native Range

Western Mediterranean region

Distribution

North America:

- U.S.: California

Ecology

This species is documented as a pest in vineyards. It can be found in multiple microhabitats, from dense vegetation to wall crevices.

Synonyms

- *Xerolenta conspurcata*
- *Helix conspurcata* Draparnaud, 1801
- *Helicella conspurcata* (Draparnaud, 1801)

References

Kerney et al. 1979

Zachrysia spp.

Family

Pleurodontidae

Species

Zachrysia provisoria (Pfeiffer, 1858)

Z. trinitaria (Pfeiffer, 1858)

Common Name

Cuban land snails

Zachrysia provisoria: Garden zachrysia

Z. trinitaria: Trinidad zachrysia

Description

Zachrysia provisoria: This snail can attain a height of approximately 20 mm and a maximum width of 32 mm, with 4-5 rapidly expanding whorls. This animal's shell is generally globose in shape. The initial whorls have an orange color, while the body whorl is tan with dark blotches and arboreal branchings.

Z. trinitaria: This species is larger than *Z. provisoria* and the shell will measure up to 45 mm.

Both species are similar in appearance; however, they can be easily distinguished by their genitalia:

Zachrysia provisoria: long flagellum on penis.

Z. trinitaria: short flagellum on penis.

Native Range

Greater and Lesser Antilles

Distribution

North America:

- U.S.: Florida (Not *Z. trinitaria*)

Central America: Guatemala

Caribbean: Cuba, Puerto Rico, Barbados, Saint Croix, Jamaica, Mustique, Nevis, Bahamas, Virgin Islands, Costa Rica, Haiti, Dominican Republic

Ecology

Zachrysia species generally are pests wherever they become established. *Z. provisoria* has been noted to be a serious pest of ornamental plants in Florida.

Synonyms

Zachrysia provisoria:

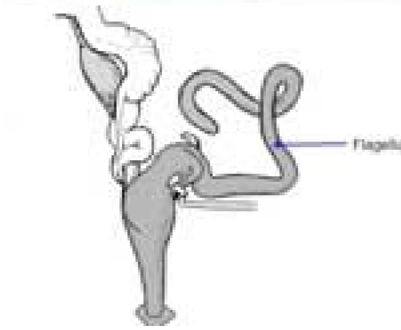
- *Helix provisoria* Pfeiffer, Malak Bl. V, 1858, p39 (Manzanillo, Cuato and Guisa); Monogr. Hel. Viv. V, 1868, p. 288. Arango, Contrib., p. 72.
- *Helix appendiculata* Gundlach, M.S. list, 1858, Pfeiffer, Monogr. V, p. 288, as synonym of *H. provisoria*; not otherwise defined.
- *H. auricoma*... les individus envoyes de Cabo Cruz, Poey, Memorias II, p. 50, 67, pl. 6, fig. 9 (genitalia).

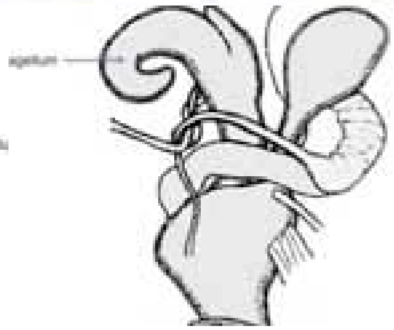
Z. trinitaria:

- *Helix bayamensis* Pfr., Malak. Blatter IV, 1857, p. 103 (desription of living animal).
- *Helix trinitaria* Gundlach, Pfeiffer, Malak. Blatter V, 1858, p.176, footnote.

References

Auffenberg and Stange 1993; Cowie et al. 2009; Pilsbry 1928; Robinson and Fields 2004; Rosenberg and Muratov 2006





Zonitoides spp.

Family

Zonitidae

Species

Zonitoides (Zonitellus) arboreus (Say, 1819)

Zonitoides nitidus (Muller, 1774)

Common Name

Zonitoides (Zonitellus) arboreus: Quick gloss

Zonitoides nitidus: Black gloss

Description

Zonitoides (Zonitellus) arboreus: The flattened-heliciform shell of this snail is approximately 5-6 mm in diameter and between 2.4 and 3 mm high. It is often umbilicate (navel-like), dark brown and shiny with irregular, faint incremental wrinkles and microscopic spiral striations. The whorls are 4-4 1/2 with the embryonic 1 1/2 whorl being smooth. The body of the snail is blue-grey, including the tentacles. However, the sides and tail are a lighter in color. The sole of the foot is white or gray with paler flecks along the margin. While moving, the foot shows no waves. The aperture is very lunate (moon-shaped) and wider than high, with a thin peristome (edge of shell's mouth). *Zonitoides arboreus* does not possess the orange spot on the mantle found in *Z. nitidus*. Also, quick gloss has a slightly flatter spire than black gloss.

Zonitoides nitidus: The flattened-heliciform shell of the black gloss snail is approximately 5.9-7 mm wide, 3.6-4 mm high, dark brown and shiny. The shell has irregular, low wrinkle-like axial striae and a total of 4 1/2 to 5 whorls. The body of the snail is black with a dull orange spot on the mantle. This orange spot can be seen through the shell in contracted individuals. It can be located behind the apertural lip, between the suture and the periphery. The snail itself is completely black except for one pale fleck along the edges of the foot. The black gloss snail can be distinguished from *Zonitoides arboreus* by the presence of an orange spot on the mantle.

Native Range

Zonitoides (Zonitellus) arboreus: North America

Zonitoides nitidus: Holarctic

Distribution

Zonitoides (Zonitellus) arboreus:

North America:

- U. S.: all states but Nevada
- Canada: Alberta, British Columbia, New Brunswick, Newfoundland, Nova Scotia, Ontario, Quebec

South and Central America: Mexico, Costa Rico, Guatemala

Caribbean: Cuba, Santo Domingo, Jamaica, Guadeloupe

Australasia: Australia, New Zealand

Asia: Japan

South Africa

Europe: Prague, Finland, Moscow, Britain, Ireland

Zonitoides nitidus:

North America:

- U.S.: Alaska, Delaware, Iowa, Illinois, Indiana, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, New Jersey, New York, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Tennessee, Utah, Vermont, Washington, West Virginia, Wisconsin
- Canada: Alberta, British Columbia, Newfoundland, Nova Scotia, Ontario, Quebec

Europe

Africa: Algeria

Ecology

Zonitoides (Zonitellus) arboreus: This species can be found in greenhouses and natural habitats and can withstand some desiccation. It is considered to be a key pest in Hawaiian orchid production. It can be found in rotting wood, leaf litter and vegetation. Its movements are very quick for a snail. The eye tentacles are widely separated with characteristically black, slightly bulbous eyes.

Zonitoides nitidus: This species generally lives in marshes, greenhouses and wet areas along the edges of rivers, sloughs, lakes and ponds where it can be found under wood, rocks, and vegetation. Black gloss snails are carnivores and have been noted to be cannibals. This species reproduces mainly by self-fertilization.

Synonyms

Zonitoides (Zonitellus) arboreus:

- *Helix arboreus* Say, 1816, [Nicholson's] Amer. Edit. British Encycl., vol. 2, art. Conchology, species no. 2, pl. 4, fig. 4.
- *H. breweri* Newcomb, 1864, Proc. Cal. Acad. Sci., 3:118 (Lake Tahoe, Cal.) Cf. H. B. Baker, Occas. Pap. Mus. Zool. Univ. Mich., 269: 13.
- *Zonites arboreus* Say, W. G. Binney, 1878, Terr. Moll., 5:114, pl. 29, fig. 3; pl. iii, fig. F (teeth).
- *Hyalina arborea* var. *viridula* Cockerell, 1888, Science-Gossip, 24: 257., Custer Co., Colo.
- *Hyalina arborea* Say, Von Martens, 1892, Biol. Centrali-Amer., Moll., p. 116, pl. 6, figs. 13-13c.
- *Zonitoides arboreus* (Say), J. Henderson, 1924, Univ Colo. Studies, 13: 147; 1929, 17: 102; 1936, 23: 109, 258; Sterki, 1893, Proc. Acad. Nat. Sci. Phila.,, p. 394, development of teeth.
- *Helix ottonis* Pfeiffer, 1840, Arch. Naturg., 6: 251 (Cuba) ; Gould, 1851, Terr. Moll., 2:238.
- *Hyalina breweri* Newcomb, W. G. Binney, 1864, Land and Fr. W. Sh. N.A., 1: 43, fig. 66.
- *Helix whitneyi* Newcomb, 1864, Proc. Cal. Acad. Sci., 3: 118 (Lake Tahoe).

- *Hyalinia whitneyi* Newcomb, W. G. Binney, 1869, L. and Fr. W. Sh. N. A., 1: 32, fig. 37; H. B. Baker, 1931, Nautilus, 44: 98 (identical with Z. arborea).
- *Hyalinia (Polita) roseni* Lindholm, 1911, Nachrbl. d. d. mal. Ges., 43: 98 (park near Moscow); cf. Lindholm 1922.

Zonitoides nitidus:

- *Helix nitida* Muller, 1774, HIst. Verm., 2: 32 (Fridrichsberg, Denmark).
- *Zonites nitidus* Muller, W. G. Binney, 1878, Terr. Moll., 5: 113, pl. iii, fig. A (teeth).
- *Zonitoides nitius* Muller, Dall, 1905, Harriman Alska Exped., 13: 42; F. C. Baker, 1920, Life of the Pleistocene, pp. 307, 339, 389; J. Henderson, Univ. Colo. Studies, 13: 147; 17;102; 23;109; H. B. Baker, 1928, Proc. Acad. Nat. Sci. Phila., 80: 38.
- *Helix hydrophyla* Ingalls, Miles, 1861, Ist. Bienn. Rept. Prog. Geol. Surv. Mich., p 235, 238.
- *Helix hydrophila* Ingalls in coll., Binney & Bland, 1869, Land and F. W. Sh. N. A., 1: 32 (as synonymn of Hyalina nitida Muller; Greenwich, Washington Co., N.Y.).

References

Abbott 1989; Anderson 2005; Cowie et al. 2008; Horsák et al. 2004; Kerney et al. 1979; Kuznik-Kowalska 2011; Pilsbry 1946; Rosenberg and Muratov 2006

Glossary of Terms

abcdefghiklmnoprstuvw

a

Aestivation (to aestivate): Being in a state of arrest (often temporary and can be broken at anytime).

Anal pore: Small opening located in the mantle; may be located anteriorly or posteriorly and is responsible for waste removal by the animal.

Annulated: Consisting of rings.

Anterior: Directional term: located in front. Nearer the head or front end of a shell.

Anterior-laterally: This is a directional term meaning towards the front, on the side.

Apertural lip: The margin of the aperture, which may be sharp or thickened depending upon the species (Also see lip).

Aperture: The major opening of a shell that the body of the animal may be retracted.

Apex: The tip of the spire of a shell.

Aphallic: The state of lacking a penis.

Apical: Top side of the shell; opposite of base.

Apical whorls: The whorls near the apex of the shell.

Arboreal: Of or relating to trees OR Tree-dwelling or frequenting trees.

Asymmetrical: Not even on both sides of a usually central axis.

Atrium: Opening or passage of the genitalia. OR Region for the reception of gametes.

Axial: Directional term: This refers to a vertical direction often parallel to the columella; opposite of spiral.

b

Band: In slugs: Any transverse line (runs from side to side, or vertically e.g., on the foot fringe). In snails: A section of a shell that is differentiated by color or texture from either side of it.

Banding: Color markings in continuous stripes.

Base: This is the lower or underside of the shell; opposite of apical.

Beehive-shaped: Shell shape: having a shape that resembles a beehive.

Body whorl: The large, final coil (most recently formed) of a mollusc shell that contains the body of the snail, i.e. from the aperture to approximately one whorl back.

Breathing pore: This is the breathing hole on the right side of the mantle of molluscs. This allows air to pass through to the mantle for gas exchange. (See also pneumostome).

c

Calcareous: Consisting of limestone or calcium carbonate.

Callus: A area of the shell that is thickened.

Carinate: Posses or have a keel.

Character: 1). A distinctive trait, quality or attribute used for recognizing, describing, or differentiating taxa; 2). The term used to denote such descriptive traits that possess states and are located within the Lucid version 2 (and later) interactive matrix panel. (compare feature)

Character state: See also state

Columella: The central axis of the shell; originates at the shell apex and ends at the umbilicus.

Conical: Shell shape: shells with an elongated spire that tapers to a point and are slightly broader at the base.

Conspecific: Of or belonging to the same species or species-group.

d

Decollate: This term is used to describe shells without an apex.

Dentate: Possessing teeth or denticles (often refers to the aperture).

Denticle: Tooth-like structure on or in the opening of a shell (not to be confused with the radulate teeth inside the mouth of the animal). (See also teeth).

Denticle (Parietal denticle): Tooth-like structure on or in the opening of a shell (not to be confused with the radulate teeth inside the mouth of the animal). (Also see teeth, denticle).

Depressed: Shrunken below a certain level.

Depressed heliciform: Shell shape: shell that is wider than high.

Detritus: Disintegrated organic material e.g. decaying leaves.

Dextral: Having the opening of the shell on the right side when oriented so that the apex is upwards and the aperture is facing you.

Diapause: Being in a state of arrest (often predetermined and lasts for a specific period of time).

Diecious: Being sexually distinct. Male and female genitalia do not occur in the same specimen.

Discoid or Discoidal: Shell shape: disc-shaped, shell that is wider than high and depressed.

Distal: The farthest part from an object or the body of the animal.

e

Entities: See also entity

Entity: In Lucid, entities are the items the key aims to identify. Lucid uses the term entity to encompass items of all types.

Epiphragm: Temporary mucus secretion deposited in the aperture of the shell during periods of inactivity (e.g., aestivation). (See also operculum).

Euphallic: The state of possessing both fully developed male and female reproductive organs.

Evaginate: To turn inside out.

Eversion (to evert): The act or condition of being turned inside out.

f

Fact sheet: 1). A presentation of data in an HTML format on any subject emphasizing brevity, key points of interest or concern, and a way to convey the most relevant information in the least amount of space; 2). An HTML page itemizing the facts or pertinent information about each of a tool's entities.

Feature: 1). A distinctive trait, quality or attribute used for recognizing, describing, or differentiating taxa; 2). The term used to denote such descriptive traits that possess states and are located within the Lucid version 3 interactive matrix panel. (compare character)

Foot: The muscular organ on the undersurface of the body of a mollusc upon which the animal rests or uses to crawl.

Furrow (s): Having pits, grooves or trenches.

g

Gastropod: A single-shelled mollusc.

Genital opening (genital pore): Orifice that serves as the entrance to the reproductive system OR the opening that allows for the eversion of the penis.

Genitalia: The reproductive structures of an animal. May refer to either male or female structure.

Globose: Shell shape: to be roughly spherical or globular in shape.

Granular: Bearing granules on the surface or having a rough appearance.

Groove: An elongate and fairly uniform depression or indentation in the shell or soft parts of a mollusc.

Growth line (s): Deeply or markedly formed transverse lines on the shell-surface due to growth-stages and rest-periods.

h

Head: The area of a mollusc's body that has the tentacles, eyes and mouth.

Height: The height of the shell is a measure of the distance between the apex and the most basal part of the shell OR the measurement taken from the apex of the shell to the base, when measured parallel to the axis of the shell.

Helical: Spirally coiled.

Hemiphallic: State of having a reduced (not of typical size and structure) penis.

Hermaphrodite: Having both male and female reproductive organs. (See also Hermaphroditic)

Hermaphroditic: State of having both male and female reproductive organs. (See also Hermaphrodite)

Hirsute: Shells with a hairy surface.

Hyponotum: The ventral surface of the mantle. This structure can be found on either sides of the foot.

i

Impressed: Term used to describe the sutures of the shell when they are recessed OR may describe the sculpturing of the shell when there are depressions or pits.

Invaginate: To fold or turn inward

k

Keel: Also known as the carina. This is a longitudinal ridge that runs dorsally along the apex of the tail of the animal.

Keel (shell of animal): This is a ridge that runs along the periphery of the body whorl.

Keel (tail of animal): Also known as the carina. This is a longitudinal ridge that runs dorsally along the apex of the tail of the animal.

l

Lip: The margin of the aperture, which may be sharp or thickened depending upon the species (Also see apertural lip).

Lirae: Raised, spiral lines on the surface of the shell.

m

Malacologist: One who studies molluscs.

Malacology: The study of molluscs.

Mantle: A fleshy, membranous covering of the anterior portion of the body of a mollusc. It secretes the materials that form the shell.

Mantle cavity: The gap or space between the mantle and the visceral mass.

Median: Along the central line or axis.

Microsculpture: Any textural feature of the shell, especially those that can be seen with the aid of a microscope.

Mollusc: Common name for animals in the phylum Mollusca. These are invertebrate animals, which have soft unsegmented bodies and may or may not possess a shell. This group includes gastropods (slugs and snails), cephalopods (octopus) and bivalves (clams, oysters).

n

Necrotic: Dead or dying tissue. Often brown to black in color.

Nocturnal: Occurring or becoming active at night.

o

Olfactory: Of or relating to the sense of smell.

Opaque: Not having the ability to see through an object. (Not transparent or translucent)

Operculum: A rigid structure that blocks the opening/aperture of the shell (partially/wholly) when the body of the snail is retracted. This structure is often attached dorsal to the tail of the animal. It can be chitinous, proteinaceous or calcareous. Often observed in aquatic species. (See also epiphragm).

Oviposit (Oviposition): The act of egg laying.

Oviviparous: Ability to give birth to live young, where the parent produces eggs that hatch internally. (See also viviparous)

Ovoviviparous: Reproductive strategy: prior to deposition, eggs are retained inside the animal until they are fully developed.

p

Periostracum: This is a thin membrane that coats the shell, often comprised of chitin or proteinaceous substances. This material may be smooth, or covered in hair or 'scale-like' projections.

Peristome: Margin of the aperture of a snail's shell. This region may be thickened in mature animals.

Pneumostome: This is the breathing hole on the right side of the mantle of molluscs. This allows air to pass through to the lung for gas exchange.(See also breathing pore).

Posterior: Directional term: the rear or tail end of an animal.

r

Radula: A rasp-like or ribbon-shaped structure that bears rows of teeth used in feeding.

Recurved: To curve back at the tip of the shell's lip. (See also reflected)

Reticulate: A network pattern of lines or grooves.

Ribs: Raised, transverse ridges on the surface of the shell.

S

Self-fertilization: This is an event where an organism is produced by the fertilization of an egg by sperm from the same organism. (See also hermaphrodite)

Semi-slug: A snail that possess a very reduced (no definite coiling) or small shell, that is often located on the posterior edge of the mantle. The animal is not able to retract into this minute shell.

Sexually dimorphic (Sexual dimorphism): This term is used to refer to any species where there is a physical difference between males and females of that same species (e.g., in peacocks, only males have the distinctly colorful feathers on the tail).

Shell: A hard, inflexible, calcareous or chitinous structure that vary in size and may either completely encasing the animal, covering some part of it or be internal.

Sinistral: Having the opening of the shell on the left side when the observer hold the shell so that the apex is upwards and the aperture faces them.

Siphon: In aquatic and semi-terrestrial gastropods, this is a narrow breathing tube formed by an extension of the mantle.

Slug: A snail that either does not possess a shell or has one that is very reduced (no definite coiling) or internal.

Spermatophore: This is a capsule or sac of male gametes and nutrients, which is produced by the male organ of the snail. This capsule is often transferred as a whole, to the female reproductive organ during mating.

Spiral: Directional term: direction of the coils of the whorls of a shell; opposite of axial.

Spire: All the coils (whorls) of a shell above the body whorl.

State: The basic component or distinct phase of a Lucid feature or character that can be observed, measured, or otherwise assessed.

Striae: Any linear indentation on the surface of the shell. They can be either spiral (stripes) or axial (bands) in direction.

Striations: Having a series of stripes, grooves or lines.

Stripe (s): 1). In slugs: Any longitudinal line that runs from the head of the animal to the tail. 2). In snails: Any spiral line that follows the whorls.

Succiniform: Shell shape: shell that is higher than wide with a very large aperture (mouth). The spire is generally brief and the body whorl very expanded.

Suture: The junction/seam between the whorls of a mollusc's shell.

t

Tentacles: Sensory projections on the head end of a mollusc. There are generally two pairs; upper (posterior) and smaller, lower (anterior). The upper pair bears the eyes. In many snails the eyes are located at the tips of this structure; however, in Basommatophoran snail species, the eyes are located at the base of the tentacles.

Tooth (teeth): Tooth-like structure in the opening of the shell (not to be confused with the radulate teeth in the mouth of the animal). (See also denticle).

Translucent: Allows light to pass through but prevents the ability to see distinct objects.

Tripartite: Having three distinct section/regions.

Tubercle: An enlarged or raised region on the body of a slug. The shape of this structure is very variable.

Tubercles: An enlarged or raised region on the body of a slug. The shape of this structure is very variable. (See also tubercle)

u

Umbilicus: A navel-like indentation or depression in the center of the shell. It may be described as open (inside of columella visible), partially closed (partly covered by base of aperture) or completely closed (not visible). The width of the umbilicus is a measure of its greatest diameter.

v

Visceral mass: The region of the mollusc's body that contains the organs.

Viviparous: Ability to give birth to live young (no eggs produced), where the embryo develops inside the parent. (See also oviviparous)

w

Whorl: A complete spiral turn/growth of the shell of a mollusc. The whorls are counted from the apex outwards.

Whorls: Pleural of whorl. A whorl is a complete spiral turn/growth of the shell of a mollusc. The whorls are counted from the apex outwards.

Width: The width of the shell is the maximum distance across the shell (including the aperture).

How to Identify Terrestrial Gastropods

Introduction

It may be difficult, even for malacologists, to identify molluscs, simply because they do not usually possess many characters that are consistently useful for distinguishing among related species. This section of the tool was designed to assist the user in becoming familiar with the common characters that are used in the identification of terrestrial snails and slugs.

Shell Classification

How do you know if you truly have a snail or a slug?

Gastropods that possess an obvious shell are termed snails whereas gastropods that appear to lack an obvious shell are termed slugs. In the case of semi-slugs it may be debatable whether the animal should be considered a snail or a slug. The entities included in this tool are divided into two major categories (snails and slugs) to reduce ambiguity and to allow users to quickly and more efficiently navigate through the key.

- Shell Present:

Shell obvious with definite coiling and animal may be able to retract into it.

Figure 1. Typical snails

- Shell Absent:

Shell very reduced or internal and if present, it has no definite coiling. If the shell is partially external, it is usually small and is located on the posterior end of the mantle (see image below, far right).

Figure 2. Typical slugs

Slug Characters

Several morphological characters can be used to identify slugs. A few of these include:

Mantle Characters:

- Body covered by mantle (partly or wholly)
- Location of breathing pore on mantle (or on the body of the animal)
- Mantle groove

Body Characters:

- Length (preserved specimens may shrink to approximately 70-80 % the length of living specimens)
- Body color
- Body markings (spots, blotches, stripes, bands)
- Mucus pore
- Length of the slug (fully extended at maturity)
- Sole color
- Tail constriction at the point of amputation (this is a faint groove that can be observed on the dorsal surface of the tail; behind the mantle. A narrow dark-colored band on the sole of the animal can also represent the point of amputation.) It should be noted that the point of amputation might not always be visible in species that typically possess one.

Mucus Color:

- White, yellow, orange, clear

Keel Characters:

- Presence or absence of the keel
- Length of the keel

Shell Characters

Shells generally have a large number of characters that can be used to distinguish between groups of snails. Shell sculpturing is one such character.

Common shell sculpturing include:

- Hairs/Bristles – projections on the shell that resemble mammalian hair
- Pits – regularly shaped indentation in the shell
- Dents- irregularly shaped indentations in a shell
- Striae – groove-like indentations that follow the whorls
- Lirae – raised ridges that follow the whorls
- Ribs – raised ridges that run at an angle (usually transversely) to the whorls
- Pleats/ Wrinkles – any type of ridging or creasing that appears to have been formed by folding or crumpling

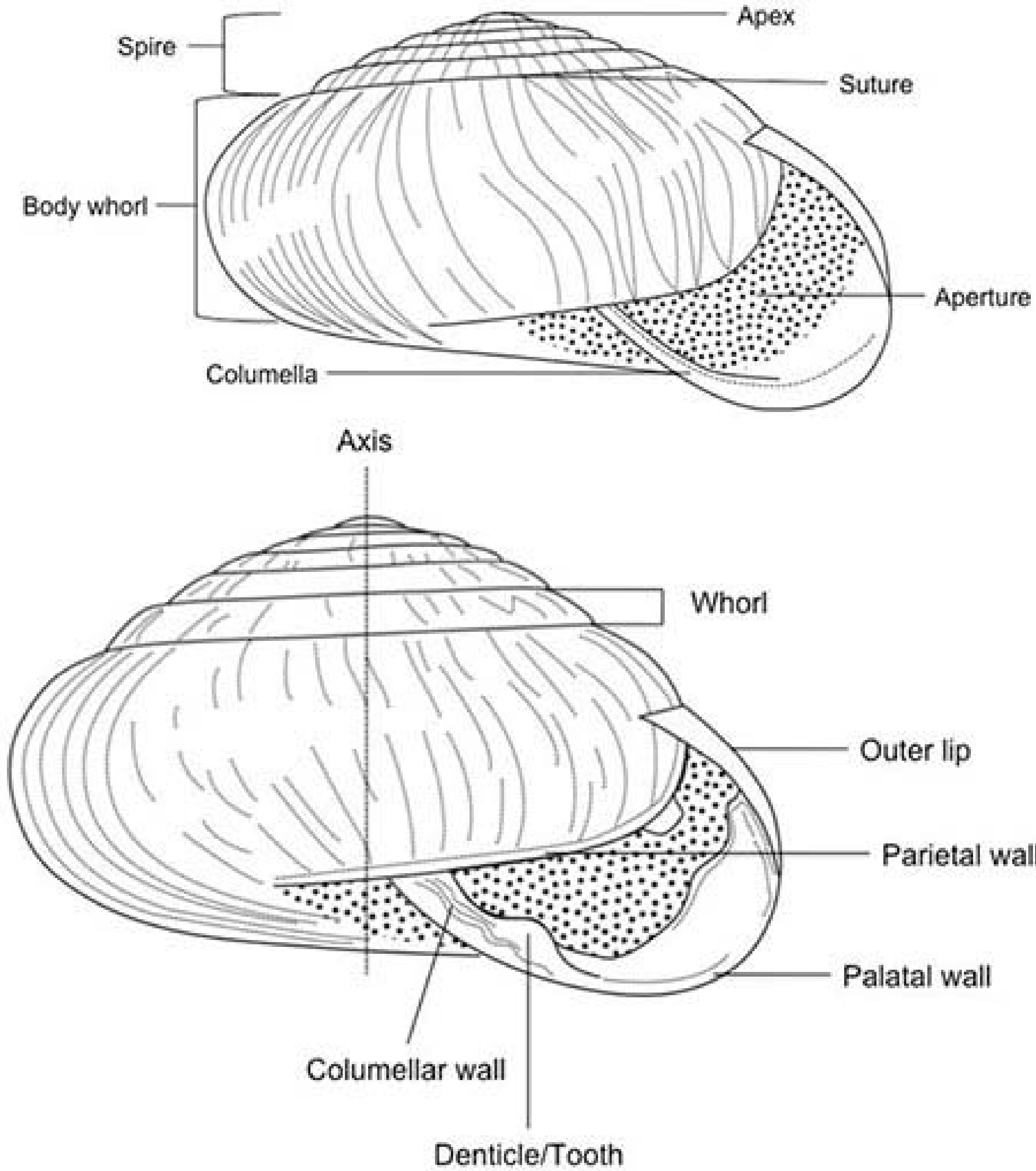


Figure 3. Shell terminology.

Common Shell Types

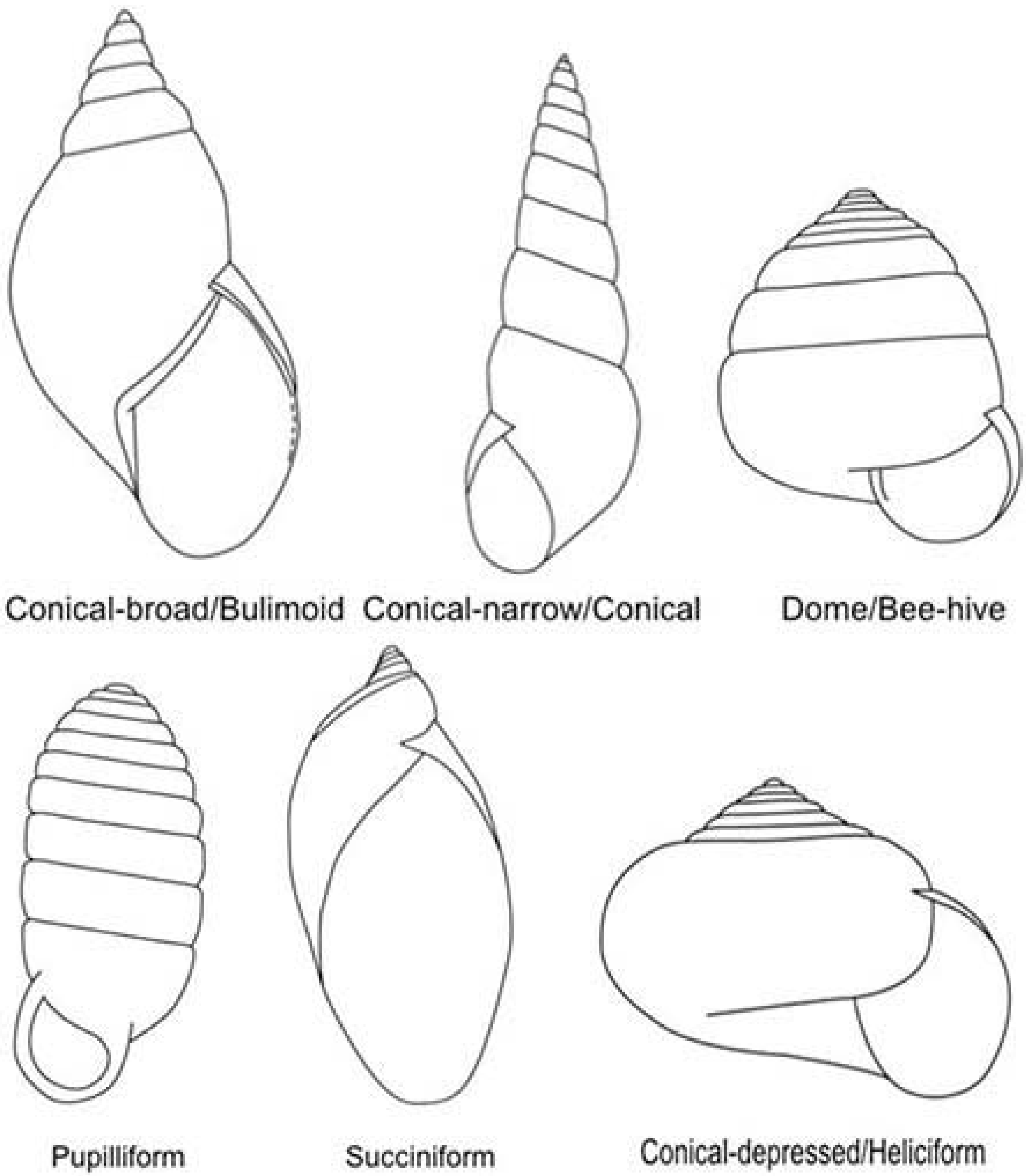
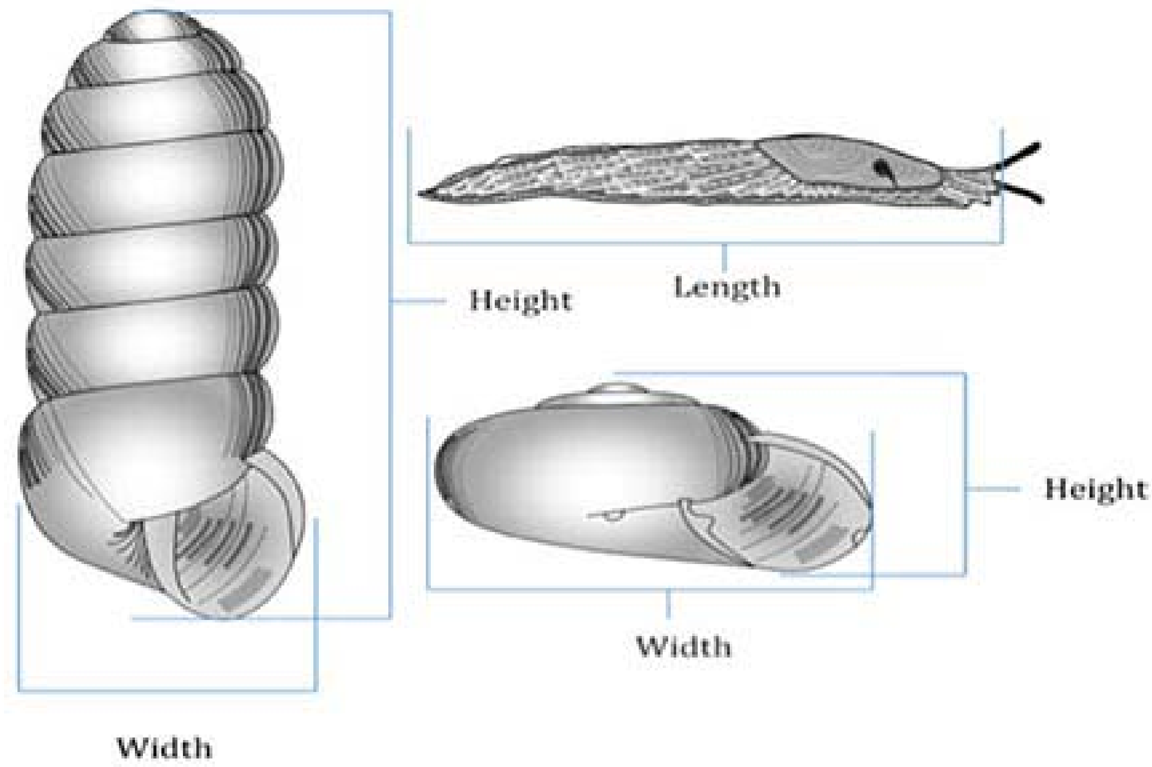


Figure 4. Common shell types.

How to Measure a Terrestrial Gastropod

Measurement can be a useful character in the identification of a terrestrial gastropod. In snails, the length is taken from the apex of the shell to the base of the aperture (mouth). The width should be taken at the widest part of the shell when the shell is oriented so that aperture faces the observer; the width is measured from the side of the body whorl to the outermost side of the aperture (mouth). Terrestrial slugs are measured from the head, excluding the tentacles to the tip of the tail (Figure. 5). It is important that the animal is fully extended to in order to obtain an accurate measurement.



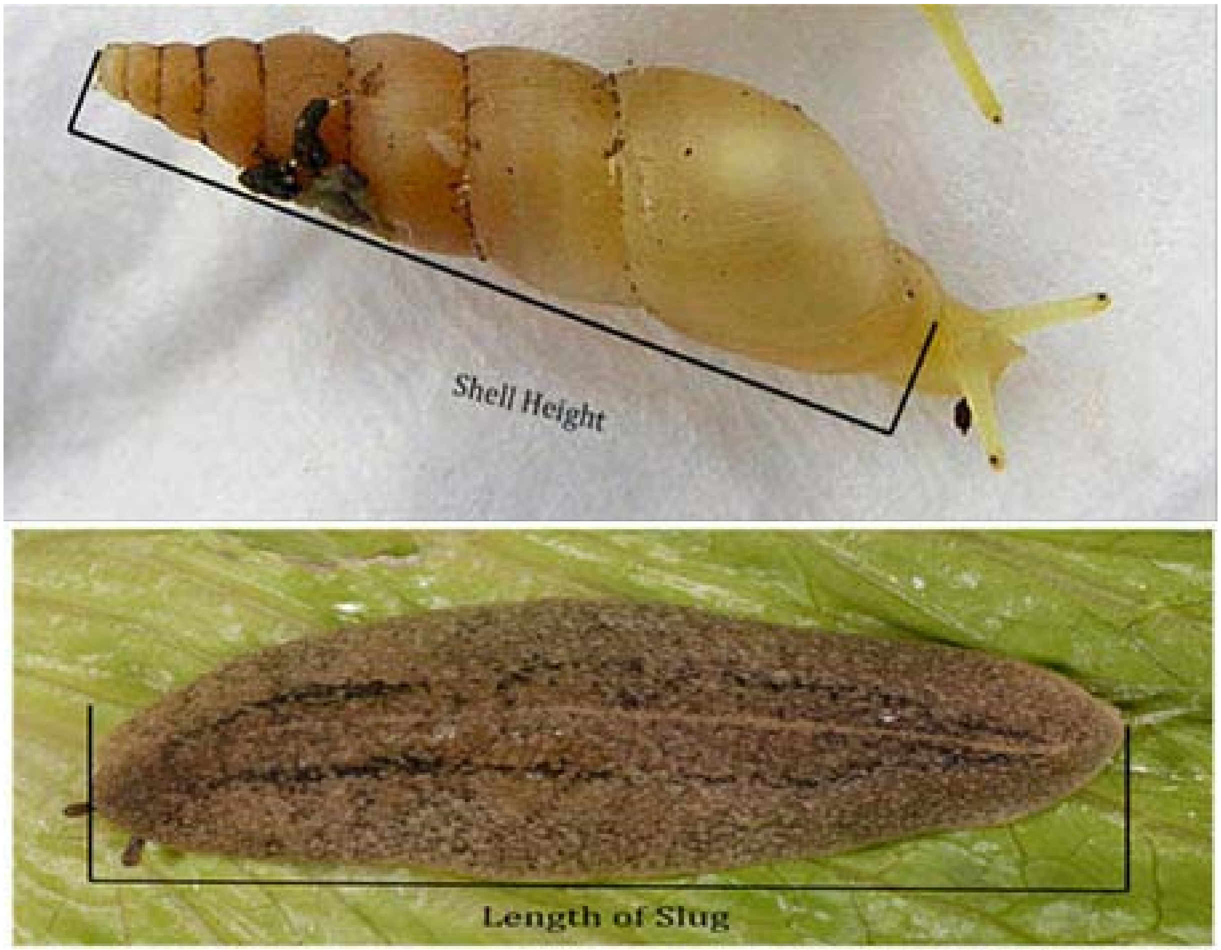


Photo © L. Buss, University of Florida

Figure 5. Measuring terrestrial gastropods

Umbilicus

The umbilicus may be used as a diagnostic character when classifying snails. The umbilicus may be open or closed. The width of the open umbilicus is taken at the widest part of the inner surfaces of the body whorl (Figure. 6).

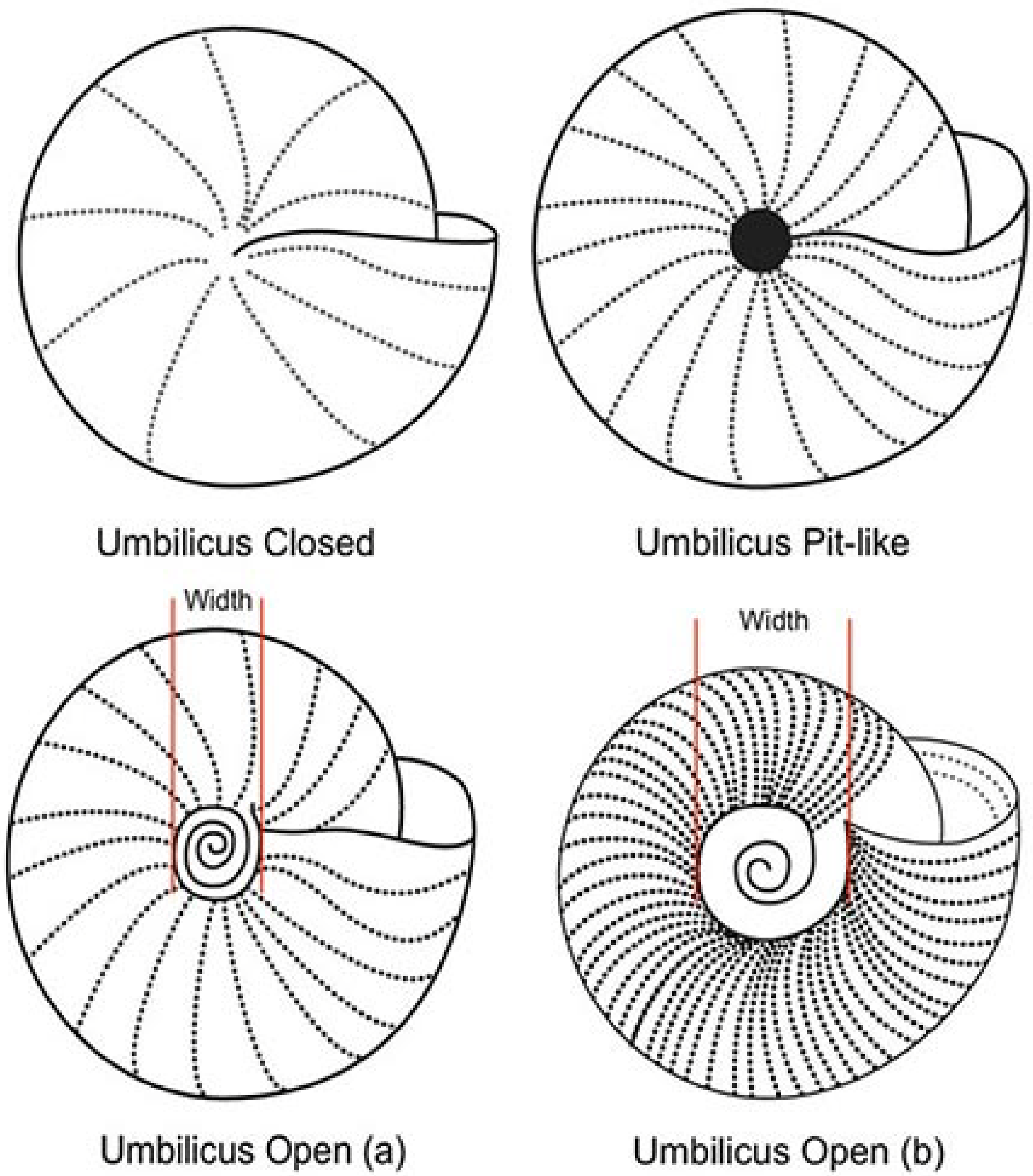


Figure 6. Types of umbilicus commonly observed in terrestrial snails.

Counting Whorls

There are several ways to count the number of whorls on the shell of a snail. The most commonly used method described by Pilsbry (1939) will be discussed here. Before counting the whorls, an imaginary line should be drawn across the shell as demonstrated in figure 7 below. The whorls are then counted following the direction of the coils. A complete turn indicates a whorl (i.e., every time the line is intersected when following the whorls). The body whorl may not be complete, meaning that it may end in quarters or thirds (Figure 7).

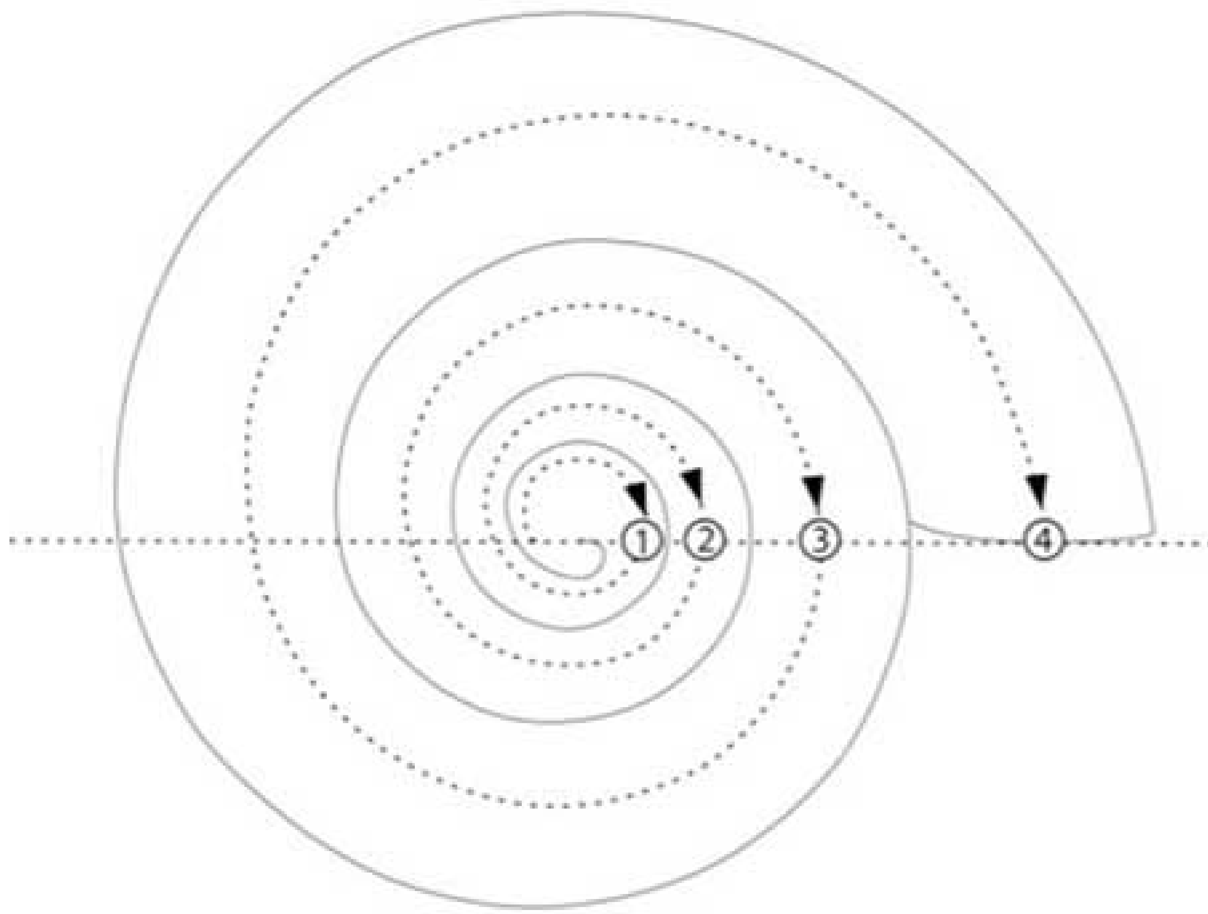


Figure 7. Counting shell whorls.

Genitalia

The genitalia (formed by the fusion of both male and female structure) are one of the most diagnostic characters used to distinguish between mollusc species. In many groups (e.g., Veronicellids), a positive identification cannot be obtained without the use of the genitalia characters. A generalized diagram of the genitalia can be found in Figure 8. There may also be reproductive structures that are present in some species and not others. Additional information on the genitalia (structure and function) can be found in the biology section of this tool.

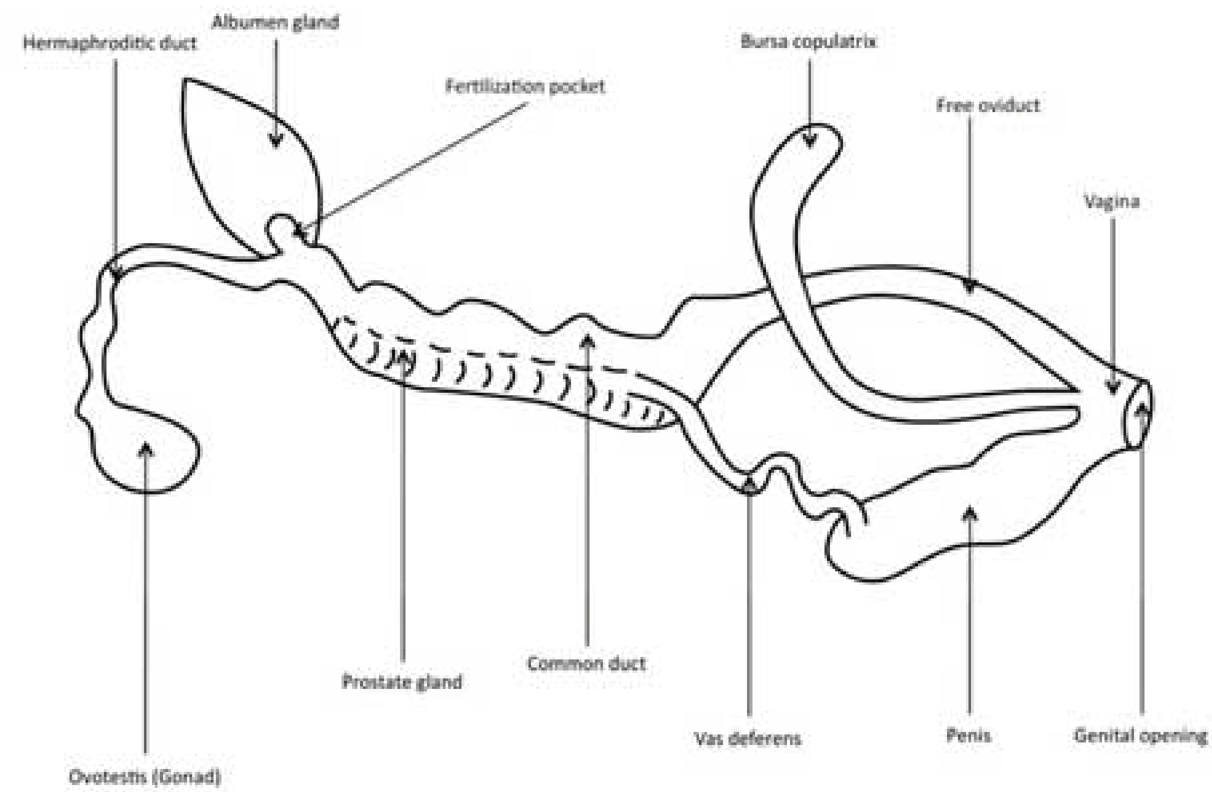


Figure 8. Generalized diagram of a terrestrial mollusc's reproductive system.

Biology and Ecology

Biology

The phylum Mollusca is one of several invertebrate (animals without a spine) groups and comprises a wide array of animals including gastropods (snails and slugs), cephalopods (squids, octopuses) and bivalves (clams, oysters). Of this group, the primary focus of this tool will be the terrestrial gastropods. In general, snails are often described as those species that possess a shell into which they can retract partially or wholly. Slugs may or may not have shells and for those species that do have shells, it is much reduced and may be internal. Also, for those slug species that have external shells, the shell cannot host the body of the animal and no obvious coiling can be observed.

All terrestrial gastropods have sensory organs referred to as tentacles. There are often two pairs: the larger, upper pair (ocular tentacles) bears the eyes at their tips, and the lower pair (oral tentacles) is used as a sensory organ for detecting odors (Figure 1). Some snail species have only one pair of tentacles (i.e., they lack the ocular tentacles).

In these species, the eyes are located at the base of the sensory tentacles.

Figure 1 . General anatomy.

The mouth of the animal is located below the tentacles. It contains a specialized structure known as a radula, which is comprised of a mass of chitinous teeth arranged in rows. The radula is used to scrape pieces of food into the mouth of the animal using a back and forth motion.

The reproductive opening (genital pore) of terrestrial gastropods is generally located anterior-laterally. In snails, the genital pore is located on the head of the animal, just behind the tentacles. Slugs, however, have their genital pore located between the breathing pore and the head, and in some cases this structure may conceal by the mantle. Slugs in the family Veronicellidae are a notable exception to this rule. The genital opening of this group is located ventrally and there are two openings: one that allows access to the female portion of the genitalia and another that allows for the eversion of the male portion of the genitalia.

In most terrestrial gastropods, both sex organs occur in the same organism; however, there are a few cases where aphallic (does not have a penis) specimens of normally hermaphroditic species (e.g., *Deroceras laeve*) do exist. However, there are a few species in which separate sexes occur (e.g., *Marisa cornuarietis*).

The mantle is a structure that is located on the dorsal surface of the animal, just behind the head, and it mainly functions to secrete compounds that are used to construction the shell. In snails, the mantle is not readily noticeable as it is often restricted to the shell. On the other hand, the mantle of slugs is readily visible and generally extends over the back of the animal, covering anywhere from 30-100% of the dorsal surface (Figure 2). The mantle may extend over the shell of a few species of semi-slugs (e.g., Helicarionidae) when they are active, and can be retracted voluntarily by the animal.

The pneumostome or breathing pore is an opening in the mantle of the animal that supports gas exchange, by serving as the entrance to the animal's lung. The pneumostome is located on the right side of the animal (i.e., when the animal is positioned with the tail facing the observer, the pneumostome is on the right of the observer).

The ventral portion of the animal bears a muscular structure termed the foot, which is used in locomotion. The skin of the entire animal secretes mucus that aids in the movement of the animal and also serves to reduce dehydration. Many terrestrial gastropods will produce copious amounts of mucus in an attempt to evade potential predators or when irritated.

Figure 2. A: Mantle covering the dorsal surface of the body: A-30%, B-100%.

Figure 3. General Shell Anatomy

Ecology

Snails and slugs display selective preference for moist, humid habitats (e.g., gardens, forests, wetlands, greenhouses). There are a few terrestrial species that are adapted to environments atypical of terrestrial gastropods (e.g., the snail *Cernuella virgata* is adapted to living in sand dunes). Snails may aestivate under unfavorable conditions, by retracting into the shell and producing a mucilaginous structure (epiphragm) in the aperture (mouth) of the shell. The epiphragm will desiccate and become papery, thus sealing the aperture to reduce moisture loss. Prior to aestivation, some species prefer to affix themselves to vertical structures such as the sides of buildings, grass blades, and fence posts.

Terrestrial slugs generally prefer to inhabit dark, humid places such as beneath rocks and logs on the forest floor, in leaf litter, and under tree bark during daylight. They are normally nocturnal, although they may be found wandering about during the day after it rains. Snails and slugs feed primarily on plant material (living or dead), mushrooms, and lichens. On occasion, terrestrial slugs and snails may feed on conspecifics, other species of molluscs and their eggs, and calcareous material (e.g., rocks, headstones).

Snails: Juvenile to Adult

It is sometimes difficult to determine if a snail of a given species is a juvenile based solely on its shell. In many cases observation of the genitalia, through dissection of the specimen, is required. As a general rule, the shell of juveniles tend to have brittle apertural lips, whereas the apertural lips of adult specimens are often thickened, rigid and may be reflected in some species (e.g., *Otala* spp. and *Eobania vermiculata*). Also, the base of the juvenile aperture curves downward, whereas in adult specimens the apertural lips generally curve outward, rather than downward (Figure 4).

Figure 4. Comparison of juvenile and adult shells of *Zachrysia provisoria*.

Reproductive System

The genitalia (formed by the fusion of both male and female structures) are one of the most diagnostic characters of molluscs. In many groups (e.g., Veronicellids), positive species identification cannot be made without the use of the genitalic characters. A generalized diagram of the genitalia can be found in Figure 5. There also may be genitalic structures present in some species and not others. Some of these structures are illustrated in Figure 6.

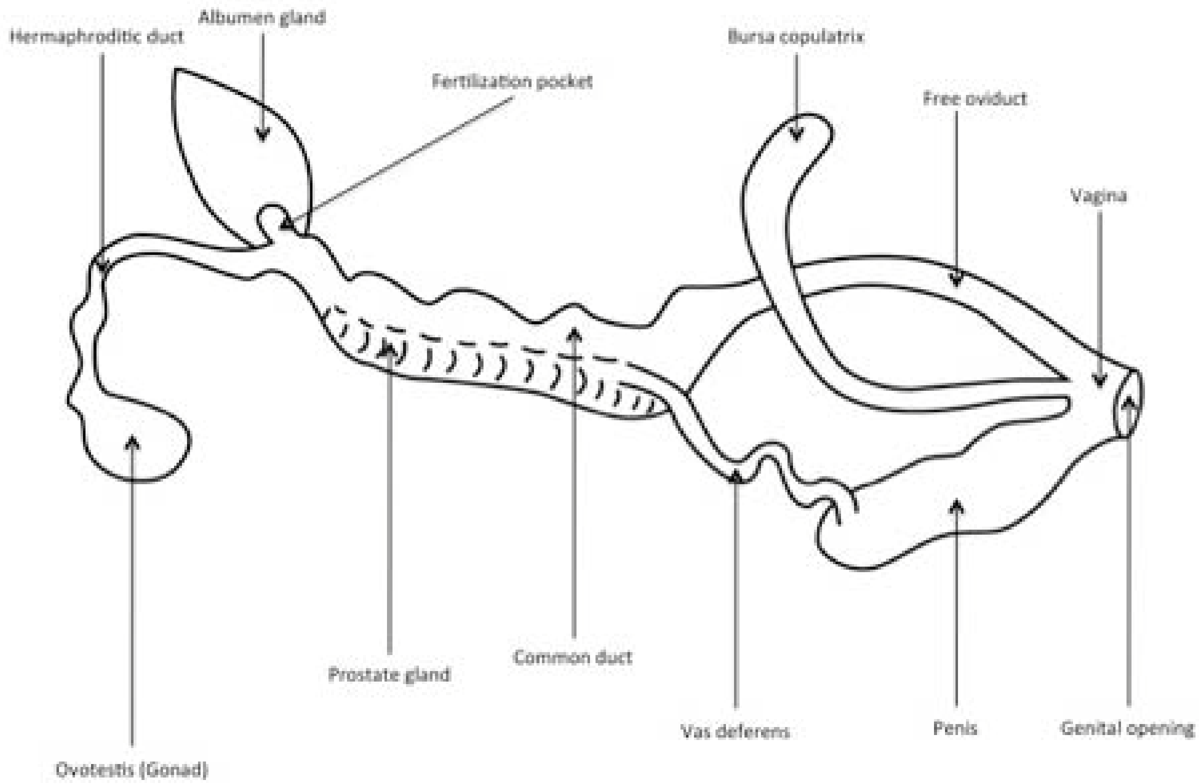


Figure 5. Diagram of a terrestrial mollusc's generalized reproductive system.

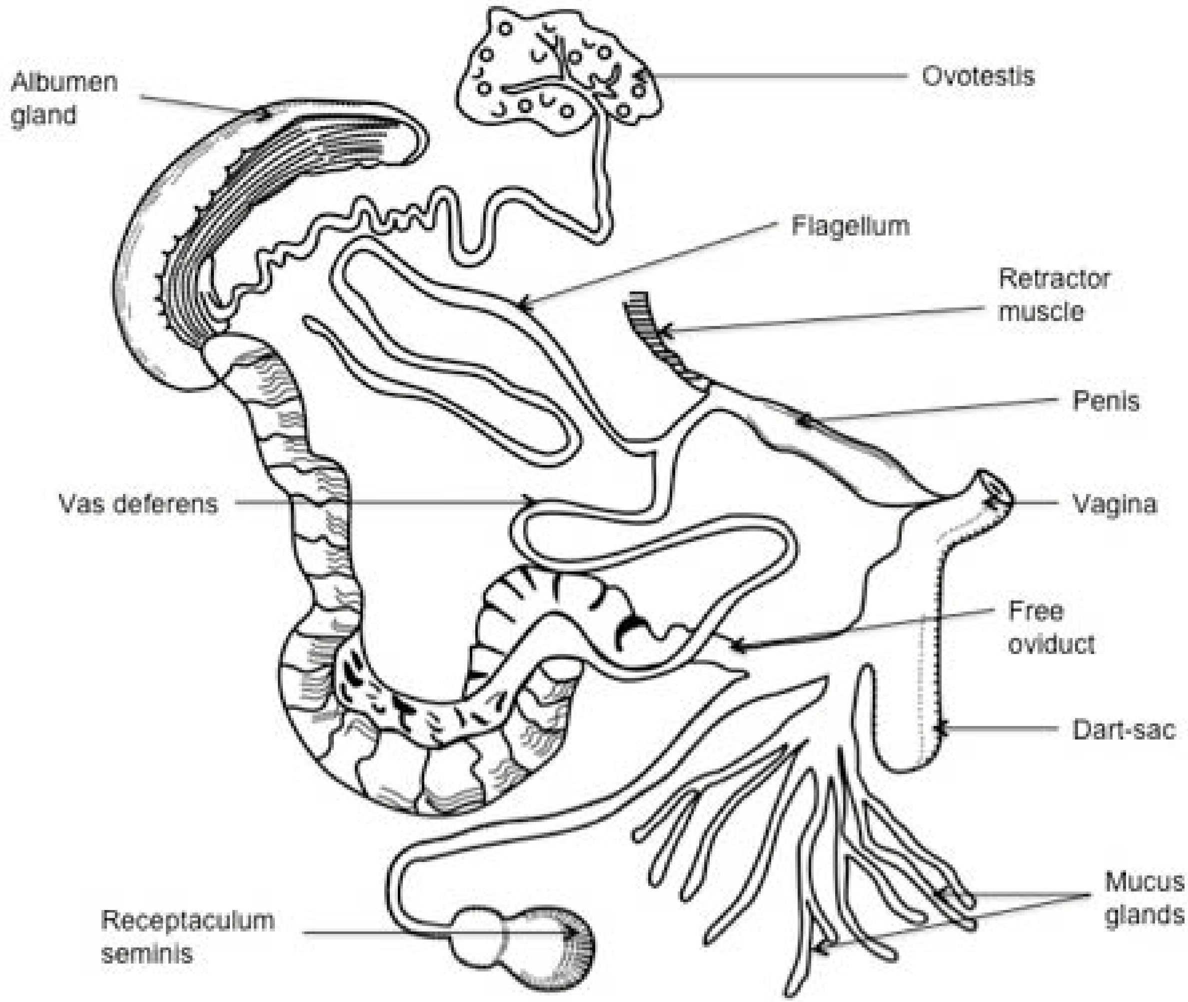


Figure 6. Diagram of a terrestrial mollusc's reproductive system with additional specialized structures.

Parts of the Reproductive System and their Function

- Ovotestis/Gonad: Site of egg and sperm development in hermaphroditic species (i.e., it functions as an ovary and a testis).
- Hermaphroditic duct/Ovotestis duct: Allows for the passage of the gametes to the fertilization pocket.
- Seminal vesicle: Functions in sperm storage (sometimes allow for further sperm maturation), re-absorption and degeneration.
- Albumen gland: The function of the albumen gland is to produce albumen or perivitelline fluid for the egg.
- Fertilization pouch-spermatheca complex (FPSC)/Fertilization pocket (pouch)/Talon/Carrefour/Spermoviduct: As its name suggests, this is the place where fertilization occurs.

- Prostate gland: Functions to produce seminal fluid.
- Bursa copulatrix/Spermatheca/Gametolytic gland: Functions to receive sperm during copulation. It is also said to have a function in sperm degradation.
- Oviduct: Functions to separate the groups of oocytes coming from the ovary into a line in order to increase the chances of being fertilized.
- Vas deferens: Functions to accumulate sperm prior to copulation.
- Vagina/Upper atrium: Functions to receive sperm during copulation.
- Atrium: Allows entry to the reproductive system.
- Flagellum: Used in sperm transfer.
- Penis: Functions to transfer sperm during copulation.

Cross-fertilization

Terrestrial gastropods have the ability to independently manipulate the movement of the eggs and sperm that originate in the ovotestis.

Figure 7. Generalized diagram of the cross-fertilization process (Modified from Wiktor 2000).

1. Sperm cells are continuously produced by the ovotestis and released into the hermaphroditic duct. The sperm cells may be temporarily stored in the hermaphroditic duct in seminal vesicles. When the sperm cells are needed for fertilization, the sperm cells actively migrate from the hermaphroditic duct to the fertilization pocket. Inside the fertilization pocket is a structure called the sperm

duct. The sperm duct forms a groove that can be voluntarily closed by the animal during copulation. This functions to prevent self-fertilization when not desired.

2. The sperm then migrates to the prostate gland, which produces fluids that provide nourishment to the passing sperm cells. This fluid is very thick and immobilizes the sperm cells. The immobilized sperm cells are then transported towards the vas deferens by the peristaltic movement of the walls of the prostate gland.
3. The sperm cells are then transferred from the vas deferens to the penis via the epiphallus. The penis is then everted and the sperm mass deposited into the recipient's atrium.
4. The sperm cells may be transferred directly into the mating partner's bursa copulatrix.
5. A small percentage of the sperm cells deposited into the bursa copulatrix will migrate into the oviduct.
6. The sperm cells now migrate from the oviduct into the fertilization pouch-spermatheca complex.
7. Eggs are voluntarily released from the ovotestis into the fertilization pouch-spermatheca complex where it will unite with sperms that have migrated there.
8. The fertilized eggs (zygotes) are provided with a nutritious albumen coat that is produced by the albumen gland. The eggs are then transported from the fertilization pouch-spermatheca complex into the oviduct section of the common duct where they may be arranged in a line (resembling a pearl necklace). Several layers of material of rich in calcium are then deposited around each egg prior to being laid by the recipient.
9. The recipient animal then deposits the fertilized eggs.

It should be noted that self-fertilization could occur in a similar manner as described above, except no donor is involved.

Snail and Slug Dissection

How to prepare the animal for dissection

Live specimens should be drowned in an airtight container that is completely filled with water. The animal should be left until completely drowned (i.e., unresponsive to touch). This will make it easier to dissect the specimen, as it kills the animal in an extended state (not contracted). Small snails may also be euthanized by emersion in boiling water. Specimens usually expire in a relaxed state and should be removed from boiling water when no longer responsive to touch.

The specimen should then be transferred to a dissecting dish containing 70 % ethanol or water. The solution should completely cover the specimen to minimize dehydration of the tissues. The dissecting dish should then be mounted onto the stage of the microscope and the dissection conducted under at least 10 X magnification.

Supplies:

Dissecting microscope
Water
Dissecting dish
Forceps
Scalpel
Dissecting scissors
Pliers
4-inch C-clamp or small vice grip (optional)
70 % Ethanol (optional)
Curved forceps (optional)
4 stainless steel insect pins (optional)

** Specimens should never be left in water for extended periods as rapid deterioration of tissues may occur.
*For photographing purposes, it is best that all organs be fully submerged. In order to optimize the quality of the photograph, ethanol should be used, as the animal will float in water.

Snail Dissection

Step 1

- Orient the specimen

Photograph of a freshly preserved animal. Note the head and tail region of the animal, as the specimen will appear different after removal of the shell. For humane purposes, ensure that the animal is completely unresponsive to touch before initiating the dissection. See supplies section on how to relax the specimen.

Figure: 01

Step 2

- Remove the animal from the shell

In some cases, it may be possible to remove the dead animal from its shell using curved forceps. If this is not possible, slowly break the shell from the aperture backwards, following the whorls, until the animal can be removed from the shell intact. (It is important to retain the broken pieces of the shell for identification purposes). A pair of needle-nose pliers may be used depending on the size of the animal's shell.

Figure:02

Figure:03

Figure:04

Figure:05

Step 3

- Submerge “Shell-less” animal in 75% Ethanol or Water

Diagram showing a Helix species with the shell removed (Figure 06) was provided to assist with the orientation of the specimen. Place the “shell-less” adult specimen in a dish with 75% ethanol or water covering it.

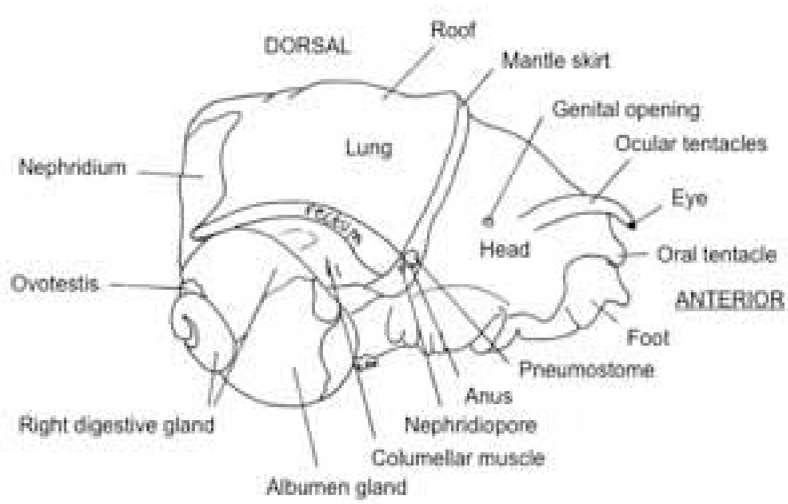


Figure 06

Figure 07

Step 4

- Uncoil snail and make an incision above the mantle skirt

Slowly uncoil the portion of the animal that was inside the shell to expose its contents. Make an incision just above the mantle skirt as indicated by the broken line in Figure 08. Be sure to make shallow incisions and angle the scissors upwards, and away from the internal organs. Cut as far along the skirt as possible.

Figure: 08

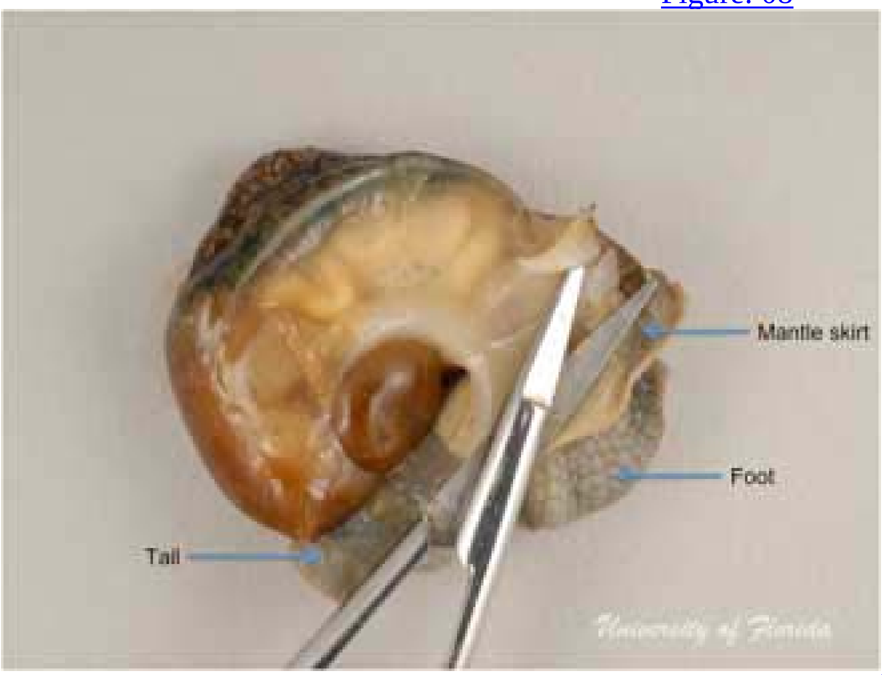


Figure: 09

Step 5

- Cut along the length of the thin membrane

Cut along the broken lines as indicated in Figure 10. Avoid all internal organs/structures by only cutting the thin (transparent) membrane. Continue with the incision along the edge of the membrane all the way to the first whorl. This will expose portions of the reproductive and digestive system. Also, cut along the lines indicated in Figure 12 to expose the base of both systems.

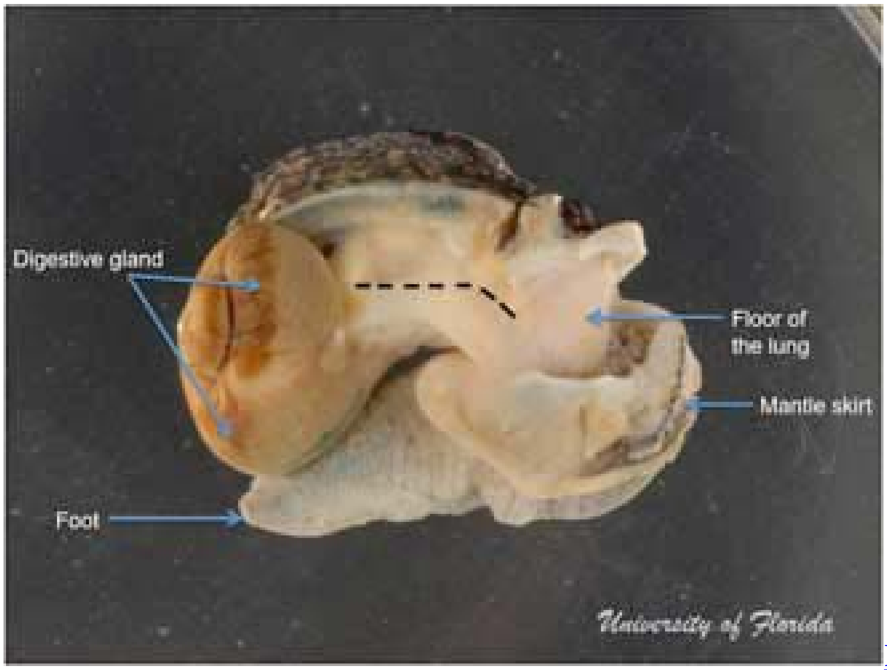


Figure: 10

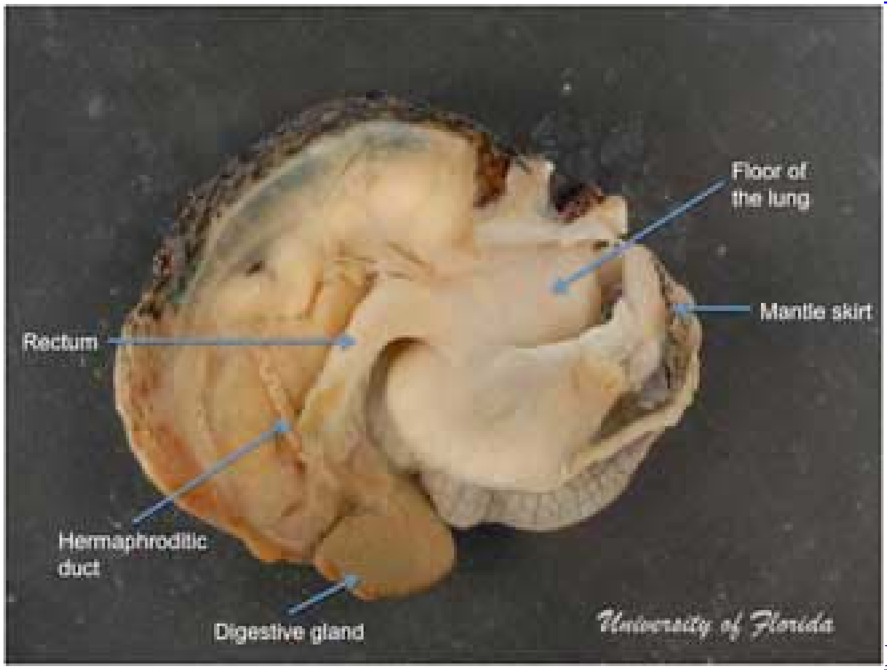


Figure: 11

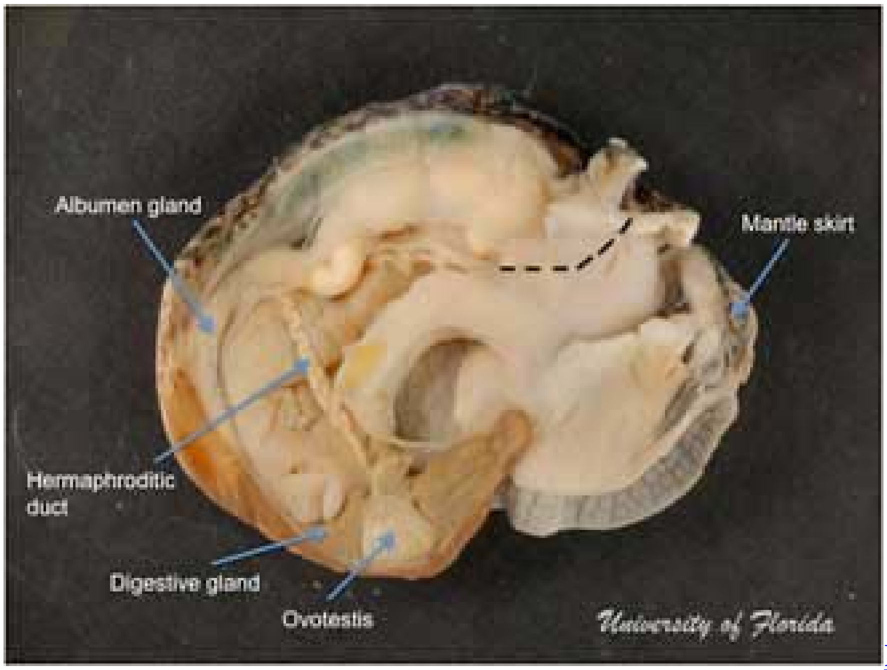


Figure: 12

Step 6

- Peel back the membrane to expose the internal organs

Peel back the transparent membrane to expose the internal organs. Continue with the incision made in Figure 12 all the way to the end of the coiled regions of the animal (portion that was retained inside the shell).The animal may be inverted to accomplish this as indicated by the broken lines in Figure 15.

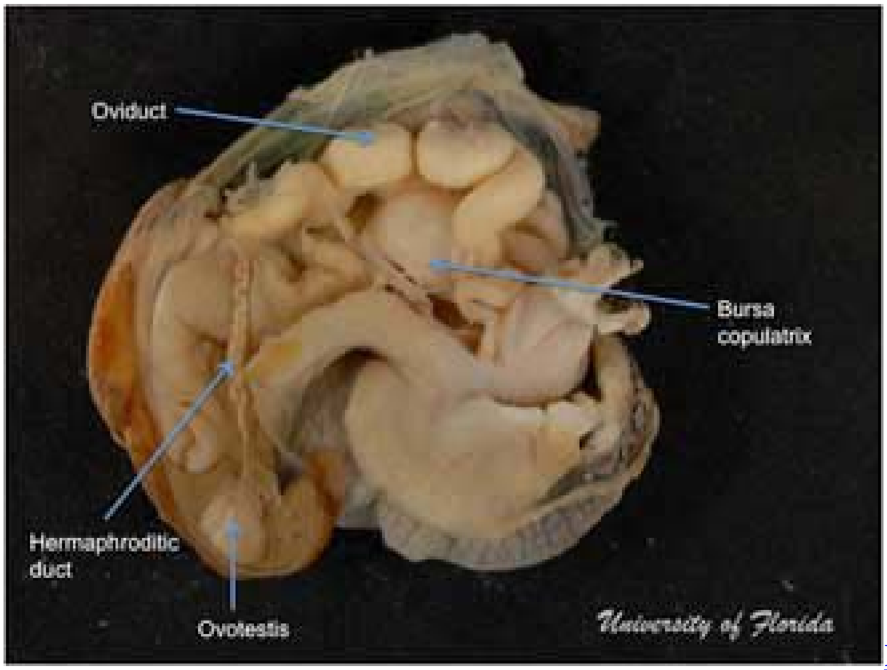


Figure: 13

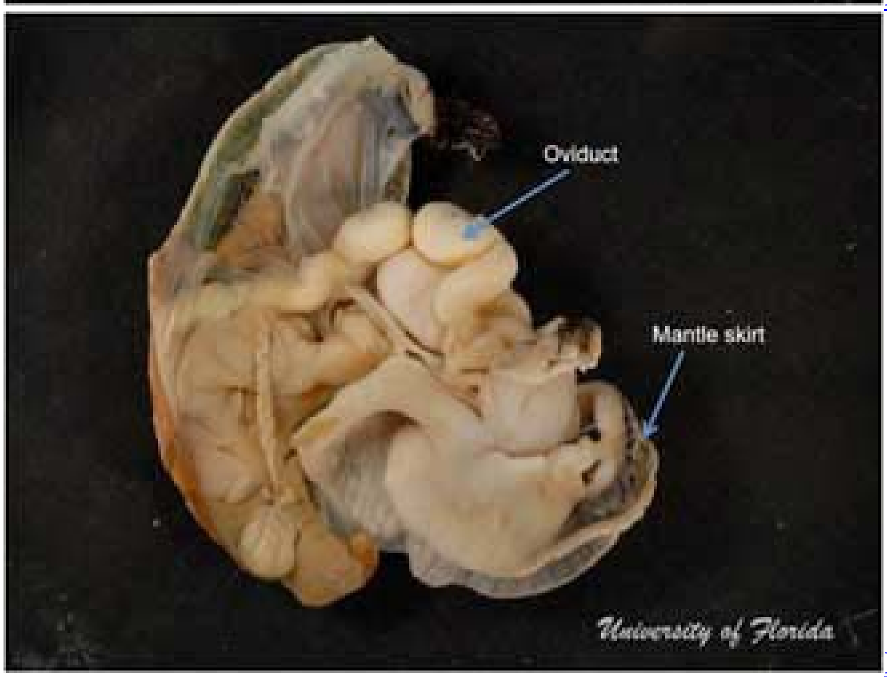


Figure: 14

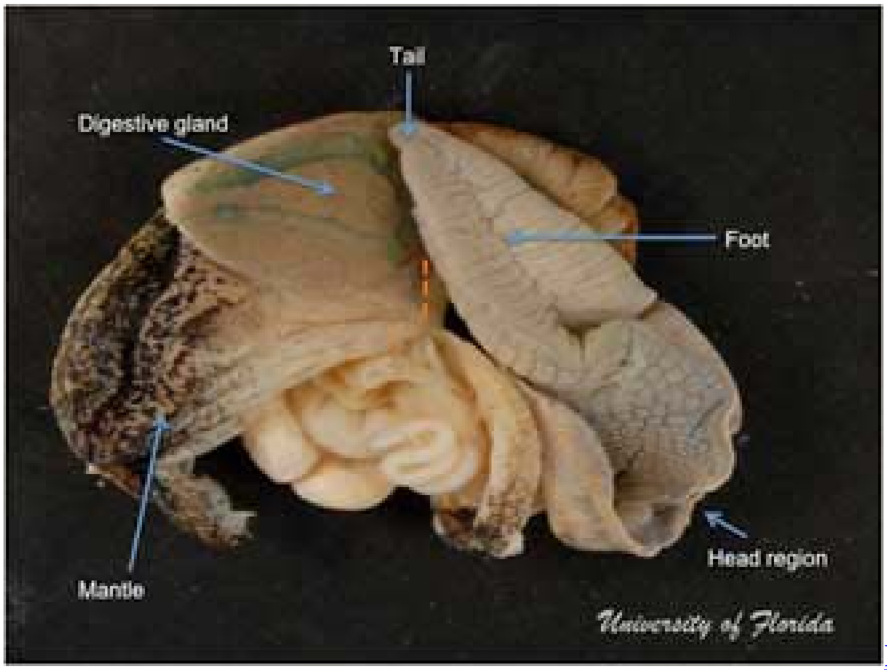


Figure: 15

Step 7

- Remove ovotestis from digestive gland

Slowly tease the ovotestis and the albumen gland away from the digestive gland. Both organs can be carefully separated with a pair of tweezers. Once dislodged, both systems can be separated as indicated in Figure 19.

Figure: 16

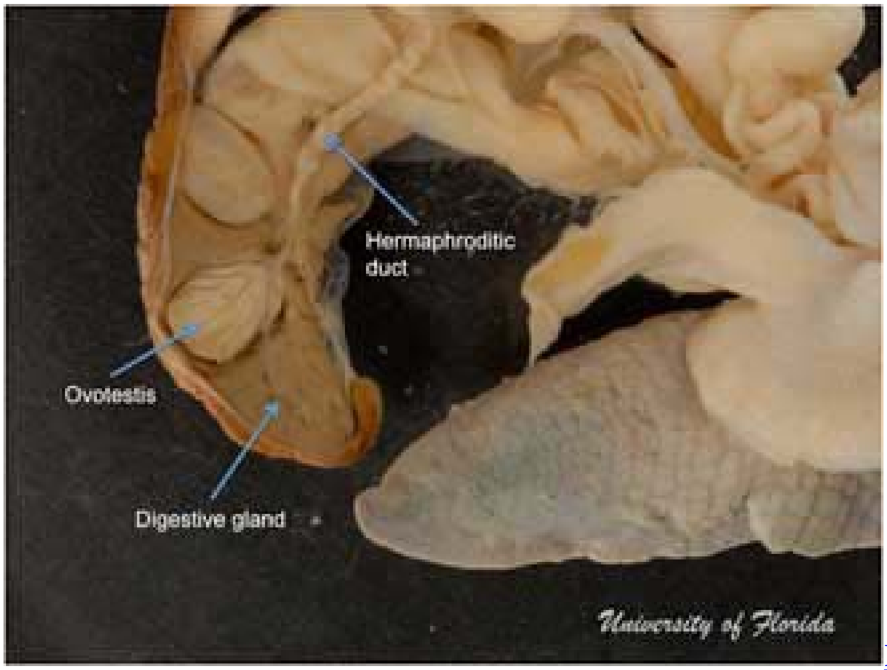


Figure: 17

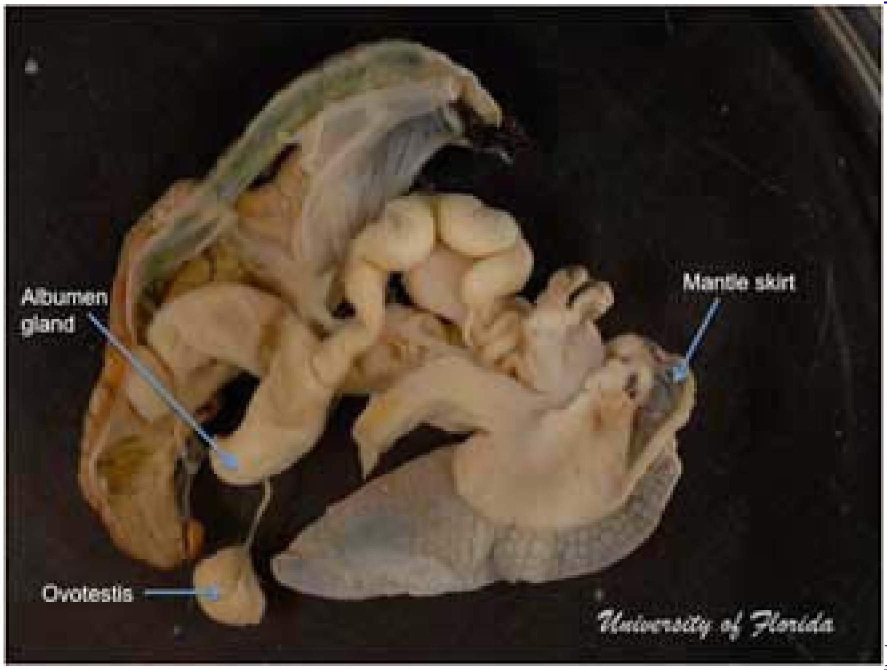


Figure: 18

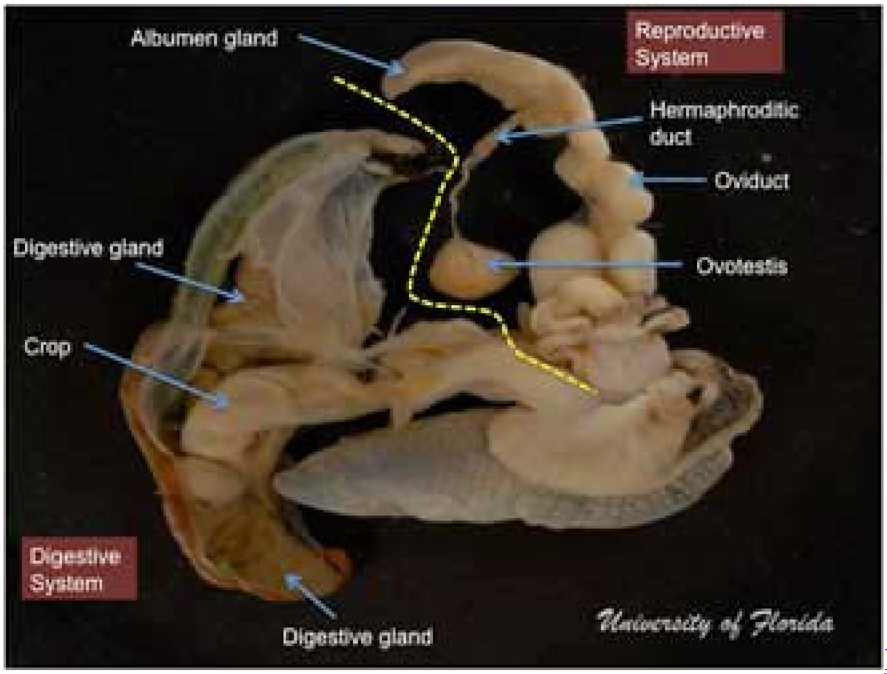


Figure: 19

Step 8

- Cut forward into the mantle skirt to expose the base of the reproductive system

Rotate the animal unto the side (may have to hold in hands) and cut into the mantle skirt going forward, towards the head. Be sure to make the incision between the ocular tentacles. This cut will expose the basal region of the reproductive system.

The pins can be removed from the specimen for photography or closer examination.

Figure: 20

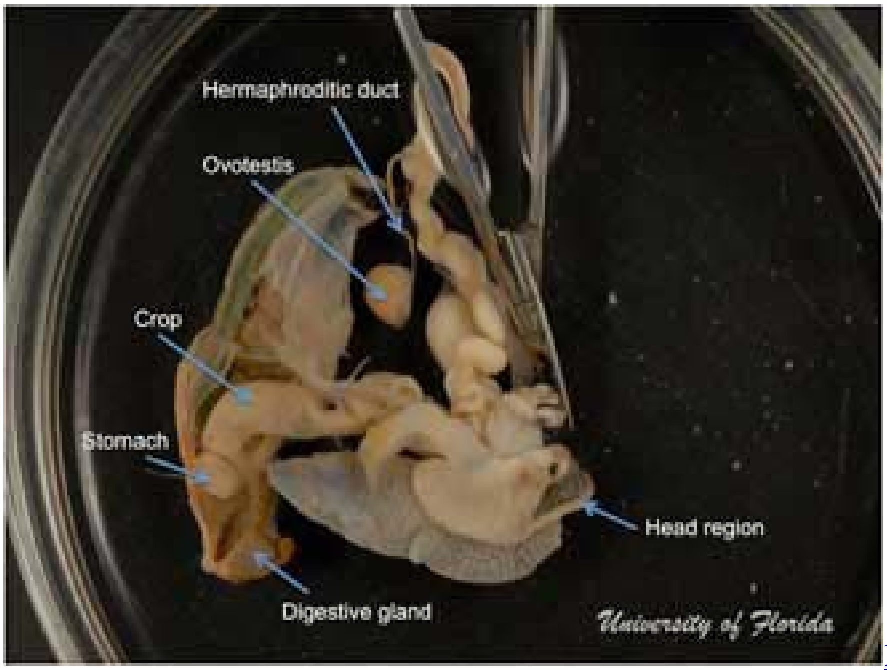


Figure: 21

Step 9

- Detach the reproductive system

Gently separate the reproductive system from the digestive system. Note the genital opening in Figure 22. Make incisions along the broken lines as indicated in Figure 22. Be careful to avoid cutting through the atrium. This incision will detach the entire reproductive system form the rest of the animal (Figure 23). Use an insect pin to gently unravel the vas deferens, bursa copulatrix, oviduct, flagellum, and penis by following the connection to each.

Figure: 22

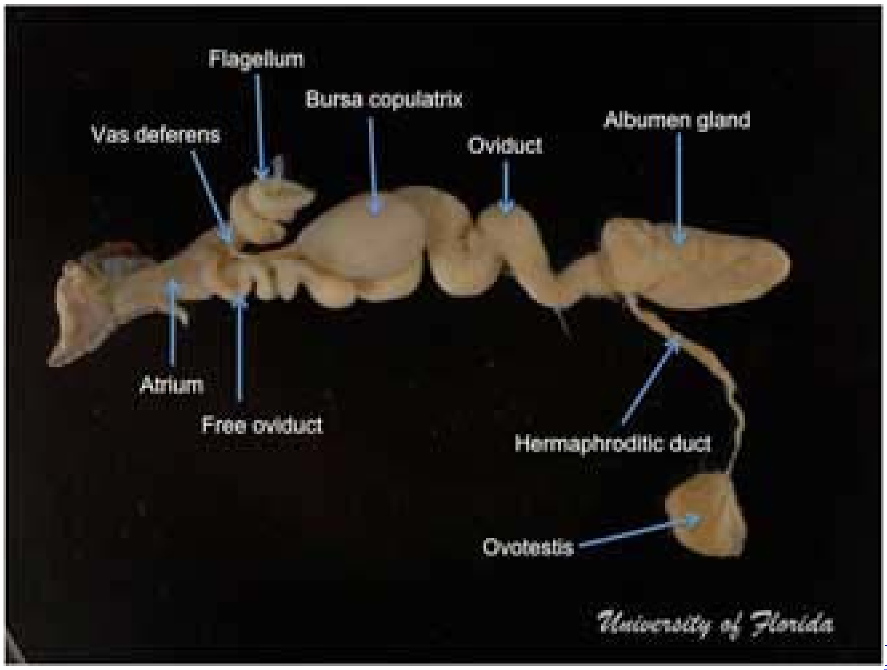


Figure: 23

Step 10

- Treatment for Photography

If a photograph of the reproductive system is required, the structures can be arranged and pinned as desired then fixed in place by immersion in 95% ethanol for approximately 15 minutes. DO NOT leave the reproductive structures in 95% ethanol for an extended period as dehydration and distortion will occur. The pins can be removed from the specimen for photography or closer examination.

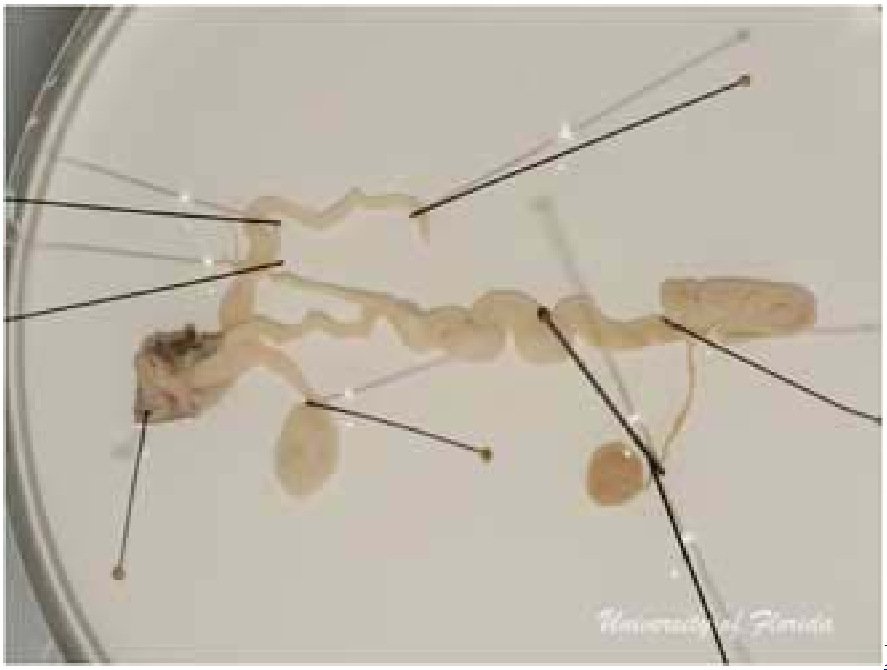


Figure: 24

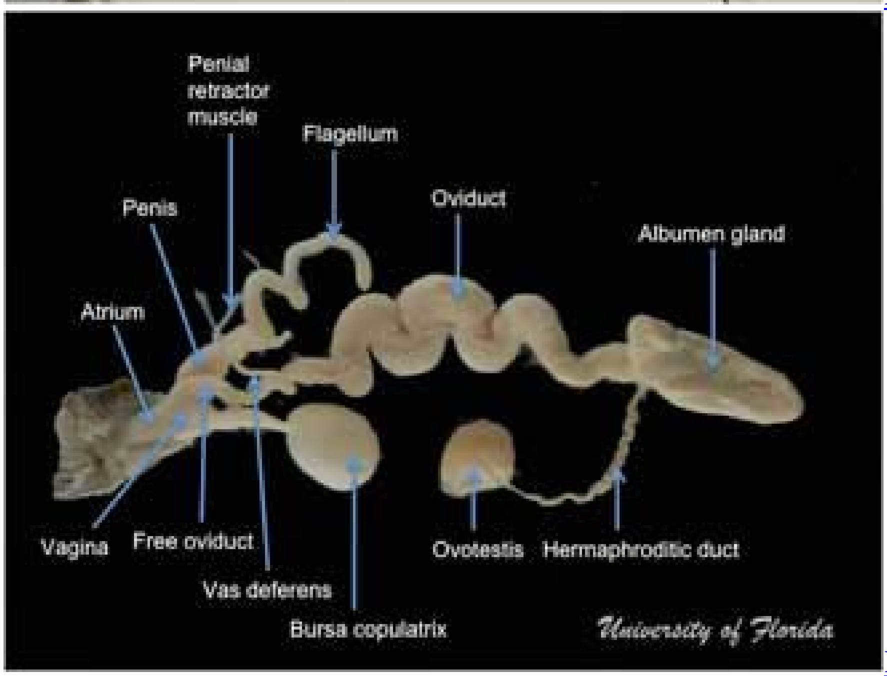


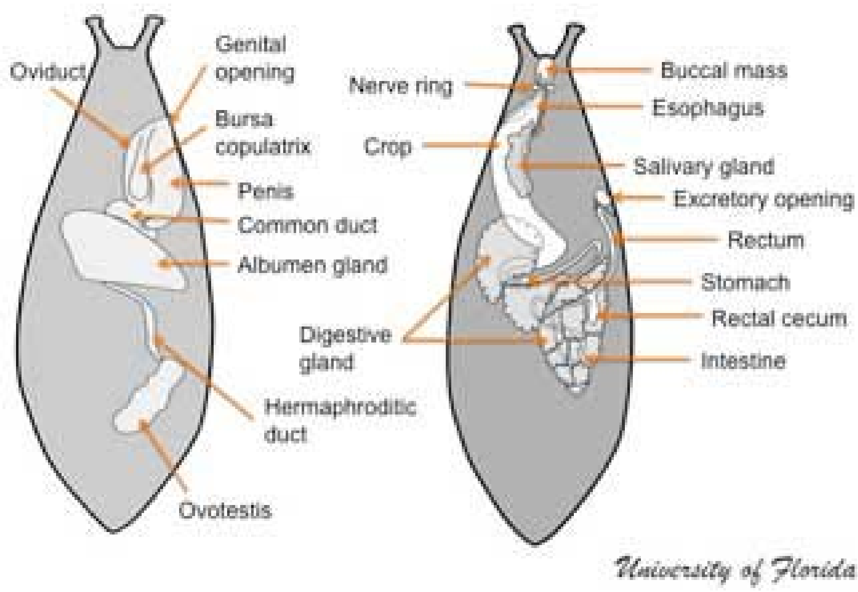
Figure: 25

Slug Dissection

Step 1

- Note general location of internal organs (dorsal view)

These are generalized diagrams of the digestive and reproductive systems. Both systems occupy most of the animal and in many cases are closely associated. Please note that the size, location and relative position of the reproductive organs may vary depending on the species.



View from dorsal surface

Step 2

- Orient the specimen

Photograph of a freshly preserved animal. Submerge the relaxed, extended adult specimen in a dish with 75% ethanol or water. Note the head and tail region of the animal, as the specimen will appear different after removal of the body covering or mantle. For humane purposes, ensure that the animal is completely unresponsive to touch before initiating the dissection. See supplies section on how to relax the specimen.

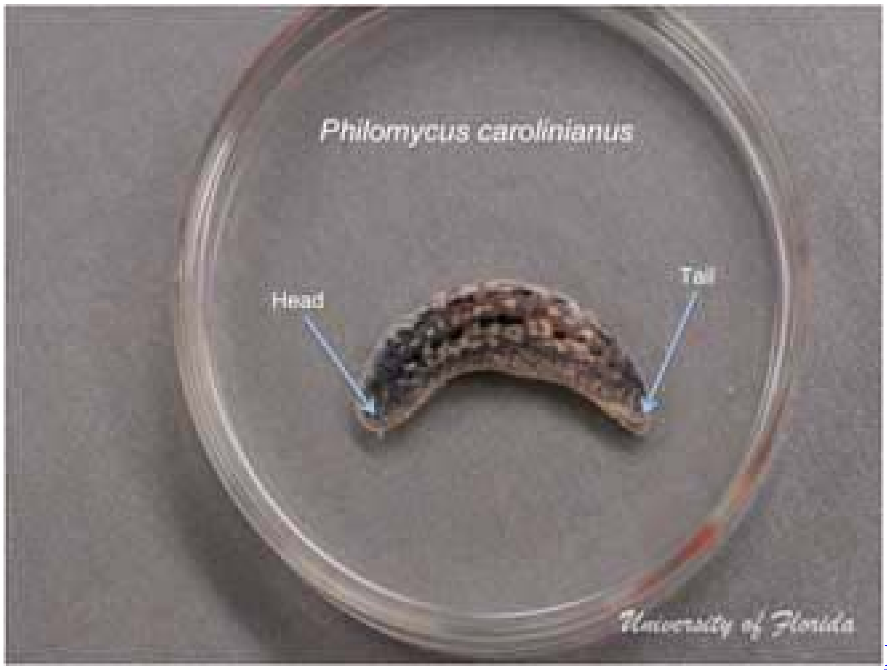


Figure 02

Step 3

- Remove the foot of the animal by cutting along the sole

Make a shallow incision near the tip of tail using a pair of sharp dissecting scissors. Angle scissors upwards and proceed with the incision along the foot of the animal. The incision should be made just above the foot fringe, groove, or where the body or mantle of the animal meets the foot. Cut towards the head of the animal (on both sides) to remove the entire foot.

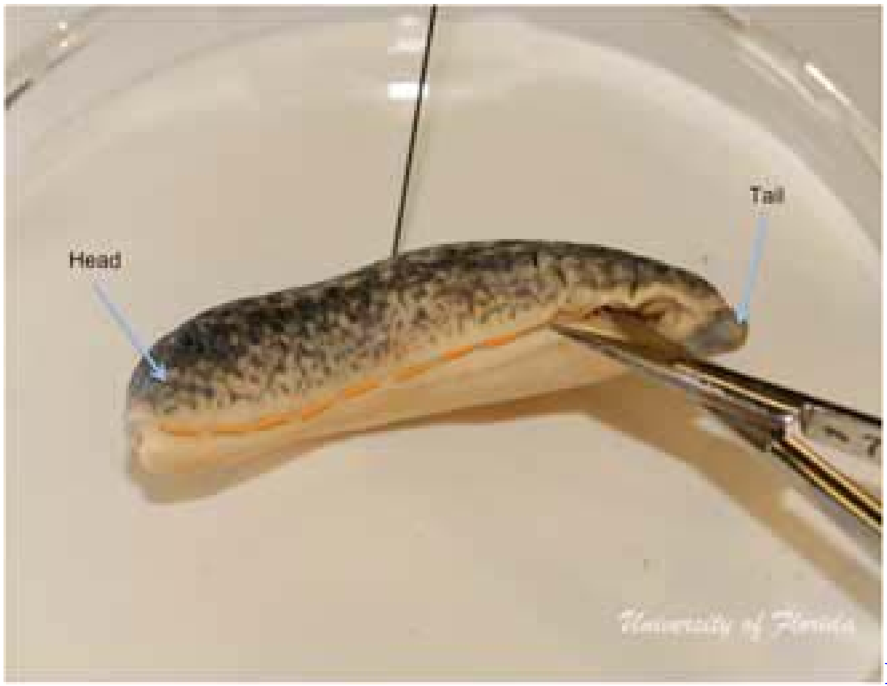


Figure 03

Figure 04


Figure 05


Figure 06

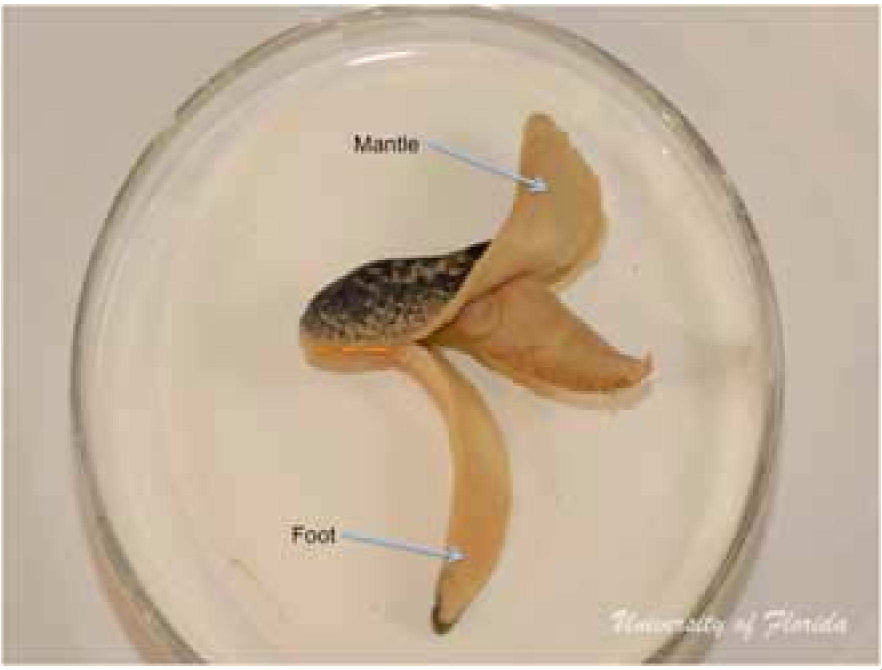


Figure 07

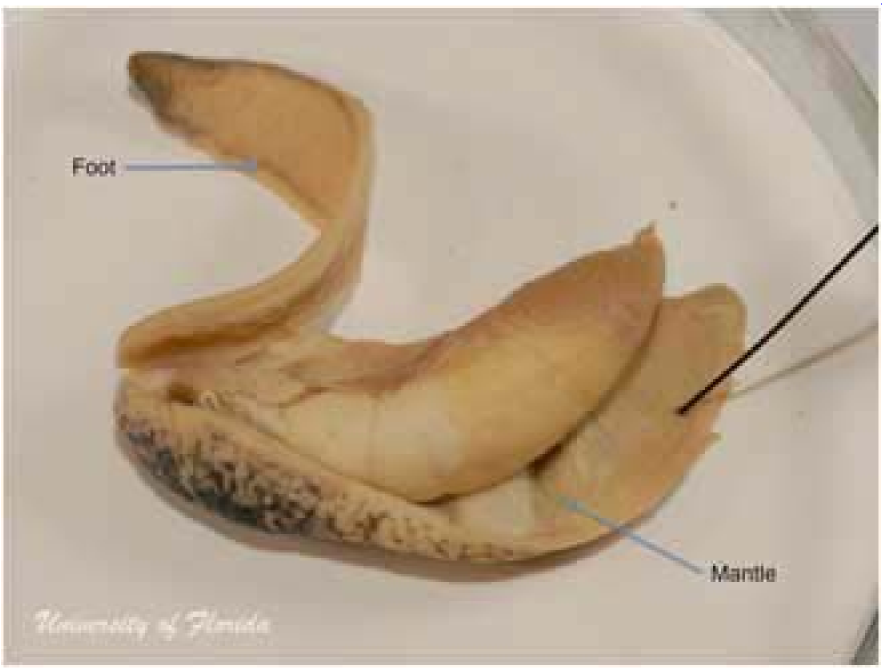


Figure 08

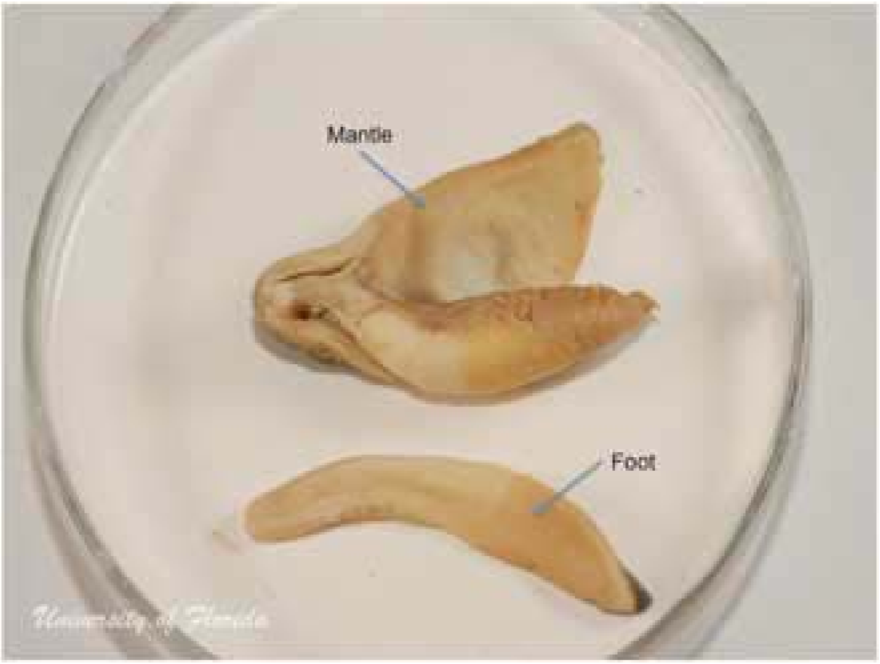


Figure 09

Step 4

- Remove the body covering and/or mantle of the animal

Gently peel the body or mantle back to expose the contents of the animal. Begin at the tip of the tail and work towards the head. Be sure to cut between the body or mantle and the heart to remove the body covering. Also, make incisions along the margin of the foot, to avoid cutting internal organs and eyestalks. Remove the body covering or mantle.

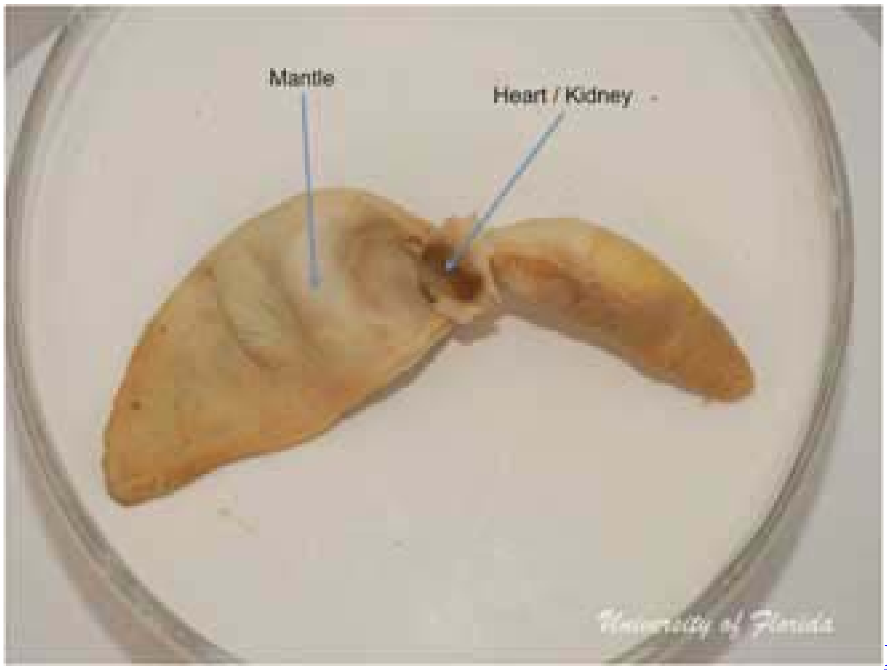


Figure 10

Figure 11

Step 5

- Separate the digestive gland from the albumen gland

Separate the digestive system from the reproductive system by gently peeling away the digestive gland from the albumen gland.

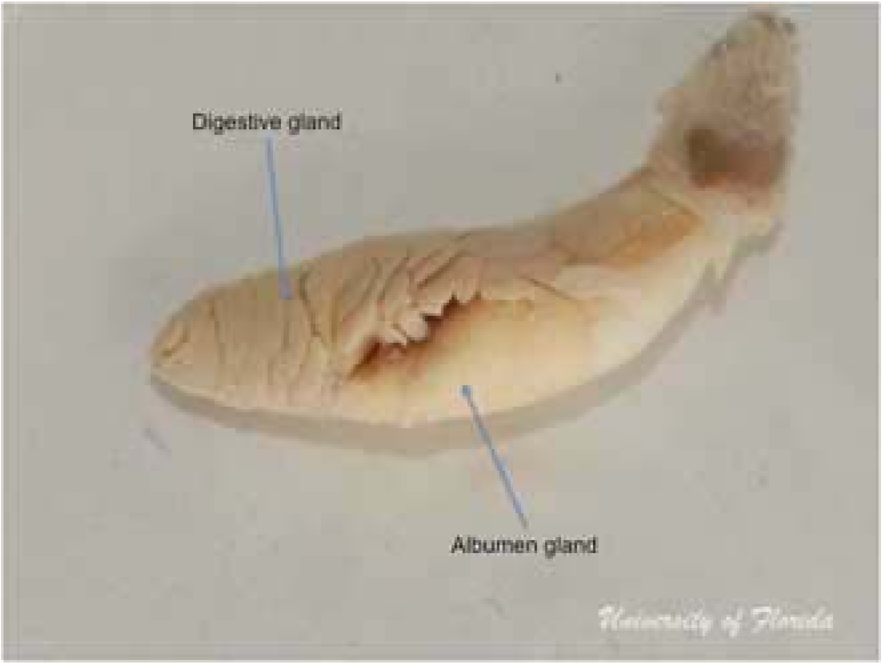


Figure 12

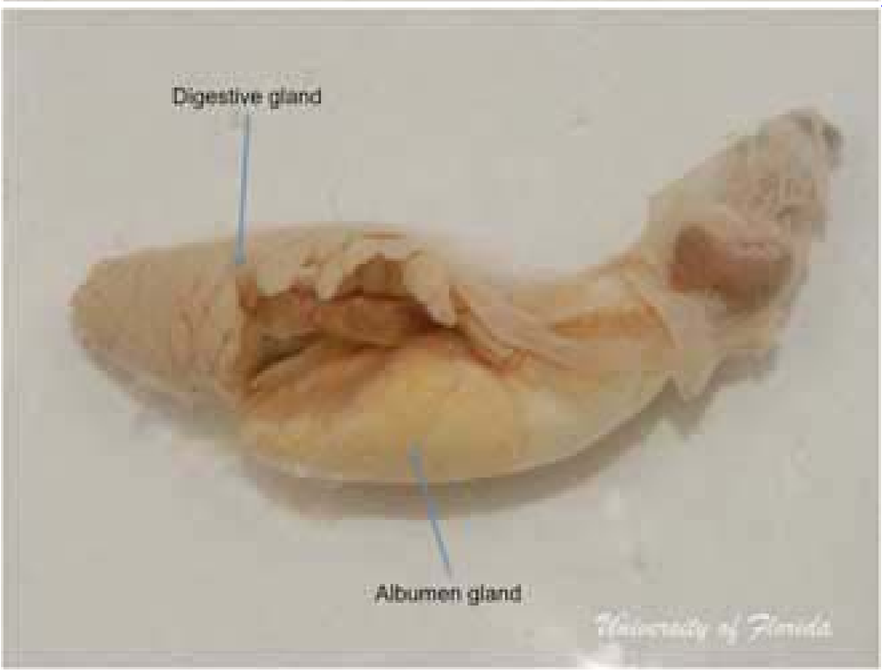


Figure 13

Step 6

- Remove the ovotestis from the digestive gland

Gently remove the areas of the digestive gland that cover the ovotestis. The ovotestis is often embedded in the digestive gland but is easily identified, as it is typically a different color (or shade). Make incisions along the sides of the hermaphroditic duct (Figure. 14) to remove all lateral connections to the digestive gland. The animal may need to be inverted for these steps.

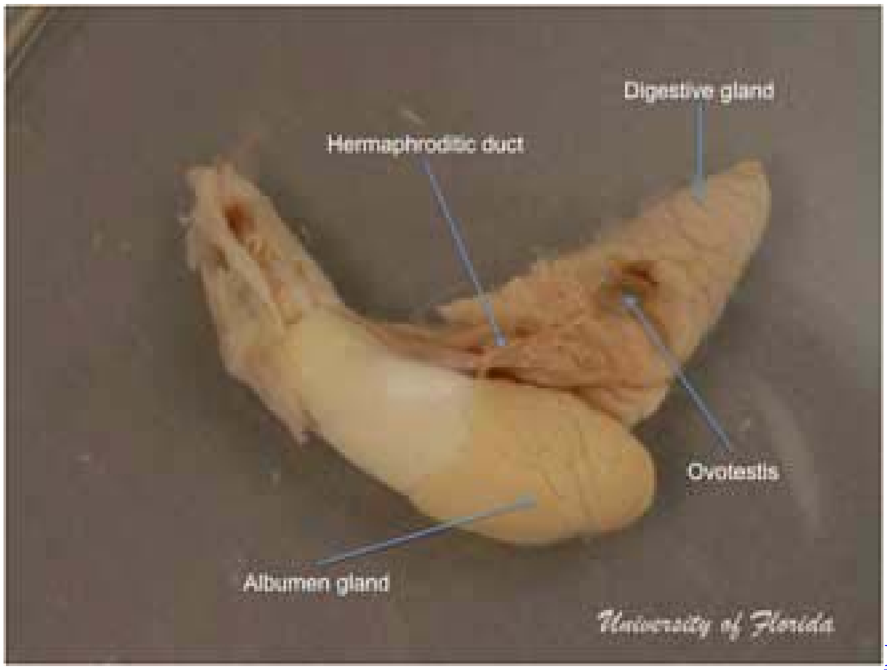


Figure 14

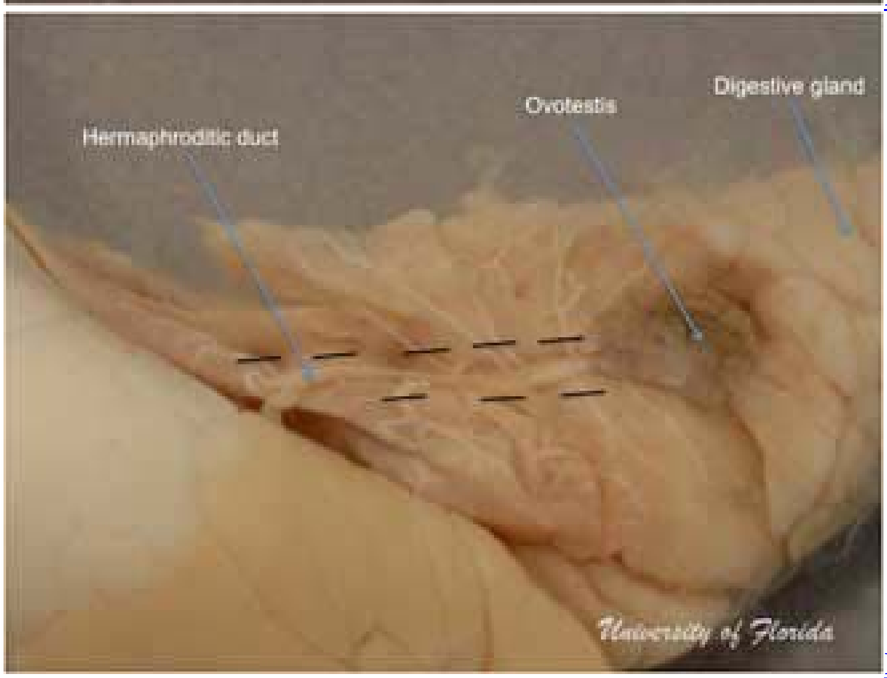


Figure 15

Figure 16

Step 7

- Remove heart and kidney to reveal bursa copulatrix

Gently remove the heart and kidney to reveal the bursa copulatrix and head region (including the optic region)

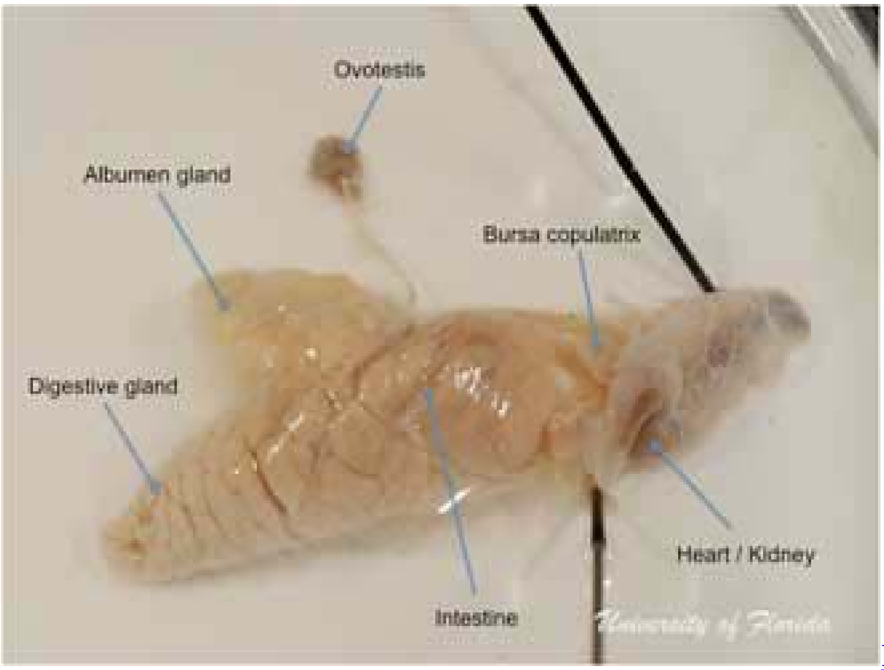


Figure 17

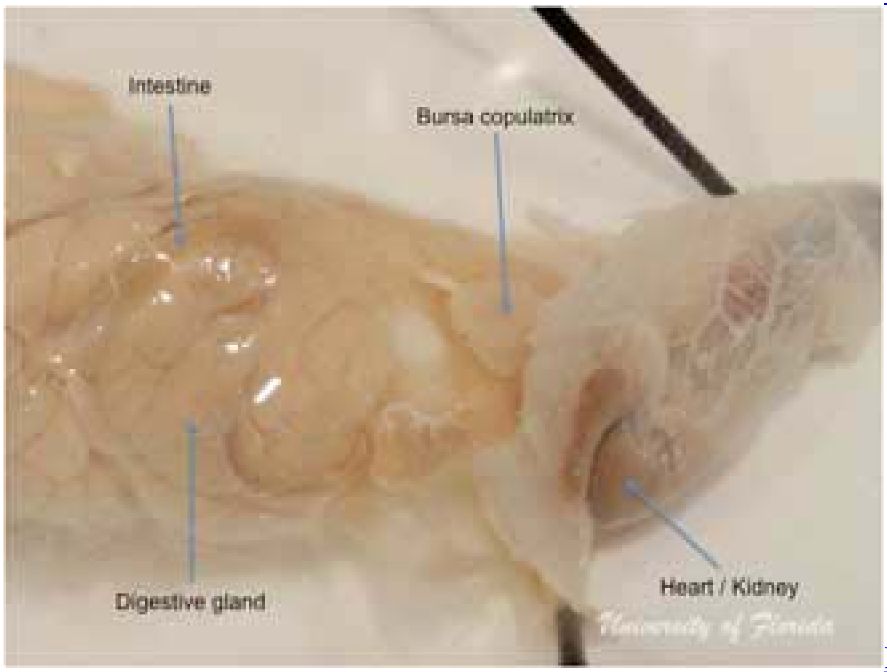


Figure 18

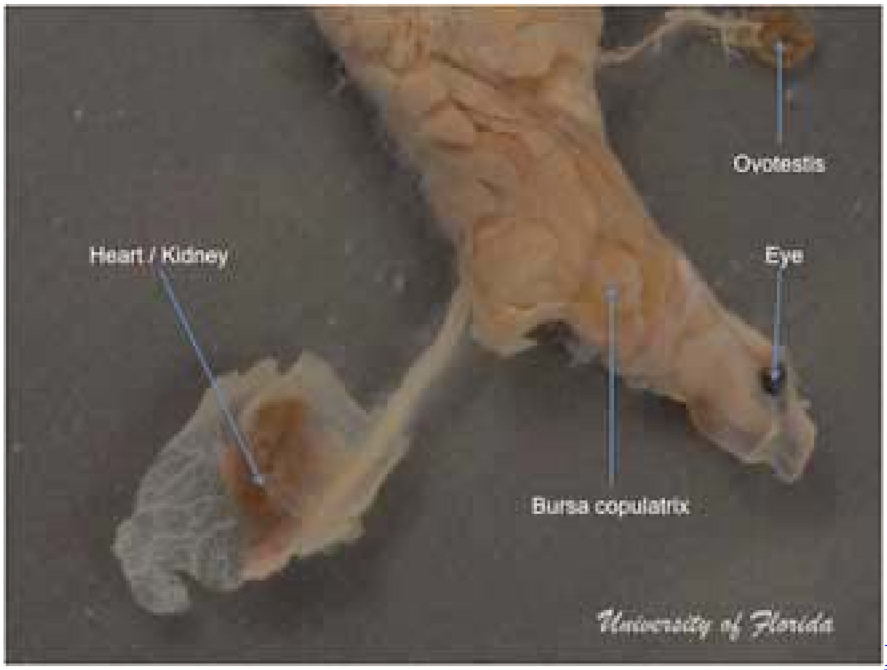


Figure 19

Step 8

- Separate the reproductive system from the digestive system

Orient the animal as illustrated in Figure 19 so that the reproductive system is above the digestive system. Tweezers can then be used to either pull the two systems apart along the dashed lines (Figure. 21) OR the structures can be slowly teased apart beginning at the buccal mass (removing the eye stalks and crop).

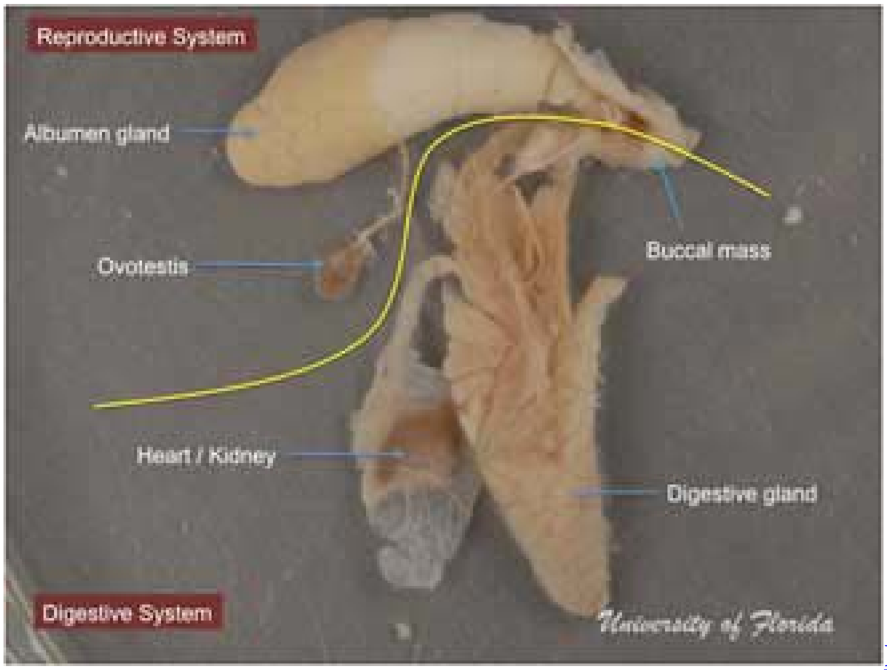


Figure 20

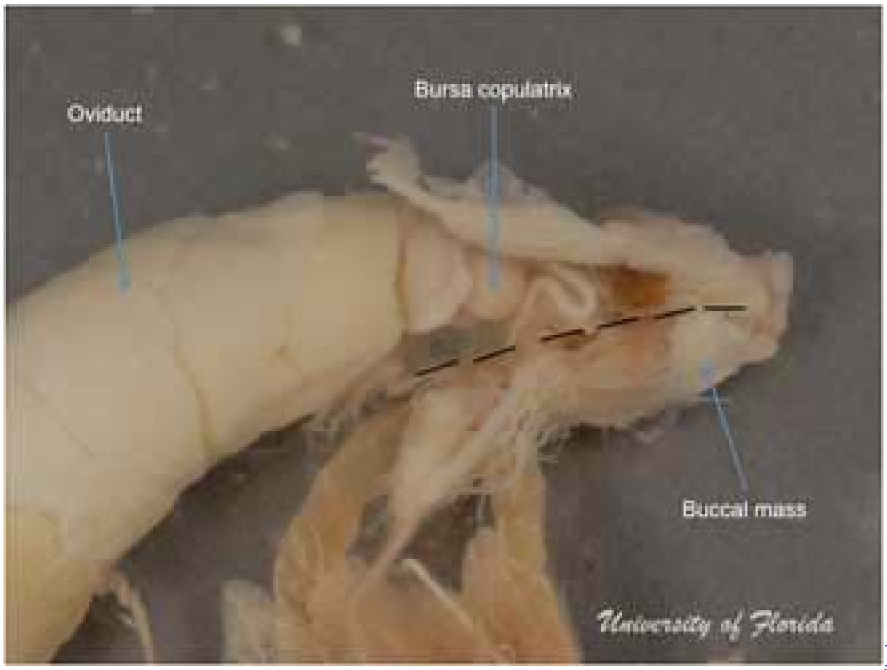


Figure 21

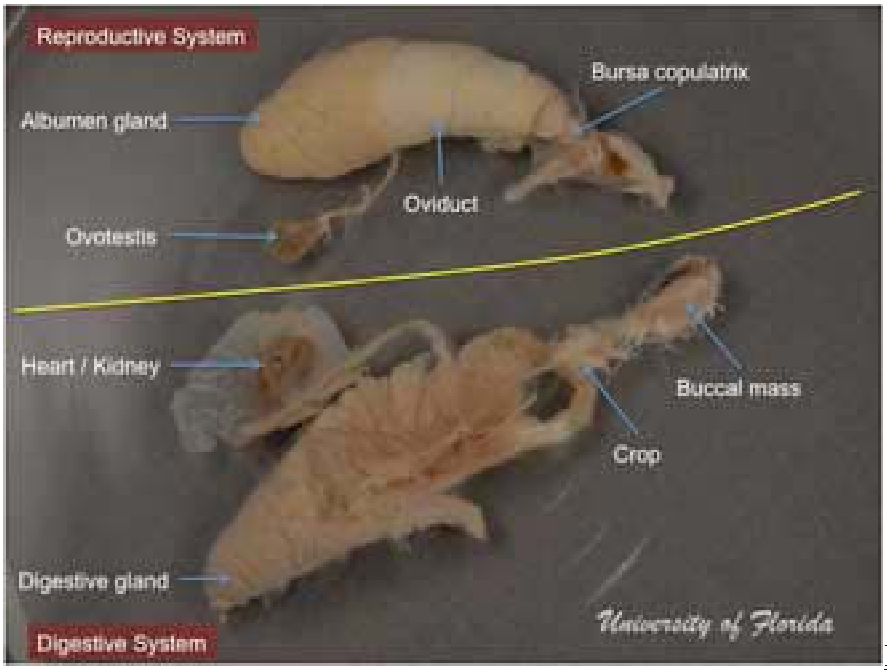


Figure 22

Step 9

- Unravel the reproductive system

Figure 23 displays the entire reproductive system of the animal. The structures are compressed and intertwined at this stage and need to be teased apart. Please Note: the red color of the atrium is not common to all slugs. Use an insect pin to gently unravel the vas deferens, bursa copulatrix, oviduct, and penis by following the connection to each.

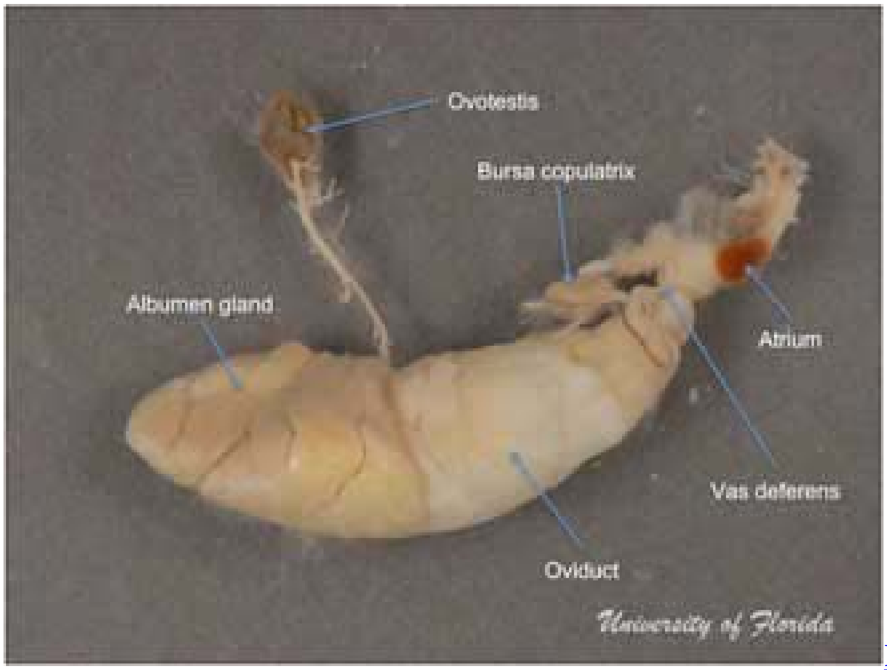


Figure 23

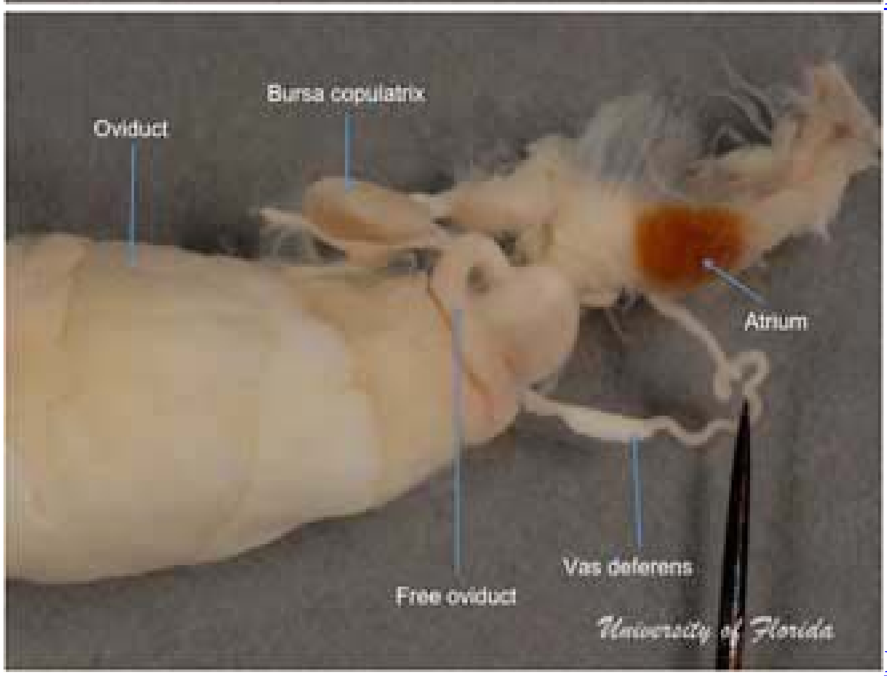


Figure 24

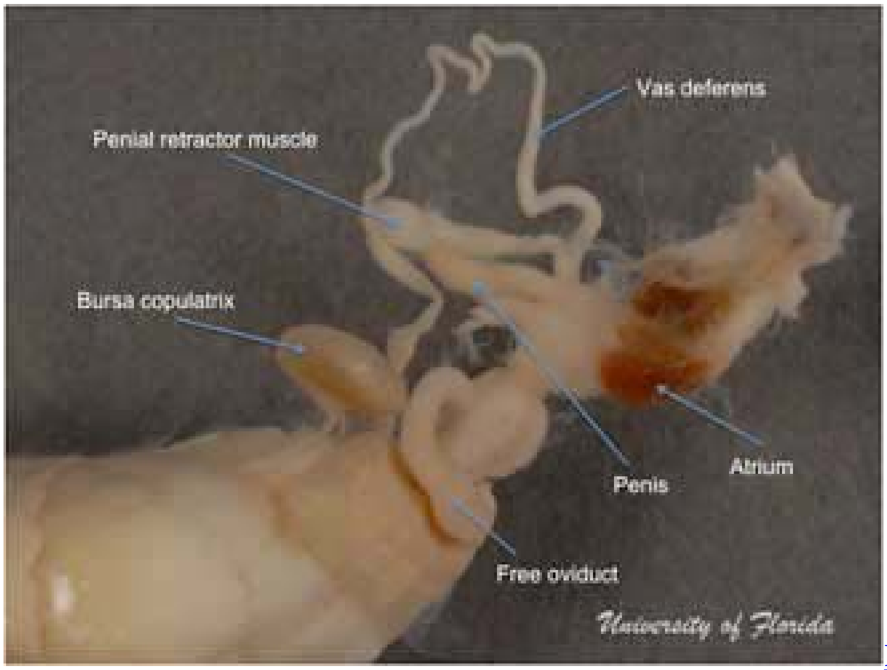


Figure 25

Step 10

- Treatment for Photography

If a photograph of the reproductive system is required, the structures can be arranged and pinned as desired then fixed in place by immersion in 95% ethanol for approximately 15 minutes. DO NOT leave the reproductive structures in 95% ethanol for an extended period as dehydration and distortion will occur. The pins can be removed from the specimen for photography or closer examination.

Figure 26

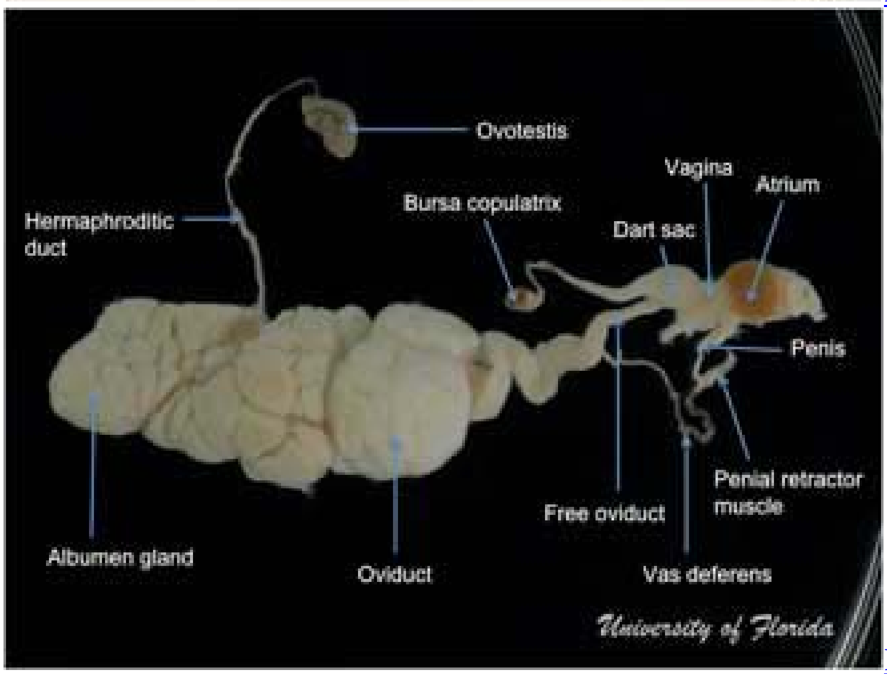


Figure 27

Veronicellidae Dissection

Step 1

- Note the external anatomy of the relaxed specimen

Submerge the relaxed, extended adult specimen in a dish with 75% ethanol or water.

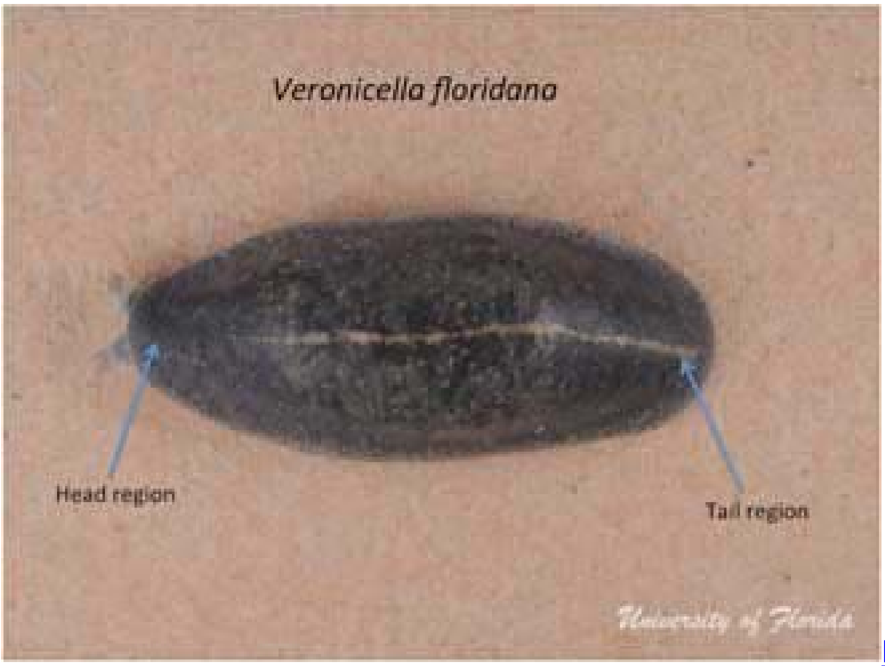


Figure:01

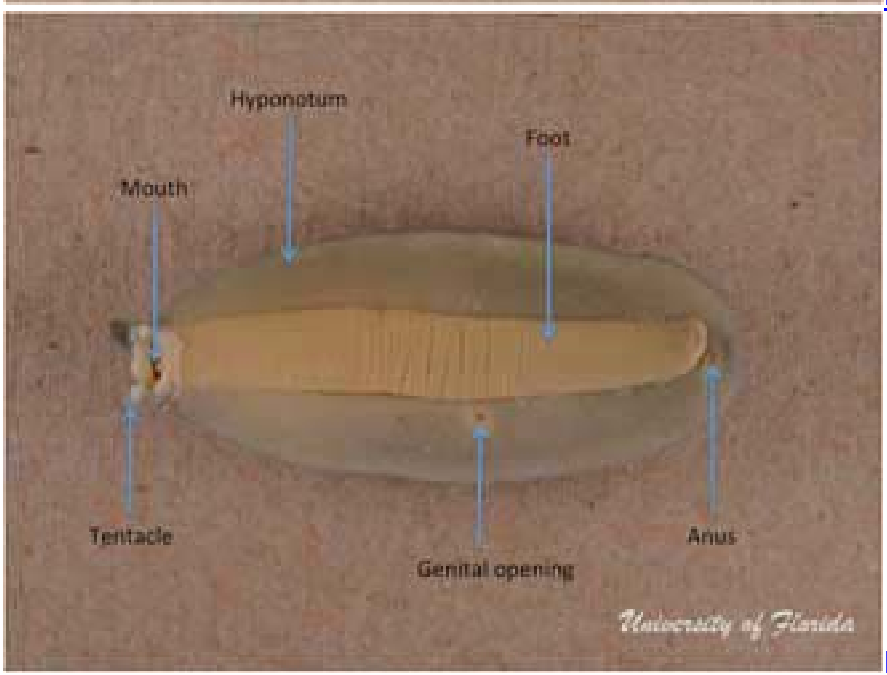


Figure:02

Step 2

- Cut along the inner portion of the hyponotum

Make a shallow incision near the anus using a pair of sharp dissecting scissors. Angle scissors upwards and proceed with incision along the hyponotum of the animal. The incision should be made on the inner side if the hyponotum. Cut towards the head of the animal (on both sides) to remove the mantle.

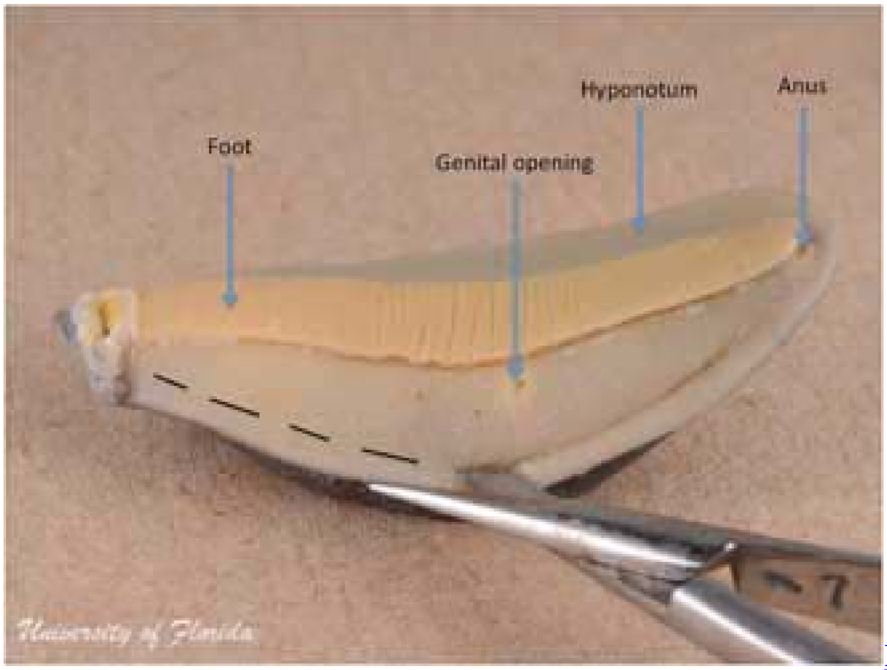


Figure:03

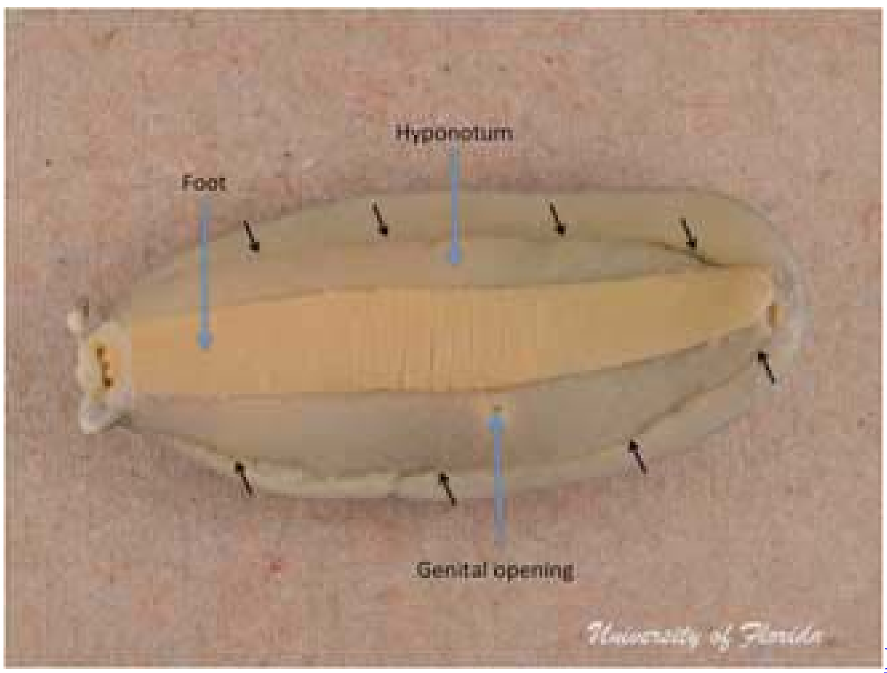


Figure:04

Step 3

- Remove the mantle of the animal

Gently peel back the mantle to expose the contents of the animal. Begin at the tip of the tail and work towards the head.

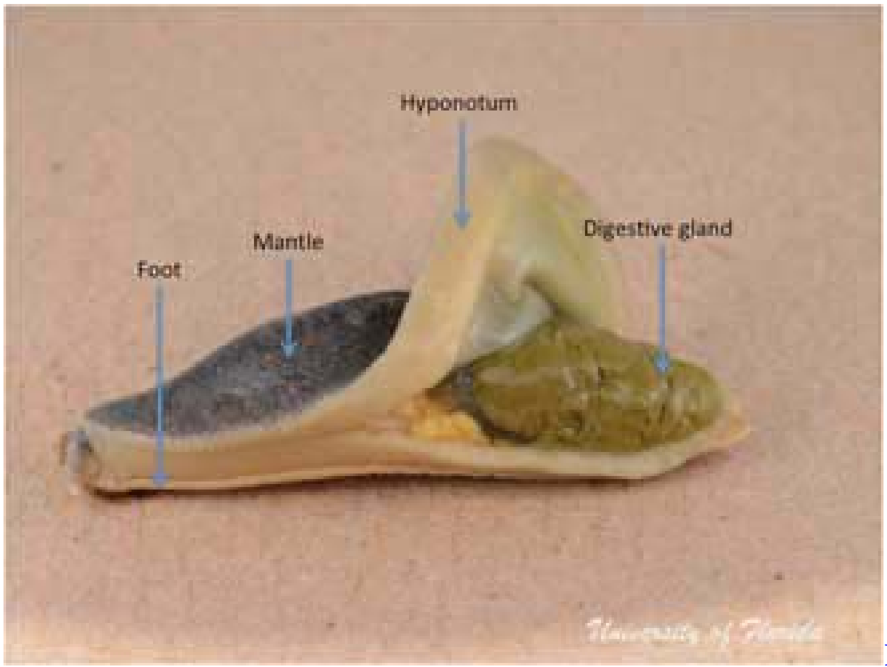


Figure:05

Figure:06

Step 4

- Remove the ovotestis from the digestive gland

Gently remove the areas of the digestive gland that cover the ovotestis. The ovotestis is often embedded in the digestive gland but is easily identified, as it is typically a different color (or shade). Make incisions along the sides of the hermaphroditic duct to remove all lateral connections to the digestive gland. The animal may need to be inverted for these steps.

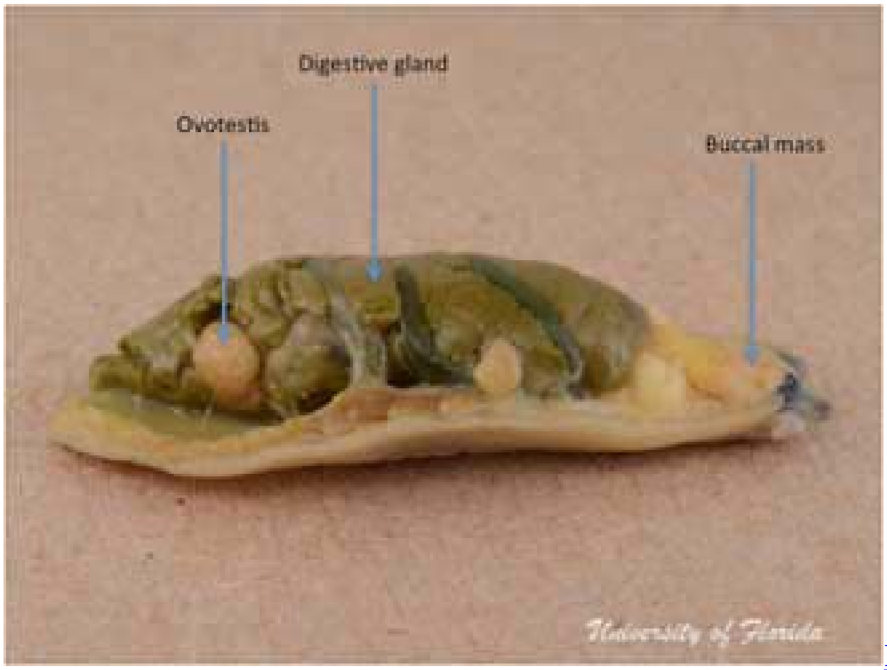


Figure:07

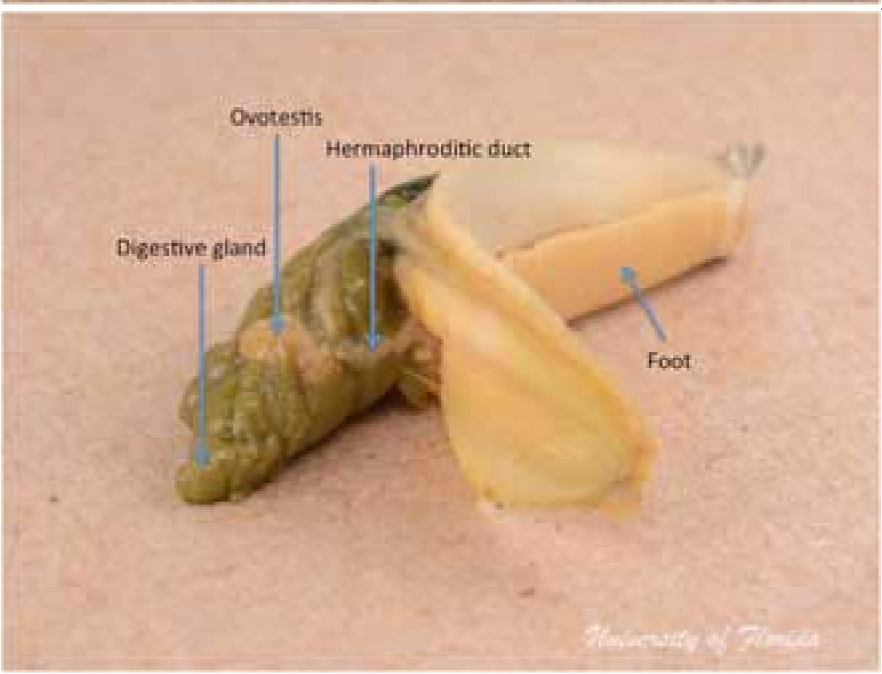


Figure: 08

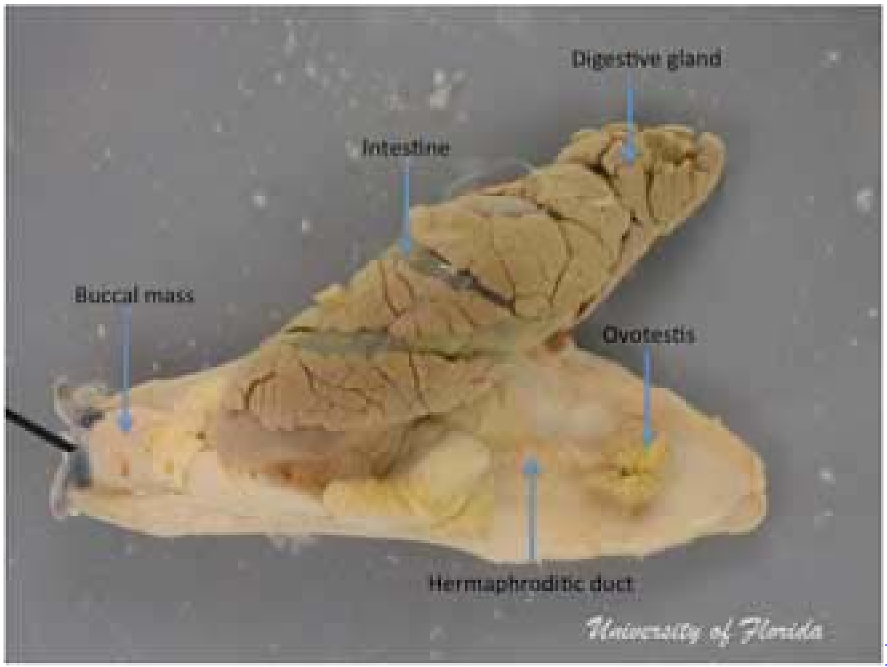


Figure: 09

Step 5

- Separate the reproductive system from the digestive system

Orient the animal as illustrated in Figure 10 so that the reproductive system is above the digestive system. Make incisions along the dashed lines to separate both systems (Figure 10-11).

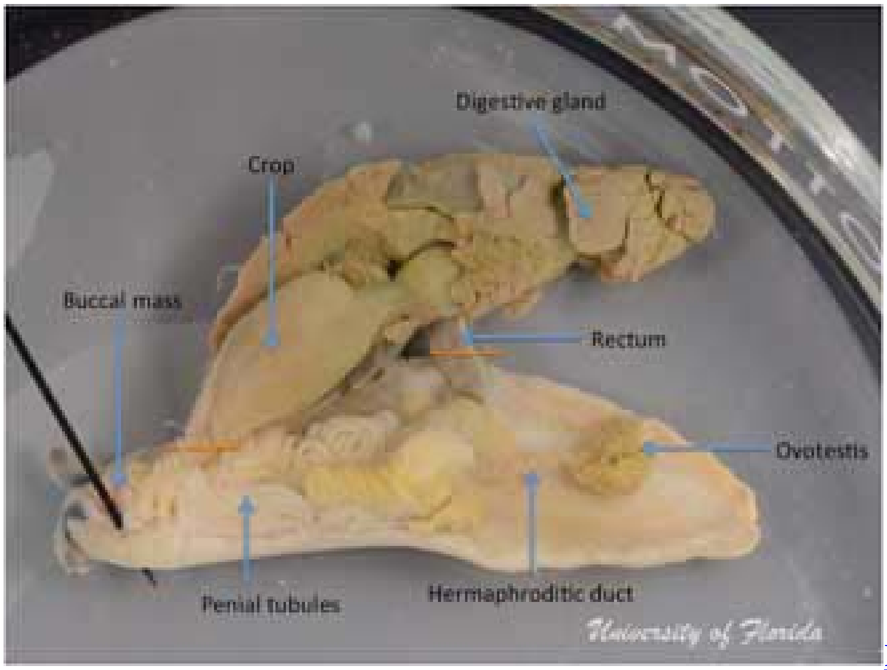


Figure: 10

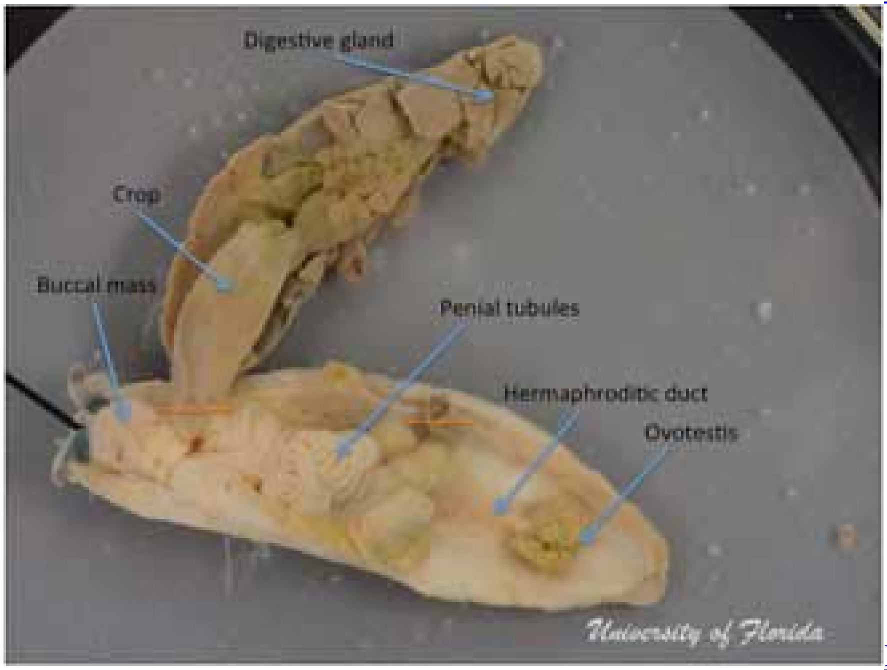


Figure: 11

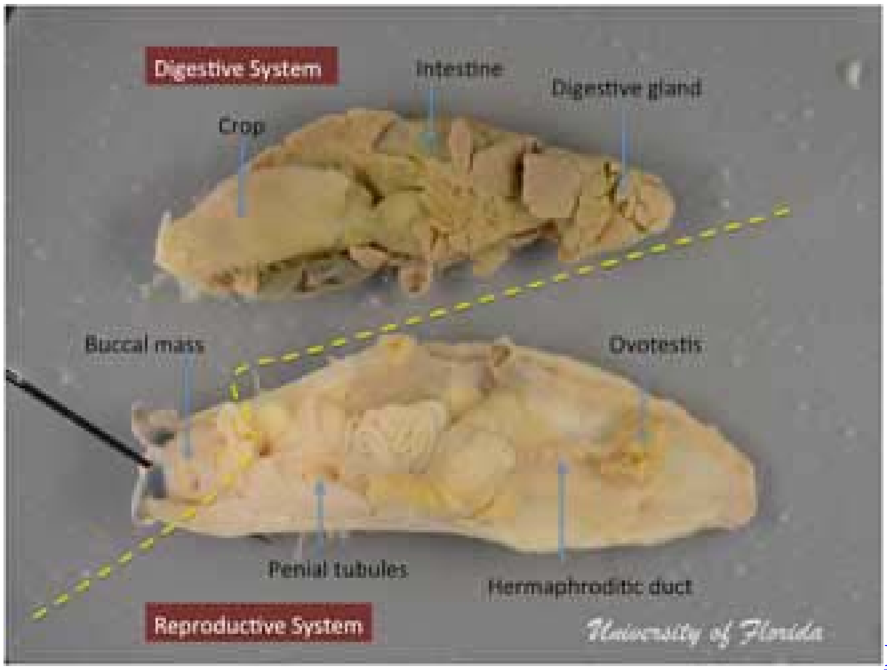


Figure: 12

Step 6

- Unravel the reproductive system

Figure 13 displays the entire reproductive system. The structures are compressed and intertwined at this stage and need to be teased apart. Use an insect pin to gently unravel each portion of the system by following the connection to each.

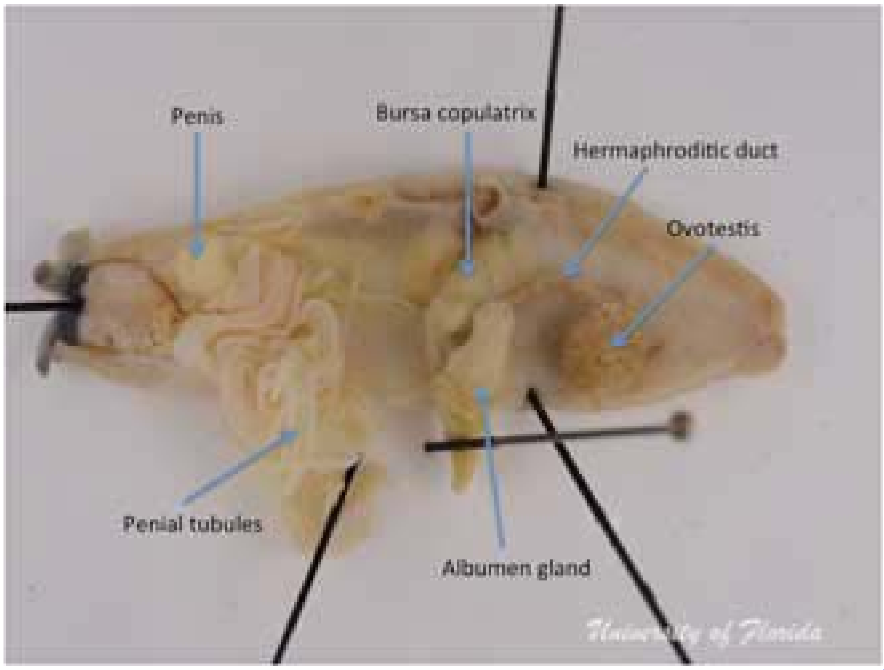


Figure: 13

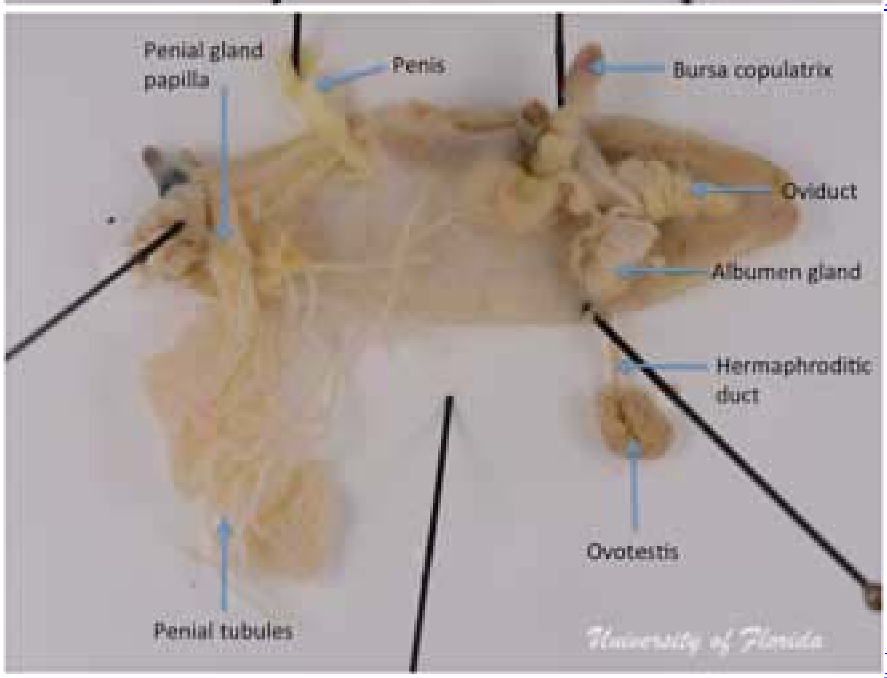


Figure: 14

Step 7

- Treatment for Photography

If a photograph of the reproductive system is required, the structures can be arranged and pinned as desired then fixed in place by immersion in 95% ethanol for approximately 15 minutes.
DO NOT leave the reproductive structures in 95% ethanol for an extended period, as dehydration

and distortion will occur.
The pins can be removed from the specimen for photography or closer examination.

The pins can be removed from the specimen for photography or closer examination.

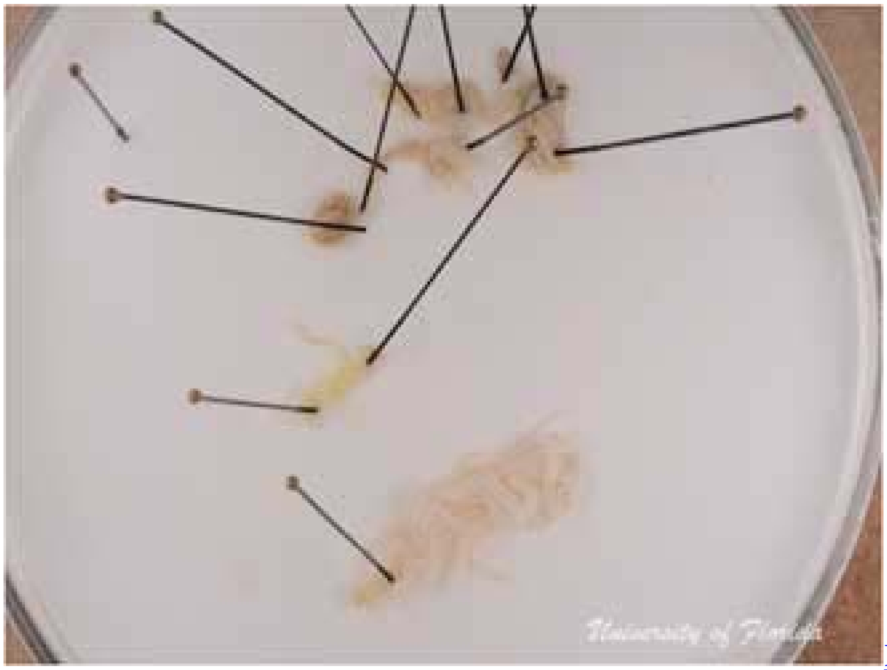


Figure: 15

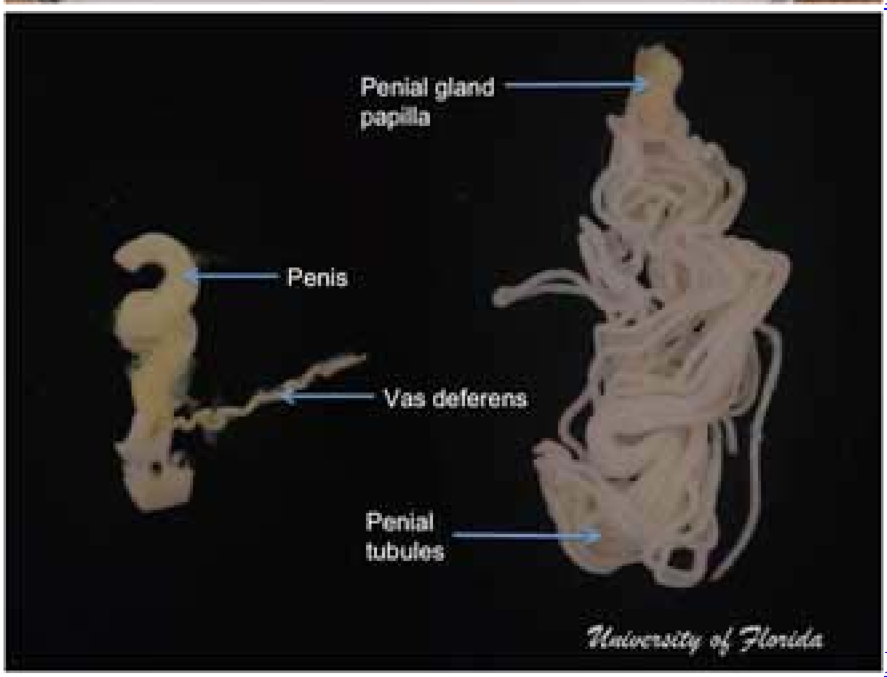


Figure: 16

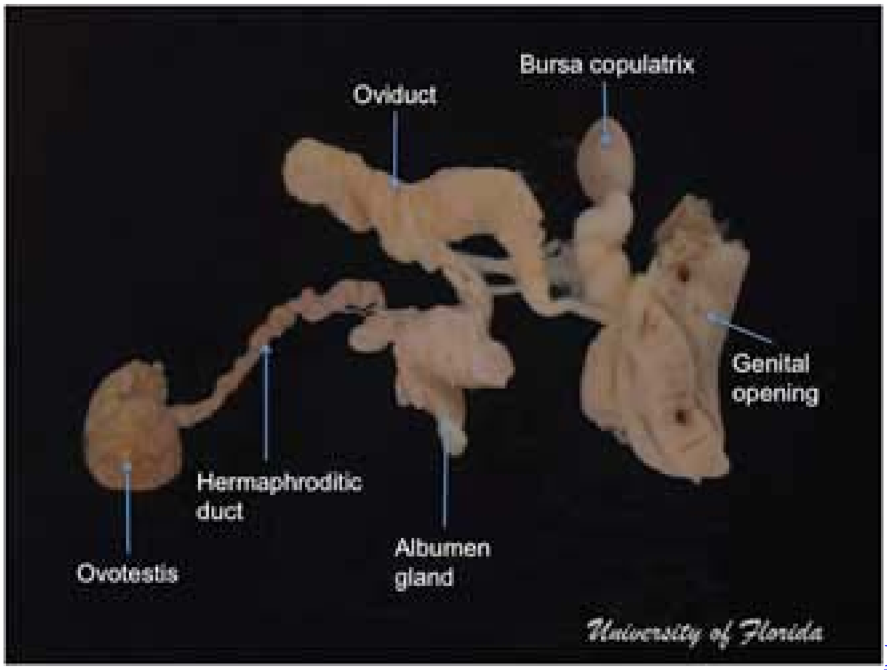


Figure: 17

How to use the Terrestrial Mollusc Key

Introduction

This key was created to assist inspectors at U.S. ports of entry to determine the identity of terrestrial mollusc species intercepted in imported cargo and shipments in-transit. Some terrestrial molluscs are important agricultural and ecological pests, and others may be contaminant species that may materially affect the quality of cargo while others may be non-pest “hitchhiker” species. It is often difficult for non-experts to accurately determine identity of terrestrial molluscs in a timely manner. This interactive key is designed to be a user-friendly tool to aid non-malacalogists to identify some important mollusc species that may affect commerce. It is however acknowledged that the scope of this key may be larger, and as such may also be used as an educational resource in a variety of fields. The taxonomy of terrestrial molluscs is very dynamic; hence, a large number of the entities (species, family, groups) included in this key may have been, and continue to be, revised. For each entity, a list of synonyms has been included in the supporting fact sheets to assist in clarifying the nomenclature.

It is recommended that the user read the ‘Identification’ and the ‘Biology’ sections of this tool in order to use the key more effectively. Only adult specimens have all the characters required by the key to achieve correct identification. Juveniles of many gastropod species often lack adult characters or they may possess additional characters that are not maintained through to adulthood. This is true for both snails and slugs. Slugs are generally more difficult to key to the species level and often require dissection. If dissection is necessary, there is a dissection tutorial available in this tool that will be able to assist the user to successfully dissect a snail and/or a slug.

***** It is important to remember that this key is not inclusive of all pestiferous mollusc species. This key is intended to serve as an aid in the identification of terrestrial mollusc species documented as major agricultural and ecological pests as well as contaminant and non-pest species that are commonly intercepted at U.S. ports of entry. *****

Equipment required for the optimal use of this key:

- Hand lens (10-20X)
- Ruler or Caliper
- Adult specimens
- Anatomy drawings (located in 'Biology' and the 'Identification' section)

Key Use Options

- There are two options ("Key Server" and "Java Applet") available on the "Begin Key" page to access and utilize the key:

(1) The "Key Server" option is the established default setting for accessing the key, and the key will load automatically using this option once the "Begin Key" page is accessed. The "Key Server" option facilitates remote accessibility of the key and is compatible with portable devices such as iPads, iPhones etc.

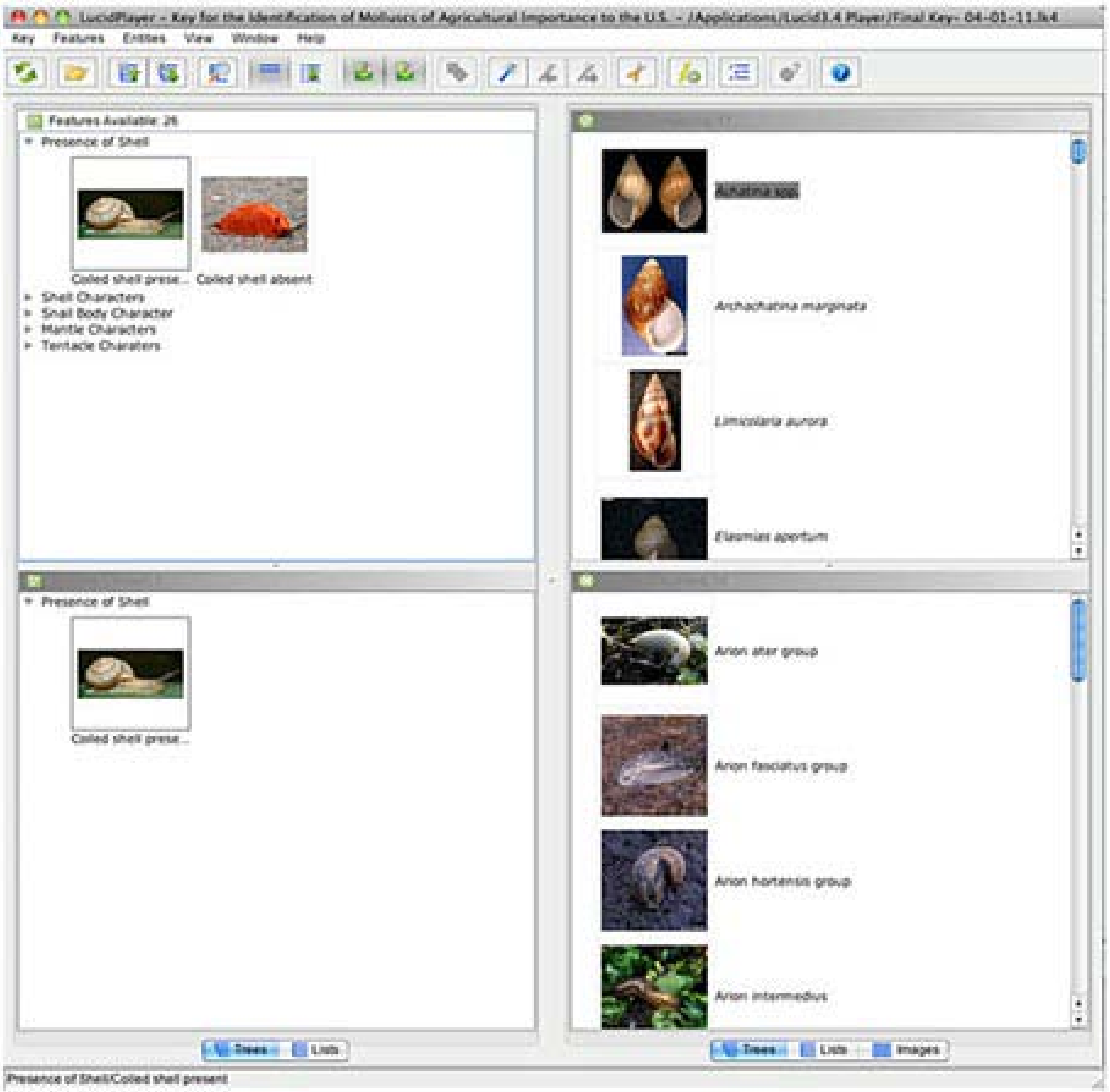
(2) The "Java Applet" option must be selected by the end-user from this tab located above the key window. The "Key Server" and the "Java Applet" options may both be viewed in "Full Screen" mode by selecting the "Full Screen" tab located immediately above the upper right quadrant of the key. Selecting the "Full Screen" mode will open a new window and will allow the user to view larger images of the entities. There is, however, inherent advantages and disadvantages associated with the "Key Server" and "Java Applet" options and the end-user should select the option that provides them with the most utility. More detailed information can be found on the System Requirements page.

- This key may take several minutes to load due to the nature of the program and the capabilities of the end-users' computer. The key contains many photographs that may slow uploading; however, once the key is loaded it should operate at a normal speed

How to Use

This non-dichotomous key is comprised of 33 families and 129 species. This key provides the user with multiple identification characters that can be selected at any time (in any order), as opposed to having sequentially paired options characteristic of a traditional dichotomous key.

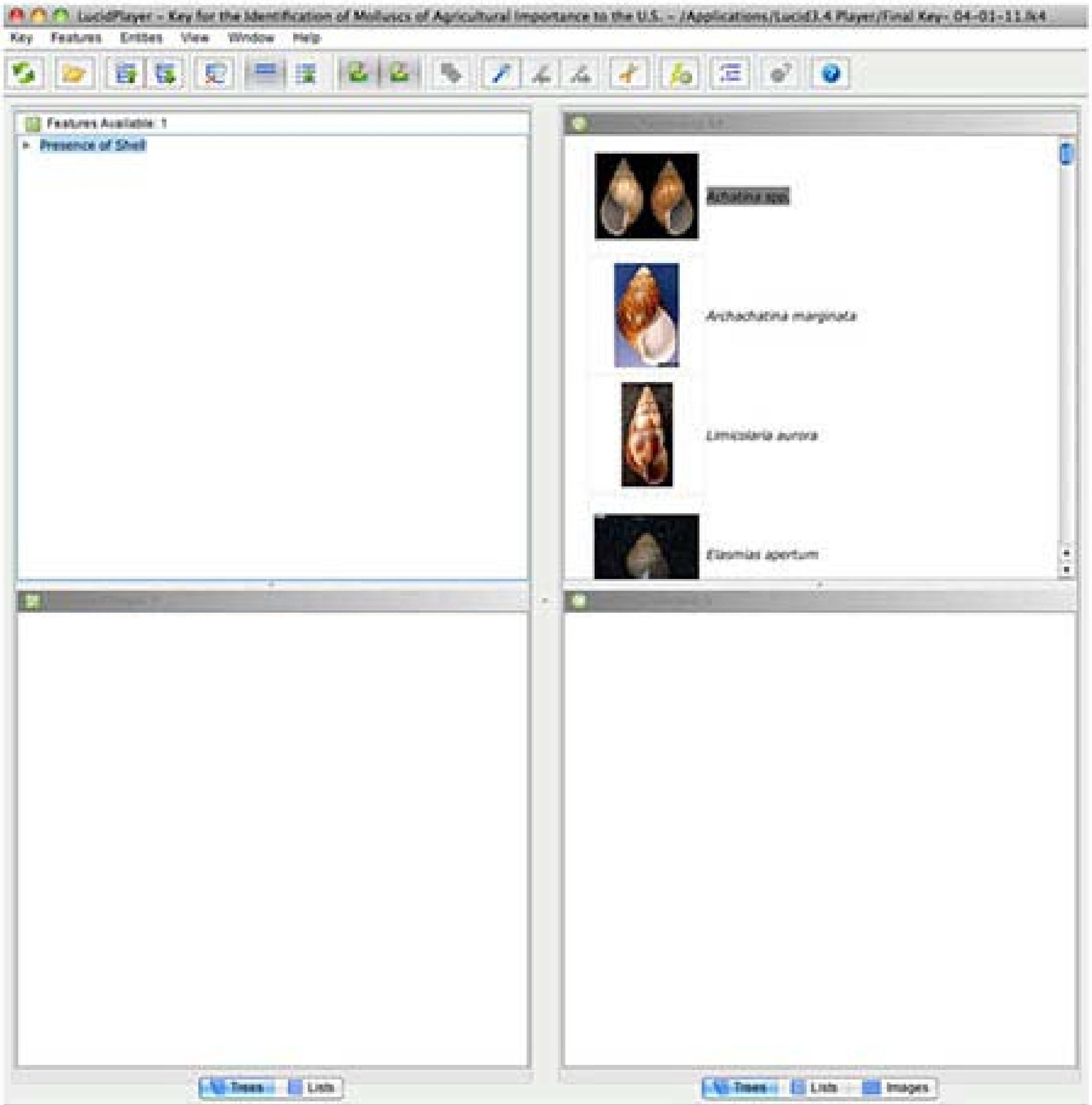
TMT Key Window



The browser window is divided into quadrants.

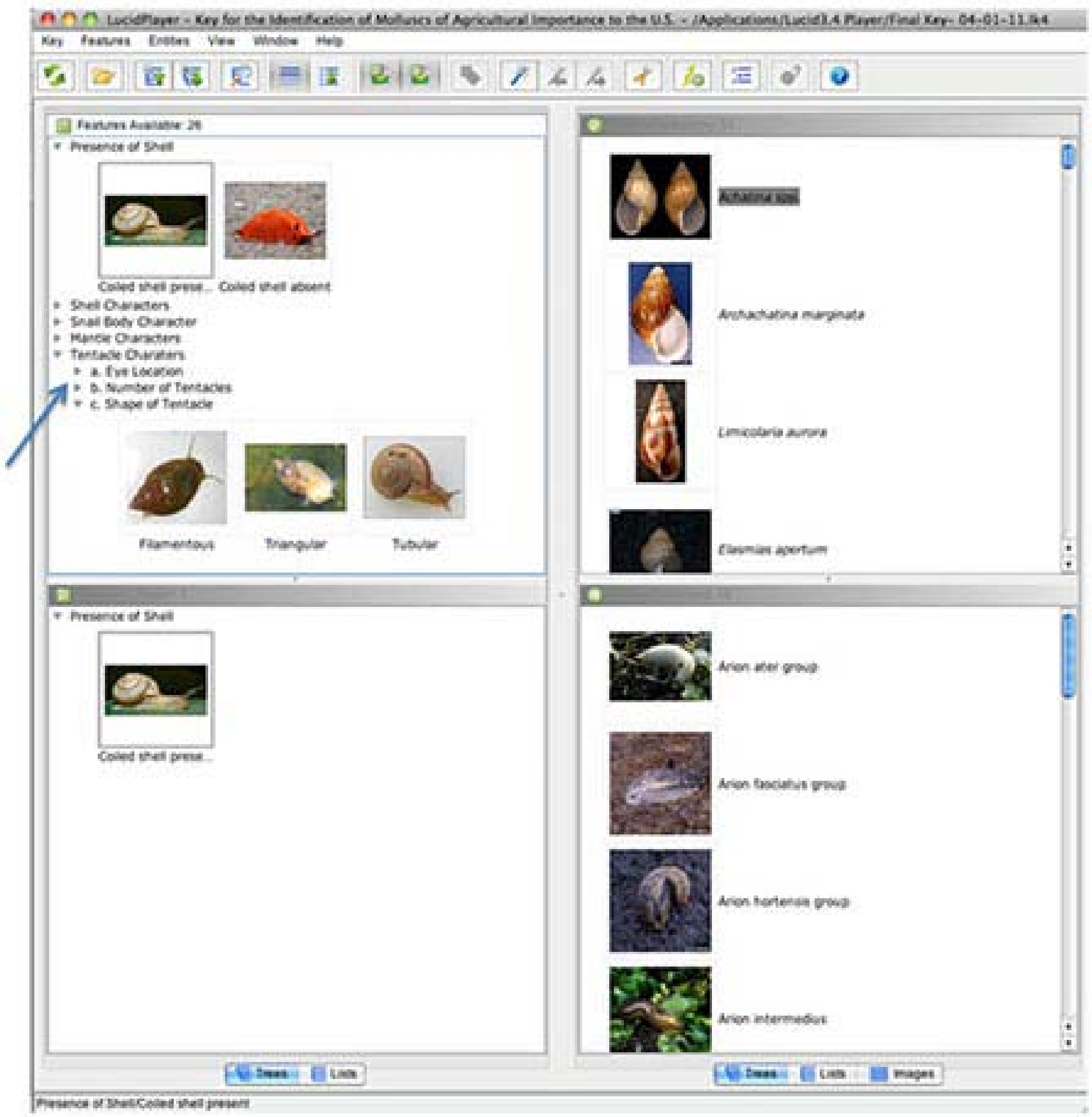
- Upper left window: Characters Available – this is a list of the features and states to select for the identification of specimens of interest.
- Upper right window: Taxa Remaining – list of families, genera and species that could possibly be the specimen of interest.
- Lower left window: Characters Chosen – list of features or states currently selected.
- Lower right window: Taxa Discarded – list of families, genera and/or species discarded from the characters available section based on the states previously selected.

Initiating Key



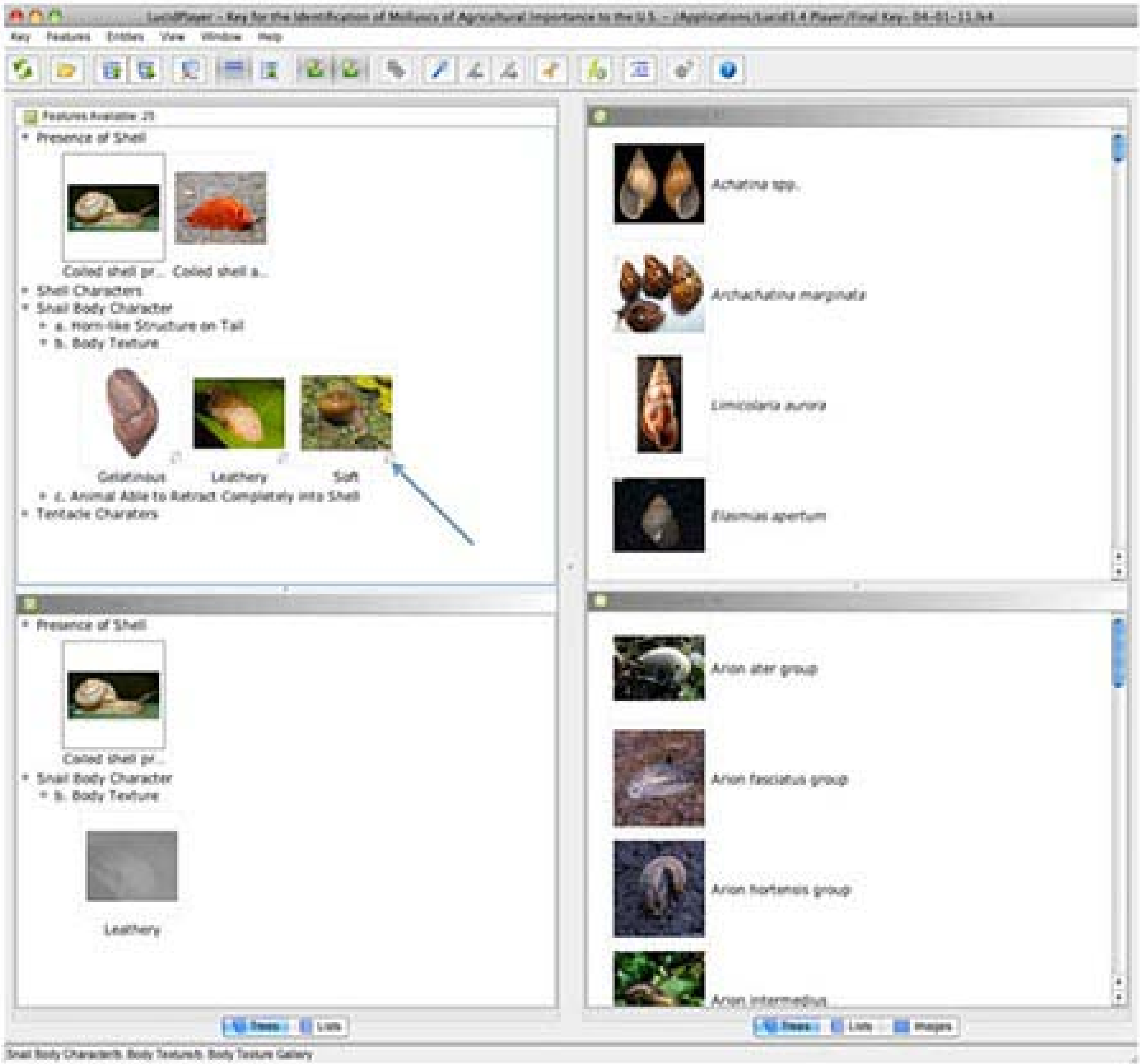
The first character in the key will be a dependency character, meaning that subsequent selections in the key are based on this character. This dependency character state is used to discriminate between a snail and a slug to allow the end user to progress through the key more efficiently.

Subsequent Selections



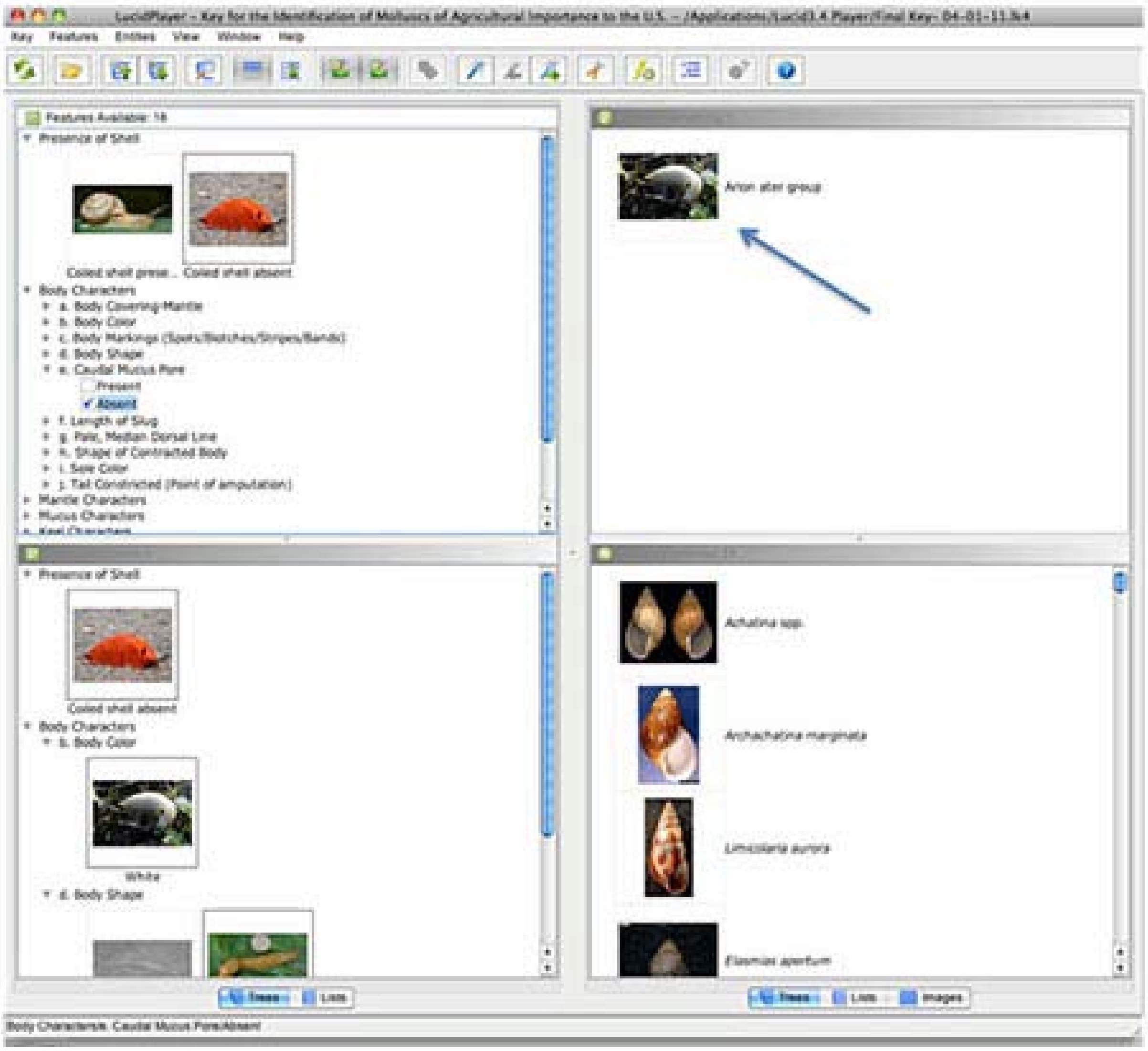
Each feature may have two or more character states. The selection options can be made visible by clicking on the arrow at the left corner of each character state. The desired character state can be selected by clicking directly onto the thumbnail photograph or illustration or the checkbox located adjacent to the character state. Also note that multiple selections can be made within each feature/state (e.g., in the above diagram filamentous and tubular can both be selected).

There is a feature called “find best”, that can be useful. It is represented by the magic wand icon at the top of the page. This function will select the best characters that are most useful in separating the remaining taxa.



Each state's photograph can be expanded by selecting the icon  located at the bottom right of the photograph. This is indicated in the diagram above.

Final Selection



The Identification Process

The keying process is complete when there is only a single selection remaining. Selecting additional character states at this point will prove to be futile as there will be no other taxa to discard. If the selection is not satisfactory, the organism can be taken through the key again, this time using other character states. Also the final selection may not be identical (color and markings) to the specimen in hand, as many gastropod species are morphologically variable. It is therefore recommended that the user read the fact sheet on the final selection to confirm the identification as additional information, including pictures, are provided in this section of the tool.

Selecting Characters

One important feature of a Lucid key is the flexibility it provides the user to choose morphological characters pertinent to the specimen in question in any order and in any combination. The user is however advised to select obvious characters first before progressing to more obscure characters. Additionally multiple characters may be selected simultaneously and unclear characters and those difficult to determine may be skipped.

Measurable characters such as height, width, length, number of whorls etc, are very useful to quickly reduce the number of “Entities Remaining”. It is therefore extremely important to correctly measure the specimen in question. The user should consult the “Identification” page for the correct procedures to measure terrestrial gastropods. **Do not** estimate measurable characters or guess any other character selections. When in doubt choose alternative character states.

Dissections and Comparing Genitalia

Several entities included in this key cannot be reliably identified using external morphological characters additionally some entities may be grouped in a species complex and require examination of genital structures for correct identification. If the specimen in question falls into the aforementioned categories and identification to a lower taxonomic level is desired the user has several options. The user could send the specimen to an expert for official identification. OR Based on skill level and appetite for adventure the user may choose to dissect the specimen in question in order to inspect the genitalia. The user should consult the dissection page for the supplies required and the procedures for correctly and humanely preparing the specimen. The slug and snail dissection tutorial provide a step-by-step guide to the dissection process. The specimen in question may be quite different from those used in the tutorials but the principles are the same. The fact sheets provide detailed illustrations of characteristic genitalic structures required for identification of entities to the species level. The dissected genitalia of the unidentified specimen should be compared to pertinent illustrations in order to make a determination.

Entity not in Key

It is probable that on occasions the end-user will be unable to make an appropriate final selection on the first attempt to key a specimen. The end-user would be advised to attempt to ‘re-key’ the specimen by selecting a different suite of characters or by selecting the “magic wand” feature after the dependency character, within the key. If no selection can be made after a reasonable number of attempts the user must consider the possibility that the specimens on hand may be a species not included in the key. Additionally, the specimen may be a juvenile, the shell may be severely weathered (snails) or the specimen may be an albino morph and therefore lack the characters required to make a final selection.

Multiple Entities Remain

The occasion may arise where the user has exhausted all possible selections from the “Features available” quadrant of the key window yet multiple entities remain in the “Entities Remaining” quadrant. The most likely explanation is that the specimen in question is not an entity included in the key. There may also be occasions where multiple entities remain in the “Entities Remaining” quadrant of the key window and multiple characters remain in the “Characters Remaining” quadrant but none of the remaining features are pertinent to the specimen in question. In such a case it is possible that the specimen in question could be a juvenile and lack the characters required for identification or may be an entity not included in the key.

All Remaning Entities Disappear

There may be occasions when the selection of a particular suite of character states result in all entities disappearing from the "Entities Remaining" quadrant of the key window. In such a case no entity in the key has been scored for the combination of character states selected. This could be attributed to a number of reasons including; user-error in selecting appropriate character states or the specimen in question may not be included in the key. The user may attempt to discover a potential error by sequentially de-selecting all dubious character states. The "Entities Remaining" quadrant may re-populate as character states are removed from the "Features Chosen" list. Carefully re-examine the specimen in question and only choose features and character states that can be selected with confidence. If all entities continue to disappear from the "Entities Remaining" quadrant after several attempts using different combinations of features and states then it is most likely that the specimen in question is not included in the key. Please remember that this key is limited to identifying only the species included.

If the identification of your specimen is critical, it may be sent to the USDA-APHIS-PPQ-National Identification Services representative:

Packaging and Handling Information
David Robinson
USDA-APHIS National Malacologist
Department of Malacology
Academy of Natural Sciences
1900 Benjamin Franklin Parkway
Philadelphia, PA 19103
Tel. 215-299-1175
Fax: 215-567-7229
Email: Robinson@ansp.org or David.G.Robinson@usda.gov

LIST OF REFERENCES

Aguiar, R. and M. Wink. 2005. How do slugs cope with toxic alkaloids? Chemoecology **15**: 167-177.

Agapow, P.-M., O.R.P. Bininda-Edmonds, K.A. Crandall, J.L. Gittleman, G.M. Mace, J.C. Marshall and A. Purvis. 2004. The impact of species concepts on biodiversity studies. The Quarterly Review of Biology. 79: 161-179.

Airey, W. J. 1987. Laboratory studies on damage to potato tubers by slugs. Journal of Molluscan Studies **53**: 97-104.

Akaike H. 1974. A new look at the statistical model identifications. IEEE Transactions on Automatic Control. 19: 716-723.

Alexander, R. D. 1974. The evolution of social behavior. Annual Review of Ecology and Systematics **5**: 325-383.

Anderson, J. B. and G. F. McCracken. 1986. Breeding system and population genetic structure in philomycid slugs (Mollusca: Pulmonata). Biological Journal of the Linnaean Society **29**: 317-329.

Bailey, S. E. R. 2002. Molluscicidal baits or control of terrestrial gastropods. *In:* G. M. Barker, ed., *Molluscs as Crop Pests.* CABI Publishing, Wallingford, UK. Pp. 33-54.

Bailey, S. E. R. and M. A. Wedgewood. 1991. Complementary video and acoustic recordings of foraging by two pest species of slug on non-toxic and molluscicidal baits. Annals of Applied Biology **119**: 147-153.

Barker, G. M. 1991. Biology of slugs (Agriolimacidae and Arionidae: Mollusca) in New Zealand hill country pastures. Oecologia **85**: 581-595.

Barker, G. M. 2002. Gastropods as pests in New Zealand pastoral agriculture, with emphasis on Agriolimacidae, Arionidae and Milacidae. *In:* G. M. Barker, ed., *Molluscs as Crop Pests.* CABI Publishing, Wallingford, UK. Pp. 361- 421.

Barratt, B. I. P., R. A. Byers and D. L. Bierlein. 1994. Conservation tillage crops yields in relation to grey garden slug (*Deroceras reticulatum* (Müller)) (Mollusca: Agriolimacidae) density during establishment. Crop Protection **13**: 49-52.

Baur, B. 1994. Parental care in terrestrial gastropods. Experientia **50**: 5-14.

Becker Underwood. 2011. Beneficial Nematodes: Nemaslug®. Access date (07-09-2011). http://www.beckerunderwood.com/en/distributors/nemaslug_us

Begon, M. and G. A. Parker. 1986. Should egg size and clutch size decrease with age? Oikos **47**: 293-302.

Bell, N. L. 2002. A computerized identification key for 30 genera of plant parasitic nematodes. New Zealand Plant Protection **55**: 287-290.

Bengtsson, J., J. Ahnström and A. Weibull. 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. Journal of Applied Ecology **42**: 261-269.

Binney, A. 1842. Binney on the naked air-breathing Mollusca. Boston Journal of Natural History **4**: 171.

Binney, A. 1842. Descriptions of some of the species of naked, air-breathing Mollusca, inhabiting the United States. Journal of Natural History. **4**: 164-175.

Binney, A. 1851. The terrestrial air-breathing mollusks of the United States, and the adjacent territories of North America. Boston, Vol 2. Pp. 13.

Bosc, L. A. G. 1802. Histoire naturelle des vers: contenant leur description et leurs moeurs; avec figures dessinées d'après nature. Vol. 1. Paris. Pp. 93, pl.8.

Bourne, N. B., G. W. Jones and I. D. Bowen. 1990. Feeding behaviour and mortality of the slug *Deroceras reticulatum* in relation to control with molluscicidal baits containing various combinations of metaldehyde and methiocarb. Annals of Applied Biology **117**: 455-468.

Branson, B. A. 1968. Two new slugs (Pulmonata: Philomycidae: Philomycus) from Kentucky and Virginia. The Nautilus **81**: 127-133.

Briner, T. and T. Frank. 1998. The palatability of 78 wildflower strip plants to the slug *Arion lusitanicus*. Annals of Applied Biology **133**: 123-133.

Brooks, A. S., A. Wilcox, R. T. Cook, K. L. James and M. J. Cook. 2006. The use of an alternative food source (red clover) as a mean of reducing slug pest damage to winter wheat: towards field implementation. Pest Management Science **62**: 252-262.

Brooks, A. S., M. J. Crook, A. Wilcox and R. Cook. 2003. A laboratory evaluation of the palatability of legumes to the field slug, *Deroceras reticulatum* Müller. Pest Management Science **59**: 245-251.

Burrows, T. M. 1983. Pesticide demand and integrated pest management: A limited dependent variable analysis. American Journal of Agricultural Economics **65**: 806-810.

Buschmann, H., P. J. Edwards and H. Dietz. Variation in growth pattern and response to slug damage among native and invasive provenances of four perennial Brassicaceae species. Journal of Ecology **93**: 322-334.

Byers, R. A. 2002. Agriolimacidae and Arionidae as pests in *Lucerne* and other legumes in forage systems of North-eastern North America. *In:* G. M. Barker, ed., *Molluscs as Crop Pests.* CABI Publishing, Wallingford, UK. Pp. 325-336.

Byers, R. A. and D. D. Calvin. 1994. Economic injury levels to field corn from slug (Stylommatophora: Agriolimacidae) feeding. Journal of Economic Entomology **87**: 1345-1350.

Carlisle, T. R. 1982. Brood success in variable environments: implications for parental care allocation. Animal Behavior **30**: 824-836.

Chang, C. 1990. Evaluation of chemical and exclusion methods for control of *Bradybaena similaris* (Férussac) on grapevine in Taiwan. Agriculture, Ecosystems and Environment **31**: 85-88.

Chang, C. 2002. *Bradybaena similaris* (de Férussac) (Bradybaenidae) as a pest of grapevines of Taiwan. *In:* G. M. Barker, ed., *Molluscs as Crop Pests.* CABI Publishing, Wallingford, UK. Pp. 241-244.

Chatfield, J. E. 1976. Studies on food and feeding in some European land molluscs. Journal of Conchology **29**: 5-20.

Chevalier, L., M. Le Coz-Bouhnik and M. Charrier. 2003. Influence of inorganic compounds on food selection by the brown garden snail *Cornu aspersum* (Müller) (Gastropoda: Pulmonata). Malacologia **45**: 125-132.

Chomczynski, P., K. Mackey, R. Drews and W. Wilfinger. 1997. DNAzol: a reagent for the rapid isolation of genomic DNA. Biotechniques **22**: 550–553.

Clark, S. J., I. F. Henderson, D. J. Hill and A. P. Martin. 1999. Use of lichen secondary metabolites as antifeedants to protect higher plants from damage caused by slug feeding. Annals of Applied Biology **134**: 101-108.

Cockburn, A. 2006. Prevalence of different modes of parental care in birds. Proceedings of the Royal Society B273: 1375-1383.

Cockerell, D. A. 1890. Notes on slugs, chiefly in the collection at the British Museum. The Annals and Magazine of Natural History, including Zoology, Botany, and Geology **6**: 380-389.

Cody, M. L. 1966. A general theory of clutch size. Evolution **20**: 174-184.

Cook, R. T., S. E. R. Bailey and C. R. McCrohan. 1996. Slug preference for winter wheat cultivars and common agricultural weeds. Journal of applied Ecology **33**: 866-872.

Cook, R. T., S. E. R. Bailey and C. R. McCrohan. 1997. The potential for common weeds to reduce the slug damage to winter wheat: laboratory and field studies. Journal of Applied Ecology **34**: 79-87.

Cook, R. T., S. E. R. Bailey, C. R. McCrohan, B. Nash and R. M. Woodhouse. 2000. The influence of nutritional status on the feeding behaviour of the field slug, *Deroceras reticulatum* (Müller). Animal Behaviour **59**: 167-176.

Cowie, R. H., K. A. Hayes, C. T. Tran and W. M. Meyer III. 2008. The horticultural industry as a vector of alien snails and slugs: widespread invasions in Hawaii. International Journal of Pest Management **54**: 267-276.

Dankowska, E. 1996. Morphology and life history of *Deroceras laeve* (Müll) (Gastropoda: Styllommatophora: Agriolimacidae) in greenhouse conditions. Annals of Agricultural Sciences Series E25: 91-95.

Davis, A. J. 1989. Effects of soil compaction on damage to wheat seeds by three pest species of slugs. Crop Protection **8**: 118-121.

de Queiroz, K. 2005. Ernst Mayr and the modern concept of species. Proceedings of the National Academy of Science. 102: 6600-6607.

Dirzo, R. 1980. Experimental studies on slug-plant interactions: I. The acceptability of thirty plant species to the slug *Agriolimax caruaneae*. Journal of Ecology **68**: 981-998.

Dirzo, R. and J. L. Harper. 1982. Experimental studies on slug-plant interactions: III. Differences in the acceptability of individual plants of *Trifolium repens* to slugs and snails. Journal of Ecology **70**: 101-117.

Donoghue, M.J. 1985. A critique of the biological species concept and recommendations for a phylogenetic alternative. The Bryologist. 88: 172-181.

Ebenso, I. E. 2003. Molluscicidal effects of neem (*Azadirachta indica*) extracts on edible tropical land snails. Pest Management Science **60**: 178-182.

Edwards, M. and D. R. Morse. 1995. The potential for computer-aided identification in biodiversity research. Tree **10**: 153-158.

Egonmwan, R. I. 1992. Food selection in the land snail *Limicolaria flammea* Müller (Pulmonata: Achatinidae). Journal of Molluscan Studies **58**: 49-55.

Ester, A. and J. H. Nijenstein. 1995. Control of the field slug *Deroceras reticulatu*m (Müller) (Pulmonata: Limacidae) by pesticides applied to winter wheat seed. Crop Protection **14**: 409-413.

Faberi, A. J., A. N. López, P. L. Manetti, N. L. Clemente and H. A. Álvarez Castillo. 2006. Growth and reproduction of the slug *Deroceras laeve* (Müller) (Pulmonata: Stylommatophora) under controlled conditions. Spanish Journal of Agricultural Research **4**: 345-350.

Fairbanks, H. L. 1989. The reproductive anatomy and taxonomic status of *Philomycus venustus* Hubricht, 1953 and *Philomycus bisdosus* Branson, 1968 (Pulmonata: Philomycidae). The Nautilus **103**: 20-23.

Felsenstein, J. 1985. Confidence limits on phylogenies: an approach using the bootstrap. Evolution. 39: 783-791.

Folmer, O., M. Black, W. Hoeh, R. Lutz and R. Vrijenhoek. 1994. DNA primers for amplification of mitochondrial cytochrome c oxidase subunit I from diverse metazoan invertebrates. Molecular Marine Biology and Biotechnology **3**: 294–299.

Fox, L. and Landis, B. J. 1973. Notes on the predaceous habits of the grey field slug, *Deroceras laeve*. Environmental Entomology **2**: 306-307.

Frank, T. 1998. The role of different slug species in damage to oilseed rape bordering on sown wildflower strips. Annals of Applied Biology **133**: 483-493.

Frank, T. and M. Barone. 1999. Short-term field study on weeds reducing slug feeding on oilseed rape. Journal of Plant Diseases and Protection **106**: 534-538.

Frank, T., K. Bieri and B. Speiser. 2002. Feeding deterrent effect of carnivore, a compound from caraway seeds, on the slug *Arion lusitanicus*. Annals of Applied Biology **141**: 1-8.

Gebauer, J. 2002. Survival and food choice of the grey field slug (*Deroceras reticulatum*) on three different seed types under laboratory conditions. Journal of Pest Science **75**: 1-5.

Geenen, S., K. Jordens and T. Backeljau. 2006. Molecular systematics of the Carinarion complex (Mollusca: Gastropoda: Pulmonata): a taxonomic riddle caused by a mixed breeding system. Biological Journal of the Linnean Society. 89: 589-604.

Gelperin, A. 1975. Rapid food-aversion learning by a terrestrial mollusk. Science **189**: 567-570.

Getz, L. L. 1959. Notes on the ecology of slugs: *Arion circumscriptus*, *Deroceras reticulatum* and *Deroceras laeve*. American Midland Naturalist **61**: 485-498.

Glen, D. M., A. M. Spaull, D. J. Mowat, D. B. Green, and A. W. Jackson. 1993. Crop monitoring to access the risk of slug damage to winter wheat in the United Kingdom. Annals of Applied Biology **122**: 161-172.

Glen, D. M., N. F. Milsom and C. W. Wiltshire. 1989. Effects of seed bed conditions on slug conditions on slug numbers and damage to winter wheat in a clay soil. Annals of Applied Biology **115**: 197-207.

Glen, D. M., N. F. Milsom and C. W. Wiltshire. 1990. Effects of seed depth on slug damage to winter wheat. Annals of Applied Biology **117**: 693-701.

Godan, D. 1983. Pest slugs and snails. Biology and control. Springer-Verlag, Berlin, Heidelberg, New York. Pp. 441.

Gomes, S. R., F. B. da Silva, I. L. Veitenheimer Mendes, J. W. Thomé and S. L. Bonatto. 2010. Molecular phylogeny of the South American land slug *Phyllocaulis* (Mollusca, Soleolifera, Veronicellidae). Zoologica Scripta **39**: 177-186.

Gould, A. A. 1841. Report on the Invertebrata of Massachusetts, Comprising the Mollusca, Crustacea, Annelida, and Radiata. Cambridge. Pp. 3.

Gouyon, P. H., P. H. Fort and G. Caraux. 1983. Selection of seedlings of *Thymus vulgaris* by grazing slugs. Journal of Ecology **71**: 299-306.

Grewal, S. K., P. S. Grewal and R. B. Hammond. 2003. Susceptibility of North American native and non-native slugs (mollusca: Gastropoda) to *Phasmarhabditis hermaphrodita* (Nematoda: Rhabditidae). Biocontrol Science and Technology **13**: 119-125.

Hagin, R. D. and S. J. Bobnick. 1991. Isolation and identification of a slug-specific molluscicide from quackgrass (*Agropyron repens*, L. Beauv.). Journal of Agricultural and Food Chemistry **39**: 192-196.

Hall, TA. 1999. BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. Nucleic Acids Symposium Series **41**: 95-98.

Hammond R. B., J. A. Smith and T. Beck. 1996. Timing of molluscicide applications for reliable control in no-tillage field crops. Journal of Economic Entomology **898**: 1028-1032.

Hammond, R. B. 1985. Slugs as a new pest of soybeans. Journal of the Kansas Entomological Society **58**: 364-366.

Hata, T. Y., A. H. Hara and B. K. S. Hu. 1997. Molluscicides and mechanical barriers against slugs, *Vaginula plebeia* Fischer and *Veronicella cubensis* (Pfeiffer) (Stylommatophora: Veronicellidae). Crop Protection **16**: 501-506.

Hatteland, B. A., K. Grutle, C. E. Mong, J. Skartveit, W. O. C. Symondson and T. Solhøy. 2010. Predation by beetles (Carabidae, Staphylinidae) on eggs and juveniles of the Iberian slug *Arion lusitanicus* in the laboratory. Bulletin of Entomology Research **100**: 559-567.

Hausdorf, B. 2011. Progress toward a general species concept. Evolution. 65: 923-931.

Holland, B. S. and R. H. Cowie. 2007. A geographic mosaic of passive dispersal: population structure in the endemic Hawaiian amber snail *Succinea caduca* (Mighels, 1845). Molecular Ecology **16**: 2422-2435.

Howlett, S. A., D. J. Wilson and K. T. Miller. 2008. The efficacy of various bait products against the grey field slug, *Deroceras reticulatum*. New Zealand Plant Protection **61**: 283-286.

Hubricht, L. 1951. The Limacidae and Philomycidae of Pittsylvania County, Virginia. The Nautilus **65**: 20-22.

Hubricht, L. 1953. Three new species of Philomycidae. The Nautilus **66**: 78-80.

Hubricht, L. 1956. Land snails of Shenandoah National Park. The Nautilus **70**: 15-16.

Hubricht, L. 1972. Two new North American Pulmonata: *Paravitrea seradens* and *Philomycus sellatus*. The Nautilus **86**: 16-17.

Hubricht, L. 1974. Brief communications. Malacological Review. **7**: 33-34.

Hubricht, L. 1985. The distribution of the native land mollusks of the eastern United States. Fieldiana: Zoology **24**: 1-191.

Huelsenbeck, J.P. and F. Ronquist. 2001. MrBayes: Bayesian inference of phylogeny. Bioinformatics **17**: 754-755.

Iglesias, J. and B. Speiser. 2001. Consumption rate and susceptibility to parasitic nematodes and chemical molluscicides of the pest slugs *Arion hortensis* s.s. and *A. distinctus*. Journal of Pest Science **74**: 159-166.

Iglesias, J., J. Castillejo and R. Castro. 2001. Mini-plot field experiments on slug control using biological and chemical control agents. Annals of Applied Biology **139**: 285-292.

Ireland, P. M. 1988. A comparative study of the uptake and distribution of silver in a slug *Arion ater* and a snail *Achatina fulica*. Comparative Biochemistry and Physiology Part C: Comparative Pharmacology **90**: 189-194.

Jennings, T. J. and J. P. Barkham. 1975. Food of slugs in mixed deciduous woodland. Oikos **26**: 211-221.

Joe, S. M. and C. C. Daehler. 2008. Invasive slugs as under-appreciated obstacles to rare plant restoration: evidence from the Hawaiian Islands. Biological Invasions **10**: 245-255.

Jordaens, K., J. Pinceel and T. Backeljau. 2006. Life-history variation in selfing multilocus genotypes of the land slug *Deroceras laeve* (Pulmonata: Agriolimacidae). Journal of Molluscan Studies **72**: 229-233.

Karlin, E. J. and C. Bacon. 1961. Courtship. Mating and egg-laying behaviour in the Limacidae (Mollusca). Transactions of the American Microscopical Society **80**: 399-406.

Keller, H. W. and K. L. Snell. 2002. Feeding activities of slugs on Myxomycetes and macrofungi. Mycologia **94**: 757-760.

Keller, M., J. Kollmann and P. J. Edwards. 1999. Palatability of weeds from different European origins to the slugs *Deroceras reticulatum* Müller and *Arion lusitanicus* Mabille. Acta Oecologica **20**: 109-118.

Klassen, W., C. F. Brodel and D. A. Fieselmann. 2002. Exotic pests of plants: Current and future threats to horticultural production and trade in Florida and the Caribbean basin. Micronesica Supp **6**: 5-27.

Kozłowska, M. and J. Kozłowski. 2004a. Consumption growth as a measure of comparisons of results from no-choice test and test with multiple choice. Journal of Plant Protection Research **44**: 251-258.

Kozłowska, M. and J. Kozłowski. 2004b. Food preferences of *Deroceras reticulatum*, *Arion lusitanicus* and *Arion rufus* for various medicinal herbs and oilseed rape. Journal of Plant Protection Research **44**: 240-250.

Kozłowski, J. and M. Kozłowska. 2008. Differences in acceptability of herb plants and oilseed rape for slugs (*Arion lusitanicus, Arion. rufus and Deroceras reticulatum*) in food choice tests. Journal of Plant Protection Research **48**: 461-474.

Linhart, Y. B. and J. D. Thompson. 1995. Terpene-based selective herbivory by *Helix aspersa* (Mollusca) on *Thymus vulgaris* (Labiatae). Oecologia **102**: 126-132.

Lipa, J. J. and P. H. Smits. 1999. Microbial control of pests in greenhouses. *In*: R. R. Albajes, M. Lodovica Gullino, J. C. Van Lenteren and Y. Elad, eds., *Integrated Pest and Disease Management in Greenhouse Crops*. Kluwer Academic Publishers, Netherlands. Pp. 295-309.

Lockwood III, J. R. 1998. On the statistical analysis of multiple-choice feeding preference experiments. Oecologia **116**: 475-481.

Lucid 3. 2004-2007. Version 3.4. Center for Biological Information Technology, The University of Queensland, Brisbane. www.lucidcentral.org.

Maddison, W. P. and D.R. Maddison. 2011. Mesquite: a modular system for evolutionary analysis. Version 2.75. http://mesquiteproject.org

Mair, J. and G. R. Port. 2002. The influence of mucus production by the slug, *Deroceras reticulatum*, on predation by *Pterostichus madidus* and *Nebria brevicollis* (Coleoptera: Carabidae). Biocontrol Science and Technology **12**: 325-335.

Mallet, J. 2007. Species, concept of. Encyclopedia of Biodiversity. pp 1-15.

Massachusetts.

Mayden, R.L. 1997. A hierarchy of species concepts: the denouement in the saga of the species problem. In: Claridge, M.F., H.A. Dawah and M.R. Wilson (Eds). The Units of Biodiversity. Chapman and Hall, London. pp. 381-424.

Mayr, E. 1996. What is a species and what is not? Philosophy of Science. 63: 262-277.

McCracken, G. F. and R. K. Selander. 1980. Self-fertilization and monogenic strains in natural populations of terrestrial slugs. Proceedings of the National Academy of Sciences **77**: 684-688.

McCullough, D. G., T. T. Work, J. F. Cavey, A. M. Liebhold and D. Marshall. 2006. Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17-year period. Biological Invasions **8**: 611-630.

Moens, R. and D. M. Glen. 2002*. Agriolimacidae, Arionidae* and *Milacidae* as pests in west European oilseed rape*. In:* G. M. Barker, ed., *Molluscs as Crop Pests.* CABI Publishing, Wallingford, UK*.* Pp*.* 425-439.

Mølgaard, P. 1986. Food plant preferences by the slugs and snails: A simple method to evaluate the relative palatability of the food plants. Biochemical Systematics and Ecology **14**: 113-121.

Nash, M. A., L. J. Thomson and A. A. Hoffmann. 2007. Slug control in Australian canola: monitoring, molluscicidal baits and economic thresholds. Pest Management Science **63**: 851-859.

Oberholzer, F., N. Escher and T. Frank. 2003. The potential of carabid beetles (Coleoptera) to reduce slug damage to oilseed rape in the laboratory. European Journal of Entomology **100**: 81-85.

Pakarinen, E. 1992. Feeding avoidance of terrestrial gastropods to conspecific and nonspecific material. Journal of Molluscan Studies **58**: 109-120.

Pallant, D. 1969. The food of the grey field slug (*Agriolimax reticulatus* (Müller)) in woodland. Journal of Animal Ecology **38**: 391-397.

Pena, J. E. and V. Waddill. 1982. Pests of Cassava in South Florida. The Florida Entomologist **65**: 143-149.

Peters, H. A., B. Baur, F. Bazzaz and C. Körner. 2000. Consumption rates and food preferences of slugs in a calcareous grassland under current and future CO_2 conditions. Oecologia **125**: 72-81.

Pickett, J. A. and J. W. Stephenson. 1980. Plant volatiles and components influencing behavior of the field slug, *Deroceras reticulatum* (Müller). Journal of Chemical Ecology **6**: 435-444.

Pilsbry, H. A. 1891. On the genus *Tebennophorus* Binney, or *Philomycus* Raf (to be continued). The Nautilus **5**: 4-8.

Pilsbry, H. A. 1891. On the genus *Tebennophorus* Binney, or *Philomycus* Raf (continued). The Nautilus **5**: 21-23.

Pilsbry, H. A. 1948. Land Mollusca of North America north of Mexico vol. II part 2. Academy of Natural Sciences, Philadelphia. Pp. 521-1113.

Port, C. M. and G. Port. 1986. The biology and behaviour of slugs in relation to crop damage and control. Agricultural Zoology Reviews **1**: 255-299.

Posada, D. and K. A. Crandall. 1998. Modeltest: testing the model of DNA substitution. Bioinformatics **14**: 817-818.

Prystupa, B. D., J. N. Holliday and G. R. B. Webster. 1987. Molluscicide efficacy against the marsh slug, *Deroceras laeve* (Stylommatophora: Limacidae) on strawberries in Manitoba. Journal of Economic Entomology **80**: 936-943.

Purvis, G. and J. W. Bannon. 1992. Non-target effects of repeated methiocarb slug pellet application on carabid beetle (Coleoptera, Carabidae) activity in winter-sown cereals. Annals of Applied Biology **121**: 215-223.

Rae, R., C. Verdun, P.S. Grewal, J. F. Robertson and M. J. Wilson. 2007. Biological control of terrestrial molluscs using *Phasmarhabditis hermaphrodita*-progress and prospects. Pest Management Science **63**: 1153-1164.

Raffaelli, D. and A. J. Mordue. 1990. The relative importance of molluscs and insects as selective grazers of cyanogenic white clover (*Trifolium repens*). Journal of Molluscan Studies **56**: 37-45.

Rafinesque, C. S. 1820. Annals of nature or Annual synopsis of new genera and species of animals, plants, &c. discovered in North America. Iowa. Pp. 10.

Rathcke, B. 1985, Slugs as generalist herbivore: Test of three hypotheses on plant choices. Ecology **66**: 828-836.

Ratnasingham, S. and P. D. N. Hebert (2007) BOLD: the barcode of life data system (http://www.barcodinglife.org). Molecular Ecology Notes **7**:355–364.

Rawlings, T. A., K. A. Hayes, R. H. Cowie and T. M. Collins. 2007. The identity, distribution, and impacts of non-native apple snails in the continental United States. BMC Evolutionary Biology **7**: 97-110.

Richardson, B. and J. B. Whittaker. 1982. The effect of varying the reference material on ranking of acceptability indices of plant species to a polyphagous herbivore, *Agriolimax reticulatus*. Oikos **39**: 237-240.

Ronquist, F. and J. P. Huelsenbeck. 2003. MrBayes version 3.0: Bayesian phylogenetic inference under mixed models. Bioinformatics **19**:1572-1574.

Rueda, A. A., F. Slansky Jr. and G. S. Wheeler. 1991. Compensatory feeding response of the slug *Sarasinula plebeia* to dietary dilution. Oecologia **88**: 181-188.

Ryder, O.A. 1986. Species conservation and systematics: the dilemma of subspecies. Trends in Ecology and Evolution. 1: 9-10.

SAS Institute Inc. 2008. What's New in SAS® 9.2. Cary, NC: SAS Institute Inc.

Schley, D. and M. A. Bees. 2003. Delay dynamics of the slug *Deroceras reticulatum*, an agricultural pest. Ecological Modeling **162**: 177-198.

Schüder, I., G. Port and J. Bennison. 2004. The behavioural response of slugs and snails to novel molluscicides, irritants and repellants. Pest Management Science **60**: 1171-1177.

Shayler, H. A. and P. A. Siver. 2006. Key to freshwater algae: A web-based tool to enhance understanding of microscopic biodiversity. Journal of Science Education and Technology **15**: 298-303.

Shen, J. 1995. Cannibalism in the terrestrial slug *Deroceras laeve*. The Nautilus **109**: 41-42.

Simpson, G.G. 1951. The species concept. Evolution. 5: 285-298

South, A. 1992. Terrestrial slugs. Biology, ecology and control. Chapman and Hall, London, UK. Pp. 1-428.

Speiser, B. and C. Kistler. 2002. Field tests with a molluscicide containing iron phosphate. Crop Protection **21**: 389-394.

Speiser, B., J. G. Zaller and A. Neudecker. 2001. Size-specific susceptibility of the pest slugs *Deroceras reticulatum* and *Arion lusitanicus* to the nematode biocontrol agent *Phasmarhabditis hermaphrodita*. Biocontrol **46**: 311-320.

Speiser, B., J. Harmaths and M. Rowell-Rhaier. 1992. Effects of pyrrolizidine alkaloids and sesquiterpenes on snail feeding. Oecologia **92**: 257-265.

Stange, L. A., J. E. Deisler and T. Fasulo. 1999. Slugs (of Florida) (Gastropoda: Pulmonata). University of Florida, Institute of Food and Agricultural Sciences Extension publication EENY-087 (IN244). Pp.1-10.

Starbird, S. A. 1994. The effect of quality assurance policies for the processing tomatoes on the demand for pesticides. Journal of Agricultural and Resource Economics **19**: 78-88.

Swofford, D. L. 2002. PAUP*. Phylogenetic Analysis Using Parsimony (*and Other Methods). Version 4. Sinauer Associates, Sunderland,

Tan, L. and P. S. Grewal. 2001a. Infection behavior of the rhabditid nematode *Phasmarhabditis hermaphrodita* to the grey garden slug *Deroceras reticulatum*. Journal of Parasitology **87**: 1349-1354.

Tan, L. and P. S. Grewal. 2001b. Pathogenicity of *Moraxella osloensis*, a bacterium associated with the nematode *Phasmarhabditis hermaphrodita*, to the slug *Deroceras reticulatum*. Applied and Environmental Microbiology **67**: 5010-5016.

Thompson, J. M., J. L. Sibley, W. G. Foshee III, G. J. Keever and A. G. Appel. 2005. Effect of copper hydroxide on slug feeding. Journal of Environmental Horticulture **23**: 167-170.

Turgeon, D. D., J. F. Quinn, A. E. Bogan, E. V. Coan, F. G. Hochberg, W. G. Lyons, P. M. Mikkelsen, R. J. Neves, C. F. E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F. G. Thompson, M. Vecchione, and J. D. Williams. 1998. Common and Scientific Names of Aquatic Invertebrates from the United States and Canada: Mollusks, 2nd Edition. American Fisheries Society Special Publication 26. American Fisheries Society. Bethesda, Maryland. Pp. 1-526.

United States Department of Agriculture-Economics Research Service (USDA-ERS): The Economics of Food, Farming, Natural Resources, and Rural America. 2011. Access date (09-13-2011). http://www.ers.usda.gov/Data/FATUS/

Wareing, D. R. 1993. Feeding history -- a factor in determining food preference in slugs. Journal of Molluscan Studies **59**: 366-368.

Webb, G. R. 1968. Observations on the sexology of *Philomycus carolinianus* Bosc. Gastropodia **1**:62.

Webster, J. and R. W. S. Weber. 2007. Introduction to fungi (3rd edition). Cambridge University Press, Cambridge, UK. Pp. 1-841.

Wiktor, A. 2000. Agriolimacidae (Gastropoda: Pulmonata) – A systematic monograph. Annales Zoologici **49**: 347-590.

Williamson, P. and R. A. D. Cameron. 1976. Natural diet of the landsnail *Cepaea nemoralis*. Oikos **27**: 493-500.

Willis, J. C., D. A. Bohan, Y. H. Choi, K .F. Conrad and M. A. Semenov. 2006. Use of an individual-based model to forecast the effect of climate change on the dynamics, abundance and geographic range of the pest slug *Deroceras reticulatum* in the U.K. Global Change Biology **12**: 1643-1657.

Yildirim, M. Z. and Ü. Kebapçi. 2004. Slugs (Gastropoda: Pulmonata) of the Lakes Region (Göller Bölgesi) in Turkey. Turkish Journal of Zoology **28**: 155-160.

Zhang, X., X. Chen and J. Cheng. 2008. SI Key: A tool to generate secondary identification key for targeted diagnosis. Expert Systems with Applications **34**: 2812-2818.

Zotin, A. A. 2007. Patterns of individual growth of gray garden slugs *Deroceras reticulatum.* Biology Bulletin **34**: 457-462.

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BIOGRAPHICAL SKETCH

Jodi A. White-McLean was born on the beautiful island of Jamaica, West Indies in April of 1983. She attended the University of the West Indies, Mona, where she earned her Bachelor of Science degree in botany (major) and zoology (minor) in the spring of 2004. She went on to pursue a Doctor of Plant Medicine degree at the University of Florida in the fall of 2005. She successfully completed this degree in the fall of 2008. During the pursuit of the Doctor of Plant Medicine degree, she developed an interest in Malacology and applied to the Entomology and Nematology Department at the University of Florida with the hope of engaging in research that relate to this interest. In August of 2009, she got accepted into a Doctor of Philosophy degree program at the Entomology and Nematology Department at the University of Florida, where she worked under the direct supervision of Dr. John Capinera. She received her Ph.D. from the University of Florida in the spring of 2012. Upon accomplishing this degree she intends to pursue a career in public service.