Pennsylvania land snails susceptible to climate change, with imperilment ranks and updated distribution maps

Final Report to the Wild Resources Conservation Program
Grant Contract WRCP-10379 (Project #441161)

Prepared by Timothy A. Pearce
Assistant Curator and Head, Section of Mollusks
Carnegie Museum of Natural History
Pittsburgh, Pennsylvania, USA
www.carnegiemnh.org/mollusks/
412-622-1916

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ABSTRACT

Climate warming that causes population shifts and extinctions might be most serious to species already confined to high elevations, especially if higher elevations are scarce in extent. Elevations in Pennsylvania span 0 to 979 m, but elevations greater than 700 m comprise only 2% of Pennsylvania's area. I sampled from 108 localities (12 localities at each 100 m elevation interval from 100 to 900 m). Although overall numbers of snail species and abundances decreased at greater elevations, five species significantly (*Helicodiscus shimeki*, *Mesomphix perlaevis*, *Neohelix albolabris*, *Striatura ferrea*, and *Striatura milium*) and four species non-significantly (*Mesomphix inornatus*, *Pallifera dorsalis*, *Philomycus flexuolaris*, and *Philomycus togatus*) occurred more often at greater elevations. If populations of these snails were forced upward due to warming climate, they would be forced into smaller geographical ranges and their populations would likely decline.

In addition to studying potential effects of climate warming, I was also able to accomplish three additional objectives: evaluating public lands most important for snail conservation, updating county-level distribution maps for Pennsylvania's land snail species, and determining imperilment ranks for Pennsylvania's land snail species.

Combining results from this sampling with existing museum records yielded 17,472 records of Pennsylvania species with locality and collection date information. That information allowed identification of 19 public lands in Pennsylvania that are priorities for conservation because they contain snail species of concern (3 top ranked lands are Wissahickon Valley, Raccoon Creek State Park, and Powdermill Nature Reserve). Updated county-level distribution maps for Pennsylvania's 129 land snail species show trends over time as well as vastly improved information of species distributions. Imperilment rankings identified 46 native species to be of conservation concern (S1-S3), and 47 natives not of conservation concern (S4-S5).

These results identify species of concern and provide information useful for studying, monitoring, and conserving them. Populations of higher elevation species should be monitored to watch for declines. Public lands that harbor snails of special concern are important to conserve. Updated species distribution maps provide new information useful to land managers and naturalists; this information can be explored from a variety of perspectives such as areas of occurrence, trends over time, and ecological questions. Imperilment ranks indicate species of conservation concern that are priorities for conservation.

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Predicting susceptibility of Pennsylvania land snails to climate change

by Timothy A. Pearce

INTRODUCTION

As climates warm, living species of plants and animals in Pennsylvania are predicted to move northward and to higher elevations to follow shifting habitats; if they cannot move or adapt, they might become locally extinct. Of these organisms, non-marine mollusks are some of the most imperiled species on earth (Lydeard et al. 2004, Régnier et al. 2009). To identify the species of land snails in Pennsylvania that are most vulnerable to climate change, this WRCF-funded project systematically surveyed land snails statewide in 2011, across elevation and latitudinal transects.

In order to sample the greatest breadth of climate conditions, this project focuses primarily on elevation transects, gaining latitude information by sampling in northern, central, and southern Pennsylvania. From a climate perspective, moving poleward 1° latitude corresponds roughly to moving up about 100 m elevation (Cogbill & White 1991). This rule-of-thumb predicts that existing climates within Pennsylvania vary nearly 4 times as much by elevation as by latitude. Pennsylvania latitude spans 2.6° from 39.7° to 42.3° (roughly equivalent to 260 m elevation) while Pennsylvania elevation ranges from 0 m to 979 m (roughly equivalent to 9.8° latitude).

Some species of land snails might occur at higher elevations because they require the cooler temperatures at higher elevations. If the climate warmed, those snails would need to move upward in order to stay in their preferred climate. However, if no higher elevations existed, then the snails would likely perish (Fig. 1).

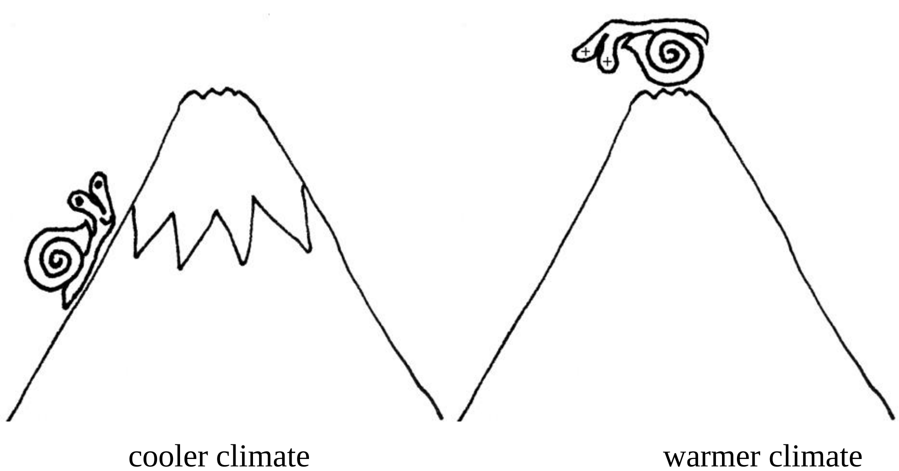


Fig. 1. Under current climate conditions, a snail species could live at a particular elevation in its preferred climate (left). However, with a warmed climate, if the snail's preferred climate shifted upward beyond the mountain top, then that species is likely to become locally extinct (right).

This report examines whether some land snail species are limited to higher elevations. If they are limited to higher elevations, and if absence from lower elevations is due to thermal intolerance, then climate warming might pose a threat to those species.

I focus on possible changes due to climate warming instead of other threats because predictions of climate warming are more easily tested. A number of distinct threats are predicted as a result of changing climate (UCS 2008). Threats that are not addressed in this paper include: changes in precipitation, movement into the area by other species (predators, parasites, diseases, or competitors), and latitudinal shifts in range of the biota, its habitat, or its host organisms (e.g., food or symbionts). These possible threats are clearly expected from climate warming models (IPCC 2007, Foden et al. 2008, Bellard et al. 2012), but I do not address them here because they do not yield distinct predictions that are easily testable (Pearce & Paustian 2013).

The results from this study has and will continue document which species might become imperiled in the future, and where effort should be focused to mitigate the effects of climate change. For example, information resulting from this project was directly relevant to preparing the "Invertebrate Assessment for the 2015 Pennsylvania Wildlife Action Plan Revision" (Leppo et al. 2015).

DELIVERABLES AND PUBLICATIONS

Deliverables Listed in the Grant Proposal to WRCF

(1) "List of susceptible Pennsylvania land snail species indicating their degree of threat from global warming. Assigning threats will consider results of this study in addition to distribution information outside of Pennsylvania. Furthermore, because the ranges of some species are currently smaller than their historical distributions, this evaluation will consider both historical and modern distributions."

Done. Results published (Pearce & Paustian 2013). Nine species occurred more at higher elevations: five species statistically significantly and four non-significantly. The five that significantly occurred more at higher elevations were *Helicodiscus shimeki*, *Mesomphix perlaevis*, *Neohelix dentifera*, *Striatura ferrea*, and *Striatura milium*. The four that non-significantly tended to occur more at higher elevations were *Mesomphix inornatus*, *Pallifera dorsalis*, *Philomycus flexuolaris*, and *Philomycus togatus*. Populations of these nine species might decline if the climate warmed.

(2) "List of public land holdings most in need of conservation."

Done. Nineteen Pennsylvania public lands that are most important to land snail conservation are shown in Appendix 1 and are discussed below.

(3) "Updated distribution maps of Pennsylvania land snails, from 2005 maps (Pearce 2008), that reflect considerable new information anticipated from this project as well as substantial new distribution records that have arrived at Carnegie Museum of Natural History since the 2005 maps were produced, as a result of the Land Snails and Slugs of Pennsylvania Atlas Project. Updated maps will appear in both the final report and on the Internet (www.carnegiemnh.org/mollusks/palandsnails/)."

Done. Updated distribution maps for 129 Pennsylvania land snail species appear in Appendix 2. This final report to Wild Resources Conservation Program with updated distribution maps in the Appendix 2 appears on the Carnegie Museum Mollusks website (http://www.carnegiemnh.org/mollusks/news.html). Methods used in updating the maps and findings are discussed.

(4) "Refined list of recommended state conservation ("S") ranks for all 120+ land snail species of Pennsylvania. I will employ the method used by the Pennsylvania Biological Survey (PABS), modified from the global method used by the International Union for the Conservation of Nature (IUCN)."

Done. Imperilment ranks for 143 species appear in Appendix 3. I used an updated imperilment ranking method from NatureServe. Methods for determining ranks are discussed below.

(5) **"**Illustrated educational fact sheet about land snails of Pennsylvania, suitable for public distribution."

Done. The educational, illustrated fact sheet, entitled "Fact Sheet: Pennsylvania Land Snails," appears in Appendix 4.

Publications and Presentations Resulting from this Project

Findings resulting from this project have been disseminated through three publications and nine presentations at scientific meetings. All of these publications and talks gratefully acknowledged and thanked Wild Resources Conservation Program for funding. One publication is in a peer-reviewed journal and the other two are in newsletters.

Two talks were presented at the American Malacological Society meeting, one talk was as an invited speaker in the Land Snail Symposium at the Western Society of Malacologists meeting. One talk was presented at each of the Ohio Valley Unified Malacologists meeting and at a joint meeting of the World Congress of Malacology and American Malacological Society. Three talks were presented at Mid-Atlantic Malacologists meetings, and one talk was at a joint meeting of four mollusk societies including American Malacological Society in Mexico City.

Pearce and M.E. Paustian continue to collaborate on an additional paper for a peer reviewed journal examining environmental influences on snail distributions.

Publications:

Pearce, T.A. & Paustian, M.E. 2013. Are temperate land snails susceptible to climate change through reduced altitudinal ranges? A Pennsylvania example. American Malacological Bulletin 31(2): 213-224.

Pearce, T.A. & Paustian, M.E. 2013. Five land snail species predicted to decline with climate warming in Pennsylvania, USA. Tentacle, Mollusk Conservation Newsletter (21): 7.

Pearce, T.A. & Paustian, M.E. 2011. A summer of leaf litter. What's Gnu, Carnegie Museum of Natural History, June: 5.

Presentations:

Pearce, T.A. 2015. Pennsylvania land snails: distribution maps and imperilment ranks. *Mid-Atlantic Malacologists Meeting*, 7 March, Wilmington, Delaware.

Pearce, T.A. & Arnold, C.D. 2014. Decline of land snails; the example of *Anguispira alternata* (Discidae) in Pennsylvania, USA. Invited talk in symposium: Terrestrial Mollusks of the Americas: Diversity and Relationships in Vanishing Habitats; at *Molluscan Meeting of the Americas, joint meeting of American Malacological Society, Western Society of Malacologists, Society of Malacology of Mexico, and Latinoamerican Society of Malacology*, 23 to 27 June, Mexico City.

Pearce, T.A. & Arnold, C.D. 2014. Decline of the Tiger Snail *Anguispira alternata* in Pennsylvania. *Mid-Atlantic Malacologists Meeting*, 29 March, Wilmington, Delaware.

Paustian, M.E. & Pearce, T.A. 2014. The likely effects of global warming upon the distributions of Pennsylvania land snails. *Mid-Atlantic Malacologists Meeting*, 29 March, Wilmington, Delaware.

Paustian, M.E. & Pearce, T.A. 2013. The land snails of Pennsylvania, USA: likely effects of global warming upon species' distributions. Presentation at *World Congress of Malacology, joint with American Malacological Society*, 25 July Ponta Delgada, Azores.

Paustian, M.E. & Pearce, T.A. 2012. The slugs of Pennsylvania: identification and analysis of species distributions. *OVUM (Ohio Valley Unified Malacologists) Meeting*, Fort Wayne, Indiana, 6 Oct.

Pearce, T.A. & Paustian, M.E. 2012. Are temperate land snails susceptible to climate change through reduced ranges upward? A Pennsylvania example. *Western Society of Malacologists Annual Meeting*, Santa Cruz, California, 26 June. [Pearce was invited speaker in Land Snail Symposium.]

Pearce, T.A. & Paustian, M.E. 2012. Are Pennsylvania land snails susceptible to climate change? *American Malacological Society*, Cherry Hill, New Jersey, 18 June.

Paustian, M.E. & Pearce, T.A. 2012. The slugs of Pennsylvania: analysis of species distributions and ecological correlates. *American Malacological Society*, Cherry Hill, New Jersey, 18 June.

METHODS

Species Susceptible to Climate Warming

Site Selection. I selected 108 sampling localities (Fig. 2) with help from Natural Heritage staff member Rocky Gleason of Western Pennsylvania Conservancy. The target localities were 12 localities at each 100 m elevation interval from 100 to 900 m. The goals for site selection included favoring (1) target elevation match; (2) geographically widespread localities across the state, particularly focusing on northern, central, and southern localities; (3) less disturbed areas and areas hosting other interesting or special-concern plants and animals; and (4) relatively easy landowner permission.

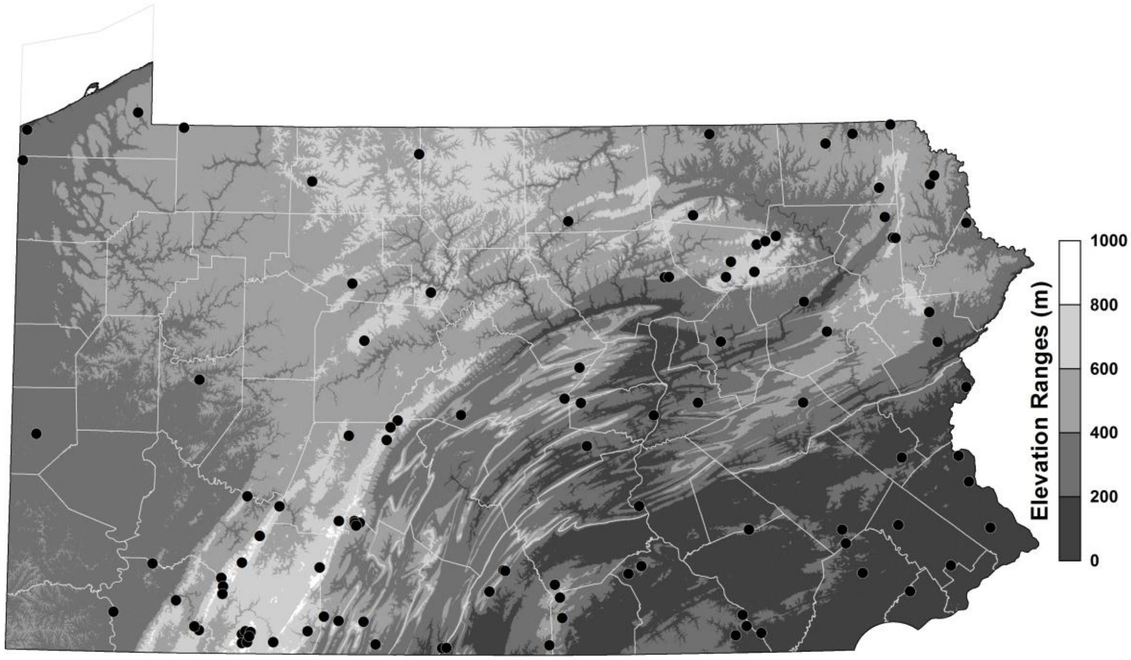


Fig. 2. Samples were taken at 108 localities (circles) throughout Pennsylvania. Because of Pennsylvania topography, low-elevation sites (100 m) were necessarily concentrated in the southeastern part of the state and high-elevation sites (800-900 m) were toward the southwest.

Obtaining geographical localities that were widespread across the state was challenging at the lowest and highest elevations because most low elevations are in southeastern Pennsylvania and most high elevations are near Pennsylvania's highpoint at Mount Davis in southwestern Pennsylvania. Consequently, finding lowest and highest elevations in northern Pennsylvania was not possible.

Although limestone areas tend to have snails in greater abundance, I gave more importance to selecting sites that hosted other interesting or special-concern plants and animals. I used this criterion on the assumption that areas with unusual biota might have unusual snails. Localities chosen using the criterion of unusual biota might not always be expected to have abundant snails since some unusual biotic organisms occur in dry and acidic conditions, which are not conducive to land snails. This method of site selection would be expected to yield greater variability in abundance of snails across sites than if sites were selected for habitat uniformity.

Sampling. Sampling of all 108 localities was completed from 20 May to 9 Oct 2011. For sampling, I located centerpoints of stations and then sampled within a 20 m radius of that point. Snail inventory included both litter sampling and visual search components. Litter samples targeted the minute land snails (median 3 mm or 1/8 inch) diameter, which make up more of the species and are typically missed or under-sampled during visual search (Fig. 3). The litter sampling component was a 4 liter leaf litter sample taken for later processing in the lab. All leaf litter samples were collected by the same person (Pearce) by brushing away the whole leaves on the surface and sampling the finer duff layer. To reach a volume of 4 liters, litter was sampled from microhabitats that by the sampler's experience were more likely to harbor abundant and diverse snails, such as beside logs or in shallow depressions.

Fig. 3. Some minute snails of Pennsylvania on a penny, demonstrating their small size. Photo by Marla Coppolino.

The visual component was a 40 person-minute visual search (twice the search time promised in the proposal) by experienced malacologists Megan E. Paustian and Timothy A. Pearce (Fig. 4). Visual search focused on larger snails and slugs that are not surveyed well by litter sampling (Emberton et al. 1996, Menez 2001, Cameron & Pokryszko 2005).

The litter was air-dried, then passed through graded nested sieves (8 sieves from 8 mm to 0.5 mm). Trained Federal work-study students from the University of Pittsburgh (Fig. 5) and volunteers picked snails from all layers >0.7 mm and from more than half of the 0.5 mm layers, using a microscope for smaller layers. Snails were identified by T.A. Pearce and slugs by M.E. Paustian.

Data and environmental variables gathered at each locality included latitude, longitude, elevation, date, time, observers, person minutes of visual search, litter volume, slope, aspect, notes on the age of the stand, tree diameter, canopy height, list of plants (in the herb layer, understory layer, and canopy layer), and estimates of percent cover by coarse woody debris and rocks. Site photos were taken at most of the localities. To further characterize the environment at the localities, soil samples (<0.5 mm fraction) were analyzed for pH, organic matter, aluminum, boron, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sulfur, and zinc by the University of Delaware Soil Testing Program, Newark, Delaware. This information will be relevant to a future publication in preparation by Pearce and Paustian.

Fig. 4. Experienced malacologists, Megan E. Paustian conducting visual search (left) and Timothy A. Pearce sampling leaf litter (right), surveying for land mollusks. Photo on right by Megan E. Paustian.

Fig. 5. Trained work-study students picking minute snails from leaf litter samples. Photo by Ken P. Hotopp.

Important Public Land Holdings

Recognizing which areas are important to snails, especially to species of concern, can be a useful step toward conserving snails. Criteria used in this assessment of important snail areas included (1) conservation concern, (2) range restricted species, and (3) habitat restricted species. For Pennsylvania land snails, habitat restriction information is largely unknown, other than limestone- and wetland-restricted species. In other states, endemism is a criterion but Pennsylvania does not have any endemic land snail species.

For determining the public lands most in need of conservation from a land snail perspective, a GIS query using locality data found from museum records indicated that Pennsylvania land snails have been found in 124 public lands. I counted the number of occurrences of land snails of concern (species ranked S1-S3, critically imperiled to vulnerable, see Imperilment Rank section below) in each public land and counted the number of occurrences of S1, S2, and S3 species in each public land (a species could occur multiple times). I arbitrarily chose weights for the imperilment ranks so that number of occurrences of S1 was 3 times more important than S2 and that of S2 was 2 times as important as S3. I calculated the sum of the weighted occurrences for each public land and ranked the lands by their scores.

Updated Distribution Maps

Distribution maps by county were updated for 129 species with additional distribution information from the previous maps presented in Pearce (2008). In the present report, for each species, two distribution maps are presented depicting distributions before and after year 2000. These maps represent my best guess at the real distributions of the species for the two time periods. The map on the right shows distributions after year 2000. The map on the left shows distributions before year 2000. However, the way I present before-2000 maps for native species differs from the way I present maps for introduced species in order to give my best guess at the real distribution from before year 2000.

During the period from 1960 to 2000, there was a considerable decrease in land snail collecting effort in Pennsylvania. Consequently, whether I use 1960 or 2000 as the cutoff date makes little difference for comparing past and present distributions. I used year 2000 as the cutoff between past and present distribution maps.

Distribution maps comparing known distributions before and after a certain date must be interpreted carefully to prevent misleading conclusions. This caution is particularly relevant if species were under-sampled in the past, as is the case with many micro snails in Pennsylvania. In contrast to introduced species, for which range expansions over time are likely, native species are expected to have had time to occupy suitable territory; therefore, dramatic range expansions over time are unexpected. Consequently, ongoing habitat and climate changes have potential to cause decreases in the ranges of native species over time.

Inferring presences of native species. Land snails in Pennsylvania have been under-sampled (as demonstrated herein), so while it is possible that native species ranges are expanding, it is more likely that an increase in occurrences over time represents better sampling of actual long-term distributions rather than immigration. To include all records, past and present, from before and after year 2000, yields a better estimate of the real distribution from before year 2000.

Presences are readily interpretable as real, but the lack of finds (absence of evidence) may or may not represent actual absence of a species in an area.

For the purpose of interpreting the maps, a past absence of a particular species from a county, that in turn became a presence, could be interpreted in two ways: dispersal (immigration to the county) or under-sampling (previously present but not detected). Of these two interpretations (for native species), new modern presences are more likely to represent past undetected presences, rather than recent immigration. For native species, instead of presenting just the known before-2000 occurrences, I chose to infer that new after-2000 occurrences represent previously undetected before-2000 occurrences.

Two examples using native micro snails illustrate the difference between maps that depict known distributions from strictly before year 2000 with distributions after year 2000, contrasted with maps depicting all known distributions with only those distributions from after year 2000.

In the first example, Fig. 6 shows two sets of distribution map pairs for the micro snail *Helicodiscus parallelus*. The upper pair compares just known occurences by county both before and after year 2000. Note that each map indicates occurrence in 41 counties; a first interpretation could be that the species is maintaining stable occurences over time. However, closer examination reveals that 14 of the county records in the before-2000 map are absent from the after-2000 map, and 16 of the occurrences in the after-2000 map were absent from the before-2000 map. A second interpretation of these patterns could be 14 county extinctions and 16 county immigrations. On the other hand, the lower pair of maps in Fig. 3' compares all known county occurrences with those after year 2000. The all-records map reveals 59 county occurrences, compared to 41 occurrences after year 2000 (a 31% decrease), which suggests the more likely interpretation that the number of county occurences might be declining over time.

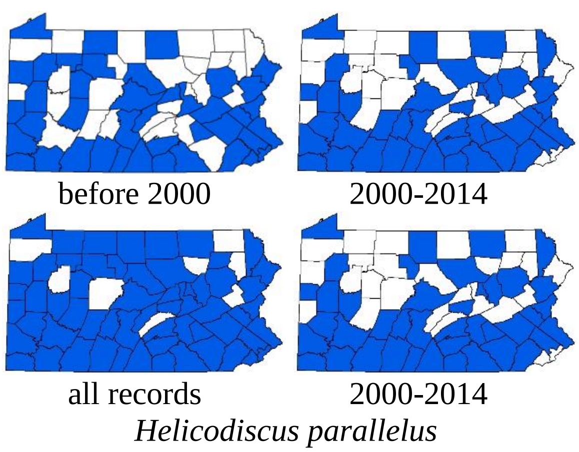
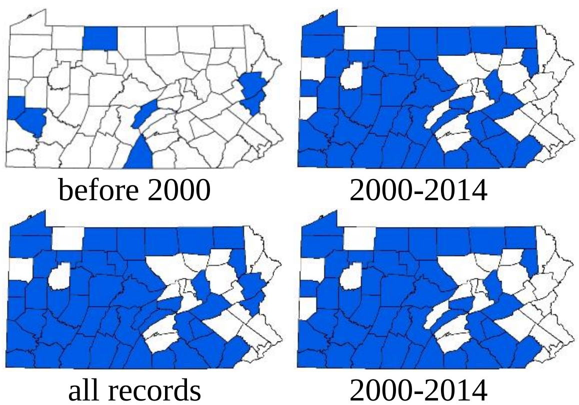


Fig. 6. Two sets of distribution map pairs for *Helicodiscus parallelus*. The upper pair of maps showing occurrences strictly before and after year 2000 gives the impression that the species is stable over time, while the lower map pairs suggest that the species might be declining over time.

In the second example using micro snails, Fig. 7 shows two sets of distribution map pairs for the micro snail *Columella simplex*. The upper pair compares just known occurences by county both before and after year 2000. With 7 county occurences before and 42 occurences after 2000, one interpretation could be that the species is spreading and has expanded its range 6 fold over 14 years. Such a dramatic expansion is unlikely for a native species. Instead, a more likely conclusion is that most or all of the former absences that later became presences were actually false absences (undetected presences). The lower pair of maps in Fig. 7 compares all known county occurences with those after year 2000. In this case, the all-records map shows 46 county occurrences before, compared to 42 occurences after 2000 (a 9% decrease), which suggests that the species occurrences are stable or declining slightly.



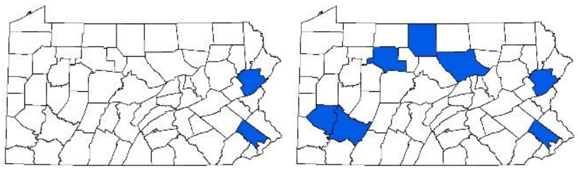
Columella simplex

Fig. 7. Two sets of distribution map pairs for *Columella simplex*. Two interpretations of the upper pair of maps (showing occurrences strictly before and after year 2000) could be that the species is spreading over time or it was seriously under-sampled before year 2000. However, the lower pair of maps might reflect reality better by suggesting that the species appears relatively stable over time.

This method of pairing maps for native species (all known records paired with the records since year 2000) has the advantage of highlighting decreases, but the disadvantage of making range expansions impossible to detect. Although both range decreases and expansions of native species are real expectations, in recent decades range decreases of native species are more expected than range expansions, so this method favors the more expected outcome.

Occurrences of introduced species. Many introduced species are likely to increase their ranges over time. Consequently, in order to permit detection of their expansions, I present actual occurrences before year 2000 for introduced species. This method is in contrast to how I inferred past occurrences for native species.

For example, for the introduced species *Arion circumscriptus* shown in Fig. 8, the left map shows known occurrences only before year 2000 (as opposed to all records). Maps for introduced species indicate how the species might be spreading, assuming that former absences were real absences. In Appendix 2, introduced species are indicated below their names labeling the maps.



before 2000 2000-2014
Arion circumscriptus
(introduced)

Fig. 8. Examples of introduced species distribution maps.

Species excluded. Maps for 49 species that have been recorded from Pennsylvania were excluded because they are (1) non-natives lacking modern records and having few records overall, or (2) non-natives that have taxonomic or identification issues so their occurrences need confirmation, or (3) native species that have taxonomic or identification issues so their occurrences need confirmation.

(1) 10 non-native species have been recorded from Pennsylvania but maps for them are not included because those species have not been recorded from the state in more than 60 years so there is no evidence for modern populations and because they had fewer than six records. These species are *Achatina fulica, Cornu aspersum (=Helix aspersa), Eobania vermiculata*, *Helix pomatia*, *Limax flavus, Otala lactea, Rumina decollata, Testacella haliotidea*, *Xolotrema fosteri,* and *Zacoleus provisoria*. *Xolotrema fosteri* is non-native in Pennsylvania, but it is native to North America's Midwest, from which it was introduced to the East Coast.

(2) 14 non-native species were excluded because the identities and occurrences of these species in Pennsylvania need confirmation. These species are *Allopeas clavulinum, Allopeas gracilis, Allopeas mauritianum, Arion fasciatus, Cepaea sylvatica, Lamellaxis micra, Lehmannia valentiana*, *Opeas johanninum, Opeas micra, Opeas octonoides, Opeas pumilum, Opeas pyrgula*, *Subulina octona*, and *Trochulus striolata*.

(3) 25 native species were excluded because taxonomic issues exist so their identities and occurrences in the state need confirmation. These species are *Carychium clappi, Daedalochila auriculata, Glyphyalinia carolinensis, Glyphyalinia cumberlandiana, Glyphyalinia virginica, Hawaiia alachuana, Helicodiscus notius, Inflectarius downieanus [=Mesodon downieana], Mesodon clausus, Mesodon elevatus, Mesodon mitchellianus, Mesomphix subplanus, Oxyloma subeffusum, Pallifera pennsylvanicus, Paravitrea capsella, Philomycus carolinianus, Pomatiopsis cincinnatiensis, Stenotrema stenotrema, Strobilops affinis, Triodopsis tennesseensis, Vallonia parvula, Ventridens acerra, Ventridens demissus, Ventridens gularis,* and *Xolotrema obstrictum*.

Imperilment Ranks

I used the NatureServe Rank Calculator (Version 3.1, Faber-Langendoen et al. 2012; Master et al. 2012) method to evaluate imperilment ranks for 141 species. Pennsylvania Biological Survey (PABS) was using the International Union for the Conservation of Nature method of evaluating imperilment ranks at the time of this grant proposal in 2010. Since then, PABS adopted the NatureServe method, which is being used by most Natural Heritage Programs in the country.

I modified the NatureServe method by examining declines over a 14-year period from 2000 to 2014 to allow better use of the available snail data rather than over a 10-year period, as used by NatureServe. I modified this method for three reasons. First, there had been very little collecting in Pennsylvania between 1960 and 2000. Consequently, using 2000 as the cutoff date would yield nearly the same result as using 1960. Second, if I used 2004 as the cutoff date, there would essentially be only 4 years of data before 2004. Third, I want to minimize the number of false absences (absence of evidence is not evidence of absence) so including 14 years would do this better than 10 years.

I assembled 17,472 records from eight major museums: American Museum of Natural History, New York (141 records), Academy of Natural Sciences in Philadelphia (3136), Carnegie Museum of Natural History (12,615), Delaware Museum of Natural History (220), Florida Museum of Natural History in Gainesville (297), Field Museum of Natural History in Chicago (422), Museum of Comparative Zoology at Harvard University (287), and United States National Museum (Smithsonian) in Washington D.C. (352). In most cases, I did not verify identities of museum specimens; instead, I accepted the identities as given.

I evaluated imperilment ranks for 141 species, using the NatureServe Rank Calculator (version 3.1). In this evaluation, I included the 129 species for which I present distribution maps (112 native, 19 non-native species). I also included 12 additional native species because their occurrences in the state are plausible but need confirmation: *Glyphyalinia carolinensis, Glyphyalinia cumberlandiana, Glyphyalinia virginica, Hawaiia alachuana, Mesodon clausus, Mesodon elevatus, Mesodon mitchellianus, Oxyloma subeffusum, Pallifera pennsylvanica, Philomycus carolinianus, Ventridens demissus, Ventridens gularis*. Although many records exist for *Philomycus carolinianus* in Pennsylvania, most or all of them appear to be misidentifications (Pearce & Paustian 2013: 215). While I calculated imperilment ranks for these 12 additional species, I did not include updated distribution maps for them.

The number of species included in this section of the report (141) is less than the number of species reported by Leppo et al. (2015) as estimated for Pennsylvania (176) and less than the number of species tracked (195) by the Pennsylvania Natural Heritage Program. My number is lower because I consider the additional species of Leppo et al. (2015) to be questionable records or historical records whose occurrence or continued persistence in Pennsylvania needs confirmation.

The main factors used in calculating terrestrial snail state ranks were range extent, area of occupancy using 4 km^2 grid cells, number of occurrences, and the long-term trend. Long-term trends were evaluated by comparing the distribution maps presented herein from before and after year 2000. Although threats are not well understood for terrestrial snails, a threat level of 'low' was assigned to the majority of terrestrial snail species, with a threat level of 'medium' assigned to two species from restricted limestone or wetland habitats.

RESULTS AND DISCUSSION

Species Susceptible to Climate Warming

At the 108 sampling localities, project personnel collected 11,007 individual specimens of 69 species, yielding 1137 species-occurrences.

Overall numbers of snail species and abundances decreased at higher elevations (Figs. 9 and 10). Most individual species tended to occur throughout sampled elevations or occurred primarily at lower elevations, so if climate warming forced them upward, the reduced altitudinal range aspect of climate warming might not threaten them.

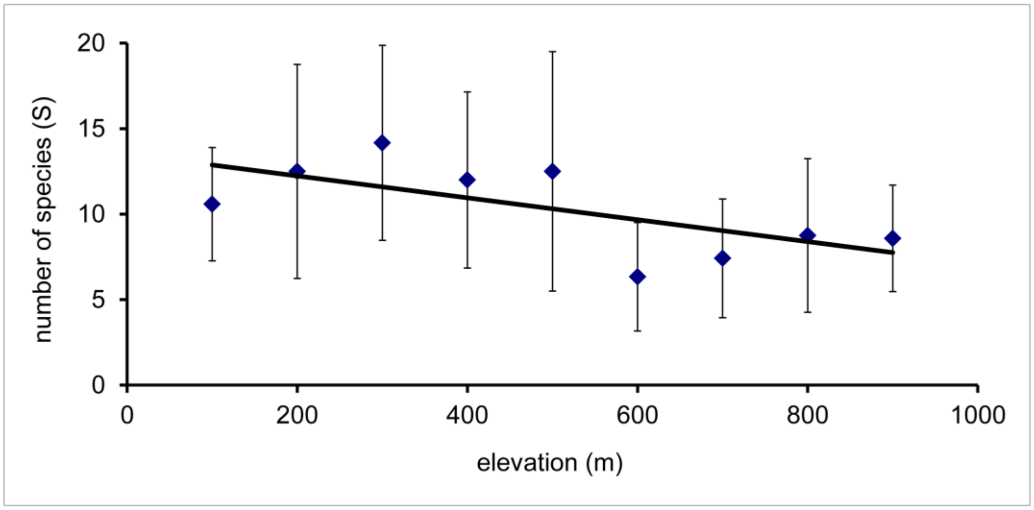


Fig. 9. Species richness (S) across elevations. Fewer species were found at higher elevations ($r=.6570$, d.f.=8, $p<.05$). Error bars are standard deviation. From Pearce & Paustian (2013).

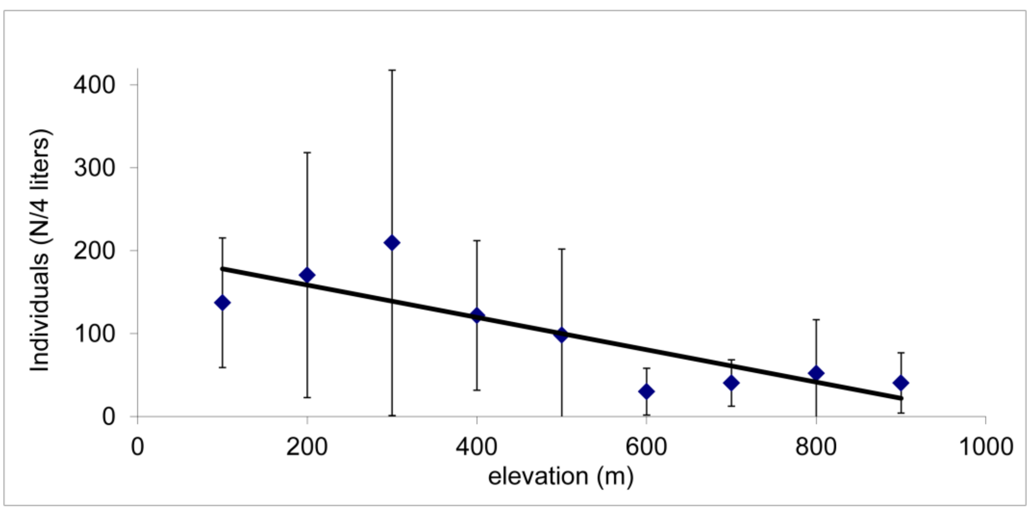


Fig. 10. Number of individuals per sample (in 4 liters of leaf duff and 40 person minutes of visual search). Fewer individuals were found at higher elevations ($r=.8316$, d.f. =8, $p<.005$). Error bars are standard deviation. From Pearce & Paustian (2013).

Variability by elevation is shown in Fig. 11. While most species occurrences decreased at higher elevations (e.g., *E. polygyratus* in Fig. 11), others remained more or less stable at all sampled elevations (e.g., *S. milium* in Fig. 11), and still others occurred more at higher elevations (e.g., *H. shimeki* in Fig. 11).

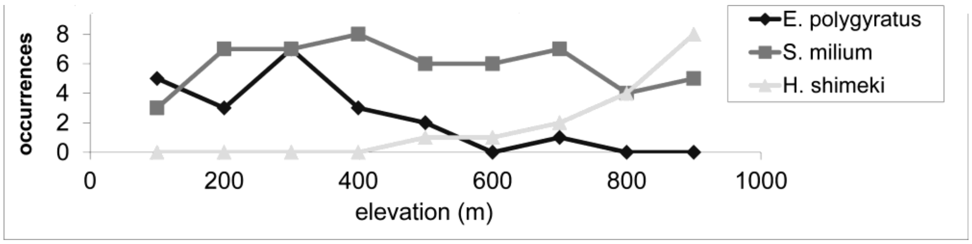


Fig. 11. Examples of snail species from the field sampling that were more commonly found at lower elevations (*Euconulus polygyratus*), at upper elevations (*Helicodiscus shimeki*), or throughout the elevation range (*Striatura milium*). From Pearce & Paustian (2013).

Five species significantly (*Helicodiscus shimeki, Mesomphix perlaevis, Neohelix albolabris, Striatura ferrea*, and *Striatura milium*) and four species non-significantly (*Mesomphix inornatus, Pallifera dorsalis, Philomycus flexuolaris*, and *Philomycus togatus*) occurred more often at higher elevations. Because they already occupy higher elevations, climate warming might force them upward but if they are already at high points, then their populations might perish. Furthermore, because higher elevations in Pennsylvania make up a small proportion of the land surface area (elevations 700–979 m comprise only 2% of Pennsylvania's area; Fig. 12), if populations of these snails were forced upward due to warming climate, they would be forced into smaller geographical ranges and their populations would likely decline (Pearce & Paustian 2013). All of these species are relatively common in Pennsylvania now, but their populations should be monitored into the future to verify whether climate warming is affecting them negatively.

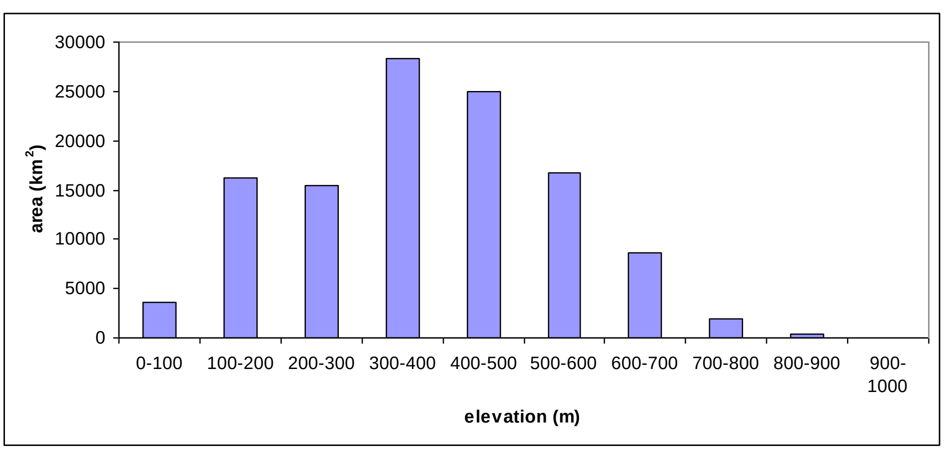


Fig. 12. Distribution of surface area by elevation in Pennsylvania. Higher elevations are scarce. Areas covered by elevation were calculated using GIS. If the climate warms and species move higher, they will occupy less area. From Pearce & Paustian (2013).

Important Public Land Holdings

A list of the 19 public lands most important to conserve to promote land snail conservation is shown in Appendix 1. The higher ranked lands had many occurrences of rare species and often contained specialized habitats to which some land snails are restricted, such as wetlands or limestone areas. These important public lands are geographically widespread across Pennsylvania. The public lands represent a wide variety of ownerships including National Forest, National Historical Park, National Recreation Area, State Forest, State Game Land, State Park, as well as other lands such as City Park, Nature Reserve, The Nature Conservancy, and a Watershed Association.

Updated Distribution Maps

Species distribution maps. Species distribution maps by counties are shown for 129 species in Appendix 2. I give paired maps for each species. For each native species, maps indicate by counties all recorded occurrences up through year 2014 (left) paired with recorded occurrences from 2000 to 2014 (right). For each non-native (introduced) species, maps show for counties just recorded occurrences before year 2000 (left) paired with recorded occurrences from 2000 to 2014 (right).

Use caution when interpreting some of the distribution maps. While presences are trustworthy, absences are much more difficult to substantiate and much more surveying is needed. For some maps, the number of distribution records might be artificially low, for five reasons.

(1) Because I have difficulty identifying certain species, or certain species have taxonomic uncertainties, the scarcity or absence of <u>modern</u> records (2000 to 2014) for these species could be artificially low. In particular, species in the family Succineidae (genera *Catinella*, *Novisuccinea*, *Oxyloma*, and *Succinea*) are so difficult to identify that, although I have found many modern specimens of this family, I have identified very few to the species level and consequently most of the modern maps of the species of this family probably reflect an artificially low number of records.

(2) In a reversal of the above pattern, <u>older</u> records of *Philomycus flexuolaris* and *P. togatus* are probably artificially low since most records of the native slug *P. carolinianus* in Pennsylvania are old records and are likely misidentifications of *P. flexuolaris* and *P. togatus* (Pearce & Paustian 2013).

(3) Whether the records on the modern maps of *Lucilla singleyana* and *Hawaiia minuscula* actually apply to one or the other species is uncertain, since I have difficulty separating them.

(4) Meadow or open-area species have likely been under-sampled because most of my modern surveying for land snails has been in woodland settings. I recognize this habitat bias, and plan to survey open areas more in the future. However, for the current map records, occurrences of species from meadows and open areas are likely to be artificially low.

(5) Native species might appear to be expanding their ranges, but the scarcity of older records is likely to reflect under sampling. Because of my interest in micro snails, I have

found many more micro snails than past workers have. Evidence presented below suggests that the native micro snails were present but were overlooked in the past.

Species-county accumulation curve. Thousands of new occurrences of species in counties over the past 150 years in Pennsylvania are reflected in the species-county accumulation curve in Fig. 13. Note that:

- This species-county accumulation curve continues to climb relatively steeply in contrast to the expectation that species accumulation curves level off as the actual number of species in counties is approached; this result suggests that many more new county records remain to be discovered.
- There was a leveling off between about 1960 and 2000, which reflects the period of time during which very little sampling of land snails occurred in Pennsylvania.
- The slope of the curve since 2000 approximately parallels the slope from 1890 to 1960; the similar slopes indicate that new records of species in counties over the past 14 years are being discovered at about the same rate as the previous period.

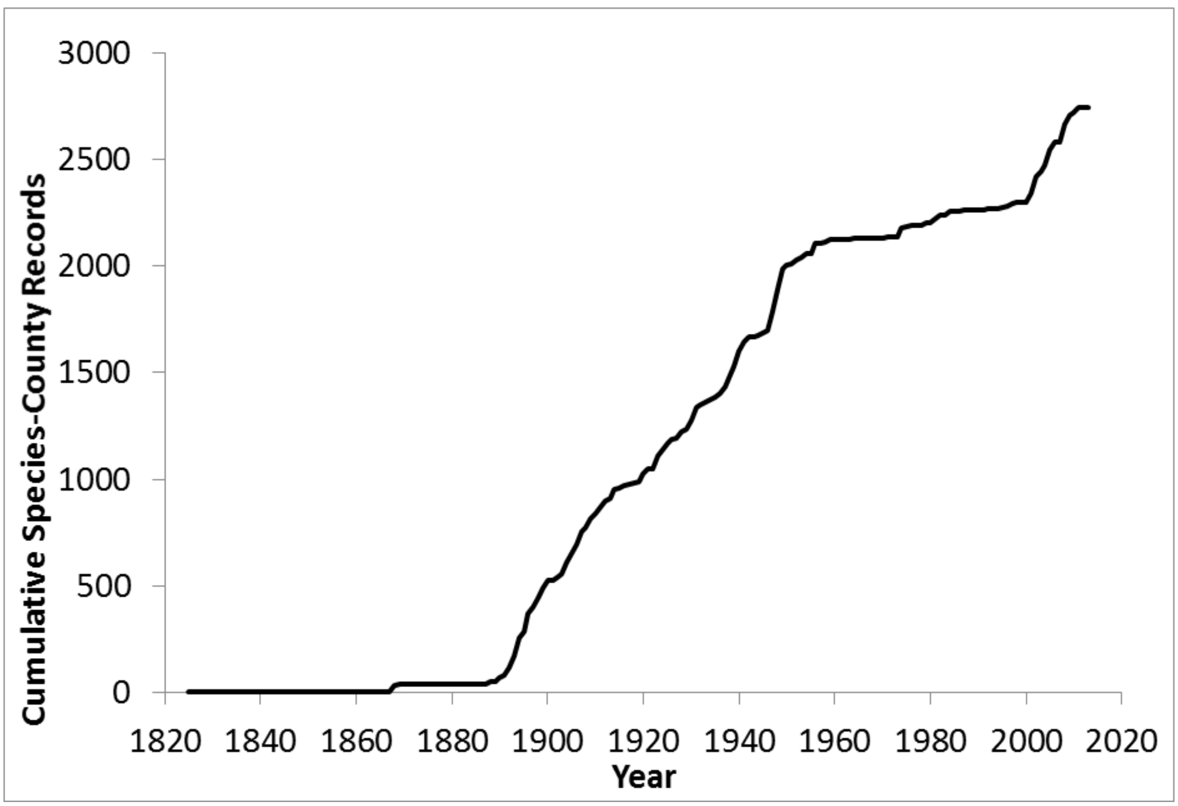


Fig. 13. Species-county accumulation curve for Pennsylvania land snails.

Species per county over time. The number of species known per county over time is shown in Fig. 14.

- The map from Hubricht (1985) shows greatest species occurrences around Pittsburgh and Philadelphia – the two places where land snails have been studied for more than 100 years – and low numbers of species in the central, mountainous parts of the state.
- The map for 2001 contains close to the actual data for species occurrences as of 1960, due to the gap of little collecting from 1960 to 2000. However, the 2001 map shows more species occurrences than the 1985 map, probably because the resources I have (e.g., access to digitized collection records) make finding information easier than it was in Hubricht's time. The low numbers of snails in NE Pennsylvania in 2001 could be due to low actual numbers of species there, or due to under-sampling. A 3 day visit to Columbia Co. increased the occurrences from the 3 previously known species to 40 known species, suggesting previous under-sampling.
- The 2008 maps show a considerable increase in the numbers of species occurrences in geographically widespread areas. This increase reflects substantial sampling effort primarily by this author, funded in part by this project.
- By the end of 2014, at least one leaf litter sample had been obtained from every county, so every county has at least that minimum amount of effort and a chance to report micro snails. Every county in the 2014 map reports at least 14 species of land snails.

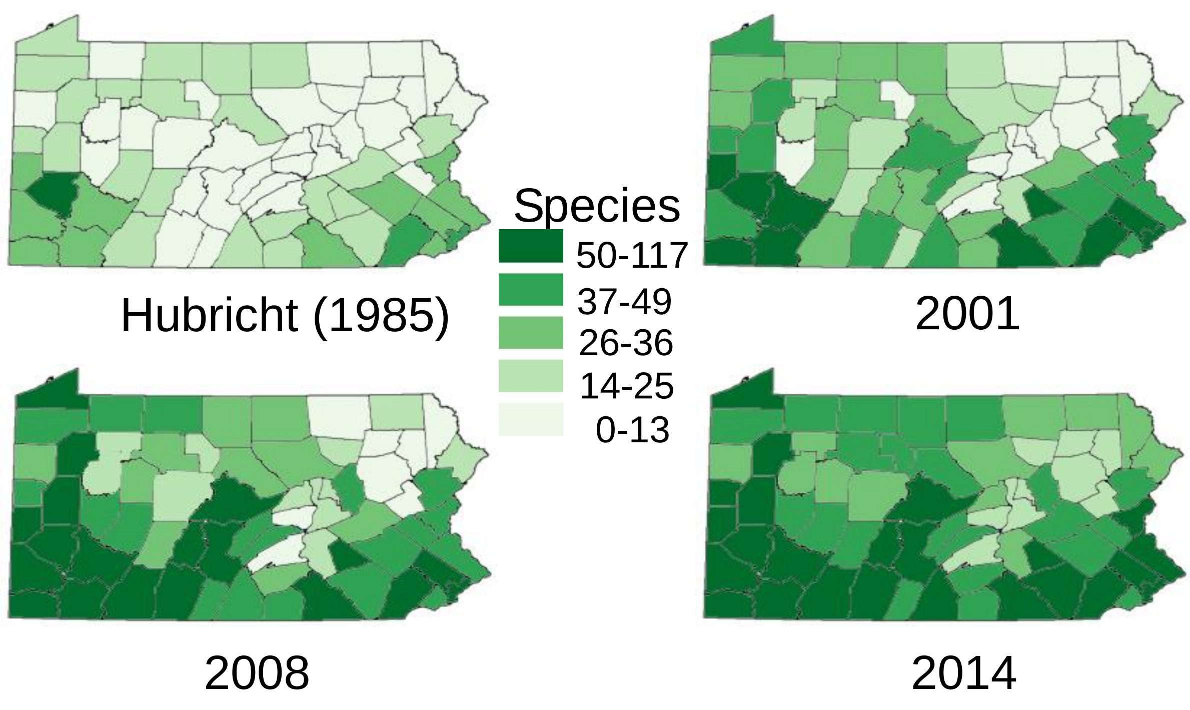


Fig. 14. Number of species known per county increases over time. These greater occurrences per county reflect more believable distribution maps for individual species than previous maps.

Imperilment Ranks

Imperilment ranks are shown in Appendix 3. The assessment found 46 species of conservation concern (S1-S3), all native species, and 47 other native species that were not of conservation concern (S4-S5). Two natives were ranked SH (state historical) because they have not been seen in more than 60 years, but insufficient surveying leaves open the possibility that they still exist in Pennsylvania. An additional 29 native species are ranked SNR (state not ranked) because of insufficient sampling, taxonomic uncertainty, or difficulty of identification. All 19 non-native species are ranked SNA (state not applicable) because conservation measures do not apply to them.

I propose that there are three main threats that present hardships for land snails. The three threats relate to habitat needs, interactions with other biota, and effects of pollution. Further study is needed about snail basic biology to evaluate how important these threats are.

- Habitat modifications include changes in ground level moisture, land use cover, installation of roads and rights of ways, edge effects, and loss of trees to activities such as logging and pests/diseases.
- Invasive species include plants such as garlic mustard, predators including rats and possibly terrestrial flatworms, and earthworms, which rapidly consume leaf litter from the forest floor, removing food, habitat, and moisture the snails need.
- Airborne pollutants, perhaps especially acid rain, can interfere with basic physiology including the ability of snails to incorporate calcium into their bodies and shells.

The importance of habitat modification could be studied by comparing snails in areas before and after a particular habitat modification is made. Sampling should include a visual search and a leaf litter sampling component. I have had little success with cover boards, which under-sample the fauna and which are biased against finding certain species. Sampling should avoid degrading the habitat. Examples of protecting the habitat include: minimizing trampling; for visual search, returning logs to their original positions after examining their undersides for snails; and for sampling leaf litter in small or sensitive areas, avoiding removal of an undue amount of snail habitat.

To study the effects of invasive species on native land snails, researchers could conduct studies in diverse locations, correlating abundances of particular snail species with abundances of invasive species. Negative correlations would suggest a possible negative effect of the invasive on the native. Interactions between those species could be examined in detail, for example through lab or field studies. The results of these studies could clarify which invasive species are threatening native snails.

Study of the effects of chemical factors on land snails, including components of airborne pollution, could be conducted in lab or field studies. Very little information exists about factors affecting land snails, other than moisture, temperature, and calcium availability. For example, no pesticides have been tested for their effects upon terrestrial mollusks.

Future Work

Future surveys will yield a better understanding of the distributions and habitat needs of land snails. For very restricted taxa, a better understanding of occupied ranges would facilitate monitoring. The most effective method for sampling the small (<5 mm) litter dwelling species (which represent most of the land snail species) is litter sampling, sieving, and picking. Although this method is time consuming, it yields a more accurate picture of the local fauna than other methods such as visual search or cover boards, which under-sample the fauna and which are biased against finding certain species. However, litter sampling results in habitat destruction (i.e., the litter is removed). If a site is to be monitored intensively, litter should be sampled in a way that does not obliterate the site (e.g., consider sharing litter samples with researchers who are sampling other biota).

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Other important micro snail picking was conducted by the following work-study students from University of Pittsburgh: Timothy J. Dolan, Eric J. Earley, Joseph LaRosa, Stephanie S.

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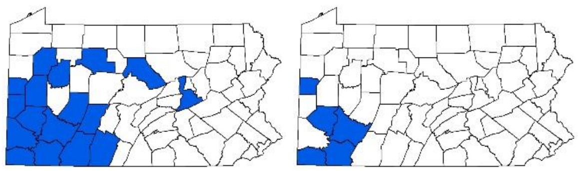
Appendix 1. The 19 public lands in Pennsylvania most important to conserve considering land snails. They harbor snail species of concern (some lands scored equally share priority ranks, e.g. there are two 18s). EOs are element occurrences; S1 spp, S2 spp, and S3 spp are number of species having those state ranks; S1 = critically imperiled, S2 = imperiled, and S3 = vulnerable. Hab restr indicates species restricted to particular habitats, limest = limestone. In this table, for the number of EOs, one species can occur multiple times, but for the number of S1, S2, and S3 species, a single species is counted just once per entry.

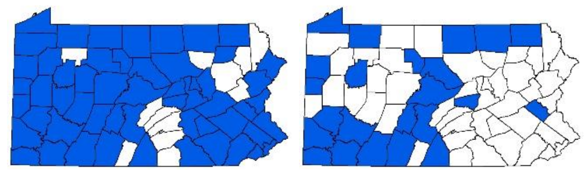
Priority to Con-serve	Name	EOs (S1-S3)	S1 spp	S2 spp	S3 spp	Justification
1	Wissahickon Valley	30	2	2	7	many occurrences of rare spp; hab restr: 1 limest, 1 wetland
2	Raccoon Creek State Park	32	1	3	11	many occurrences of rare spp; hab restr: 1 limest, 1 wetland
3	Powdermill Nature Res	29	0	2	7	many occurrences of rare spp
4	Presque Isle State Park	16	2	4	5	many occurrences of rare spp; hab restr: 1 limest, 1 wetland
5	Valley Forge	12	2	2	3	many occurrences of rare spp; hab restr: 1 limest, 1 wetland
6	Schenley Park Parcel 1	20	0	2	5	many occurrences of rare spp; hab restr: 1 wetland
7	Delaware Water Gap	5	1	1	1	few occurrences of rare spp
8	Fairmont Park	5	1	0	2	few occurrences of rare spp
8	Pine Grove Furnace State Park	12	1	1	7	many occurrences of rare spp; hab restr: 1 limest, 1 wetland
10	Michaux State Forest	9	1	0	5	some occurrences of rare spp
10	State Game Land 112	4	1	0	1	few occurrences of rare spp
10	State Game Land 214	8	2	1	2	some occurrences of rare spp; hab restr: 1 wetland
10	State Game Land 302	14	0	1	6	many occurrences of less rare spp; hab restr: 1 limest, 1 wetland
14	Westfall Ridge Prairie	6	2	0	4	some occurrences of rare spp; hab restr: 2 limest
15	State Game Land 51	10	0	2	4	many occurrences of less rare spp; hab restr: 1 limest
16	Allegheny National Forest Non-Reserved	12	0	1	5	many occurrences of less rare spp; hab restr: 1 wetland
16	Moraine State Park	8	1	0	3	some occurrences of rare spp; hab restr: 1 limest, 1 wetland
18	Frick Park	12	0	0	4	many occurrences of less rare spp; hab restr: 1 wetland
18	Ryerson Station State Park	10	0	2	5	many occurrences of less rare spp: 1 limest, 2 wetland

Appendix 2. Pennsylvania land snail distribution maps by counties. For native species, maps show all recorded county occurrences up to 2014 (left) and from 2000 to 2014 (right). For introduced species, maps show occurrences before 2000 (left) and from 2000 to 2014 (right). Introduced species are indicated. See text regarding interpreting maps.



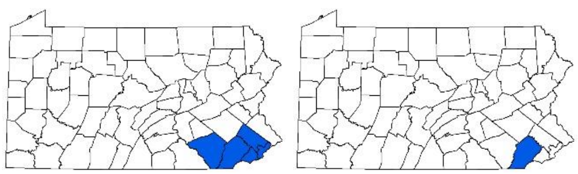
all records 2000-2014

Allogona profunda



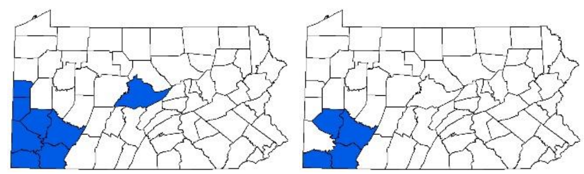
all records 2000-2014

Anguispira alternata



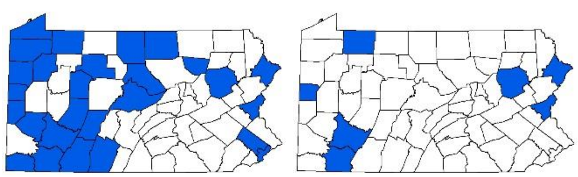
all records 2000-2014

Anguispira fergusoni



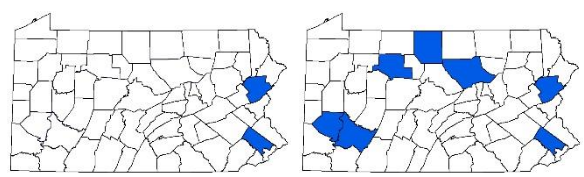
all records 2000-2014

Anguispira kochi



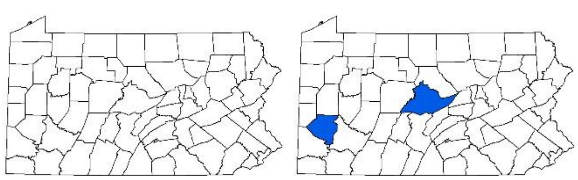
all records 2000-2014

Appalachina sayana



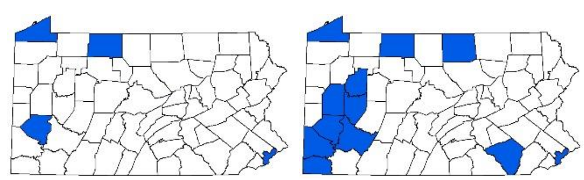
before 2000 2000-2014

Arion circumscriptus
(introduced)



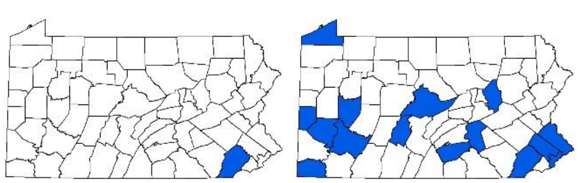
before 2000 2000-2014

Arion distinctus
(introduced)



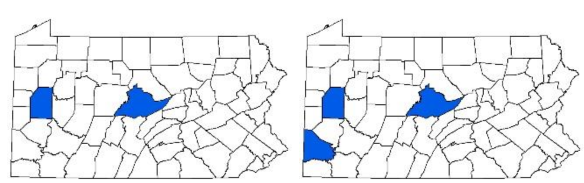
before 2000 2000-2014

Arion hortensis
(introduced)



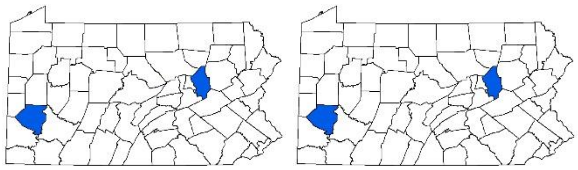
before 2000 2000-2014

Arion intermedius
(introduced)



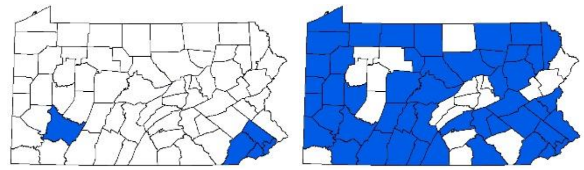
before 2000 2000-2014

Arion rufus
(introduced)



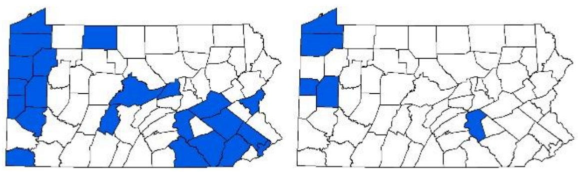
before 2000 2000-2014

Arion silvaticus
(introduced)



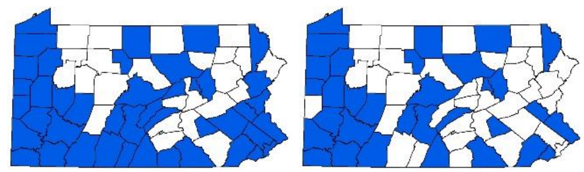
before 2000 2000-2014

Arion subfuscus
(introduced)



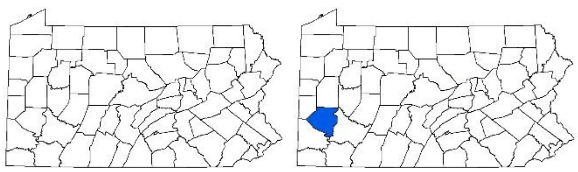
all records 2000-2014

Carychium exiguum



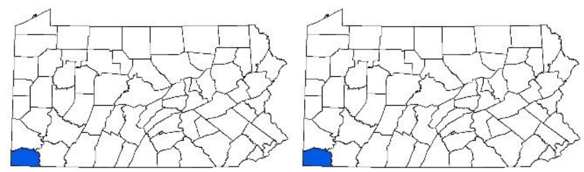
all records 2000-2014

Carychium exile



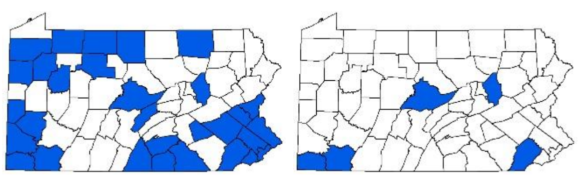
before 2000 2000-2014

Carychium minimum
(introduced)



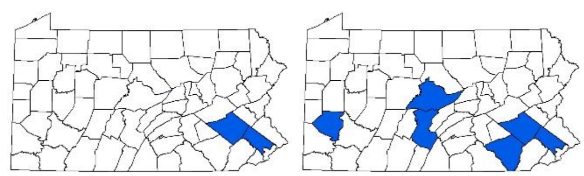
all records 2000-2014

Carychium nannodes



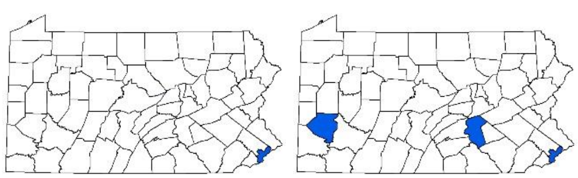
all records 2000-2014

Catinella vermeta



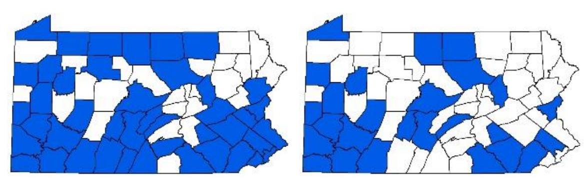
before 2000 2000-2014

Cecilioides acicula
(introduced)



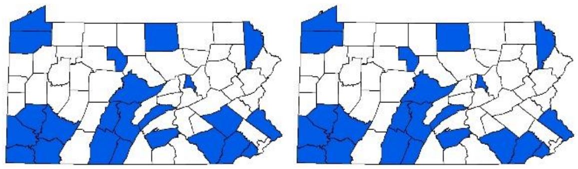
before 2000 2000-2014

Cepaea nemoralis
(introduced)



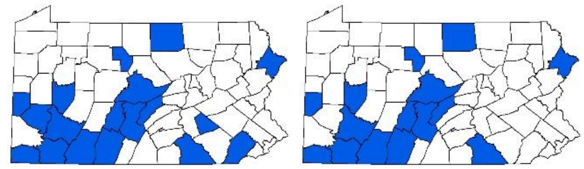
all records 2000-2014

Cochlicopa lubrica



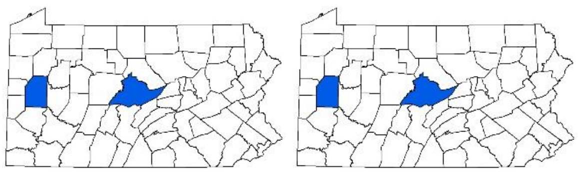
all records 2000-2014

Cochlicopa lubricella



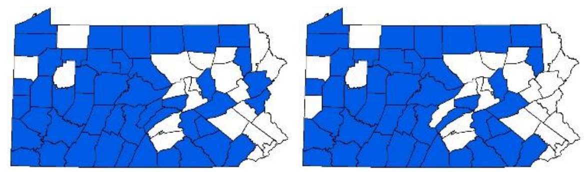
all records 2000-2014

Cochlicopa morseana



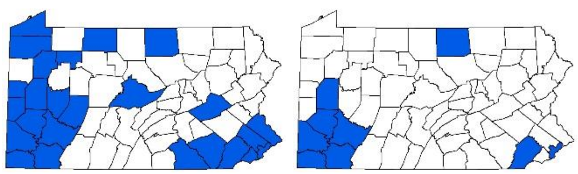
all records 2000-2014

Columella columella



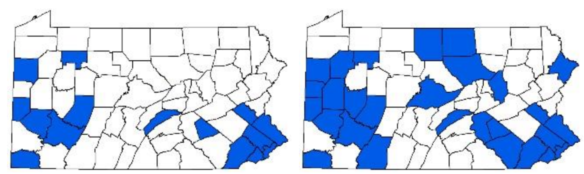
all records 2000-2014

Columella simplex



all records 2000-2014

Deroceras laeve



before 2000 2000-2014

Deroceras reticulatum
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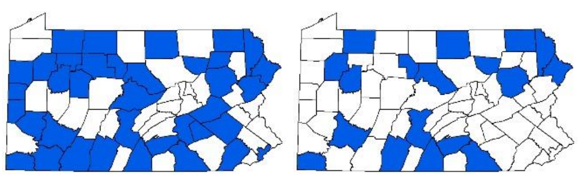
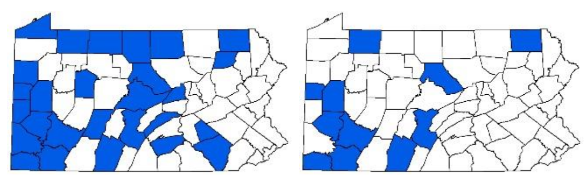


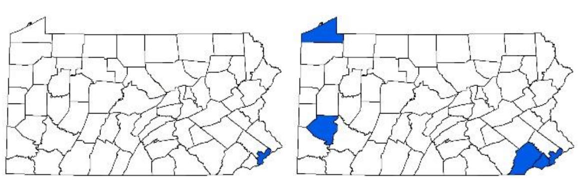
all records 2000-2014

Discus catskillensis



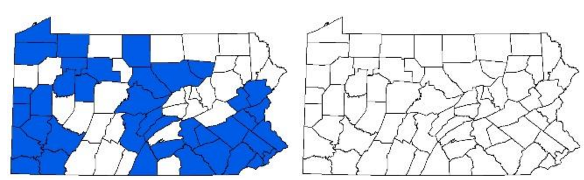
all records 2000-2014

Discus patulus



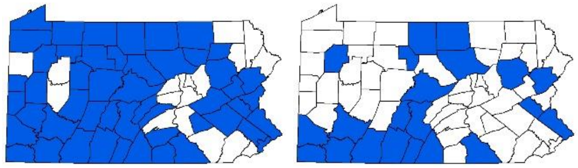
before 2000 2000-2014

Discus rotundatus
(introduced)



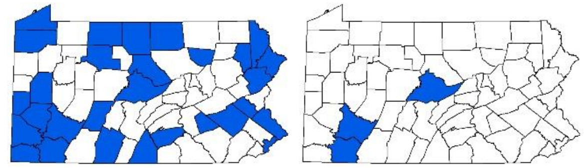
all records 2000-2014

Discus whitneyi



all records 2000-2014

Euchemotrema fraternum



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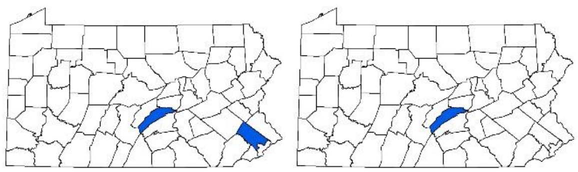
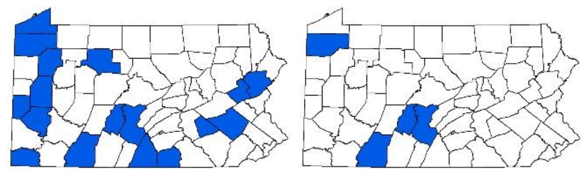
Euchemotrema leai



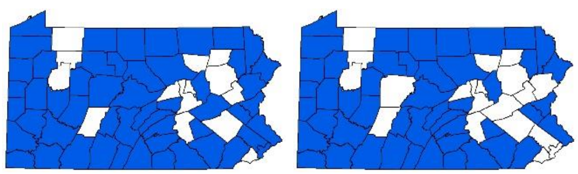
all records 2000-2014

Euconulus dentatus



all records 2000-2014

Euconulus fulvus



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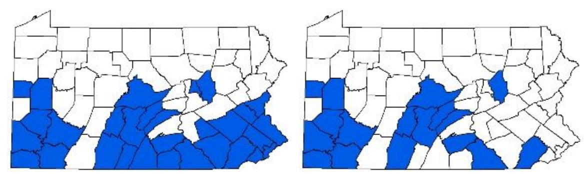
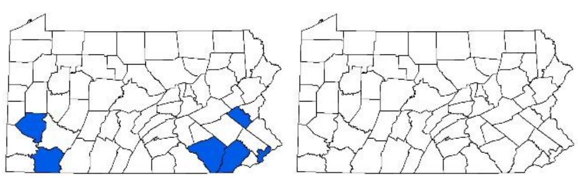
Euconulus polygyratus



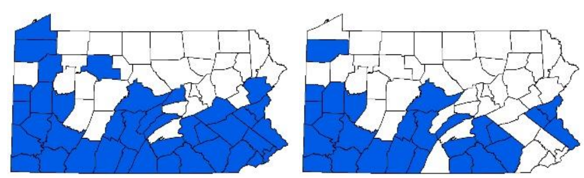
all records 2000-2014

Gastrocopta armifera



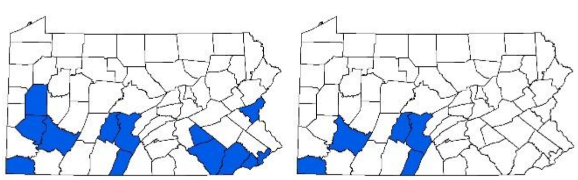
all records 2000-2014

Gastrocopta clappi



all records 2000-2014

Gastrocopta contracta



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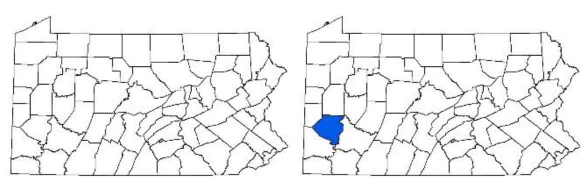
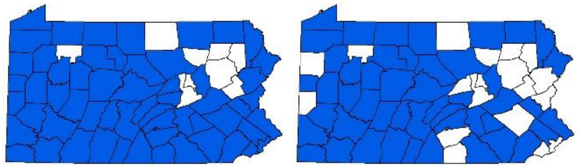
Gastrocopta corticaria



all records 2000-2014

Gastrocopta cristata



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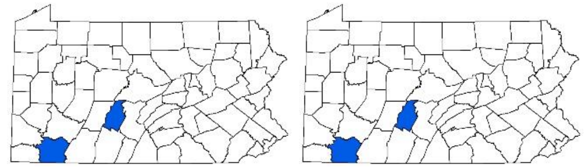
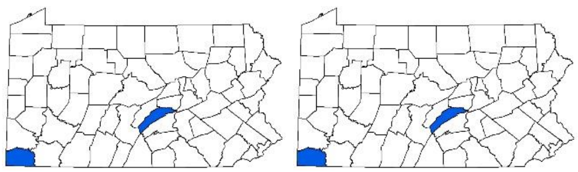
Gastrocopta pentodon



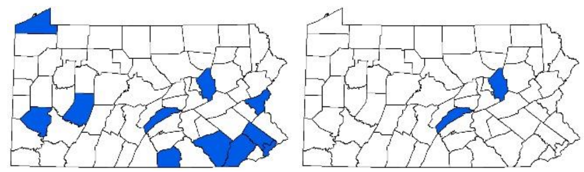
all records 2000-2014

Gastrocopta procera



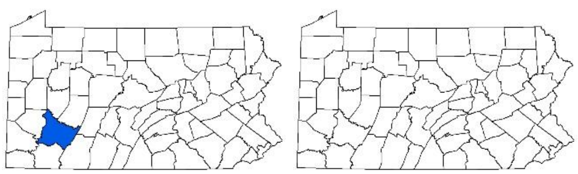
all records 2000-2014

Gastrocopta similis



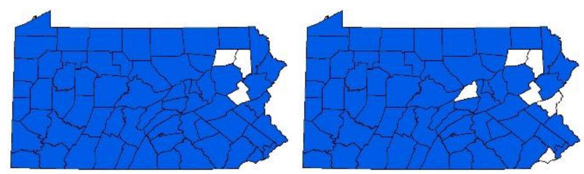
all records 2000-2014

Gastrocopta tappaniana



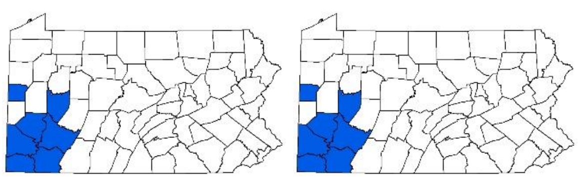
all records 2000-2014

Gastrodonta interna



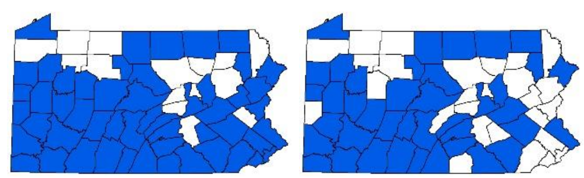
all records 2000-2014

Glyphyalinia indentata



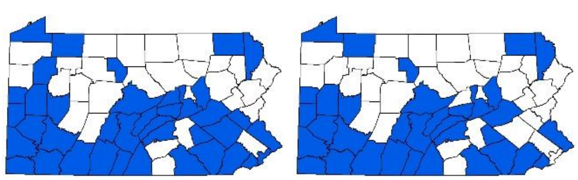
all records 2000-2014

Glyphyalinia raderi



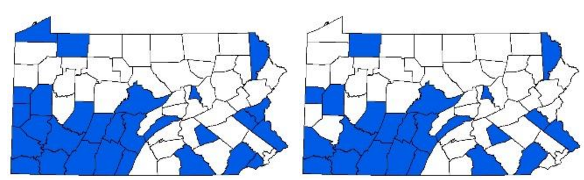
all records 2000-2014

Glyphyalinia rhoadsi



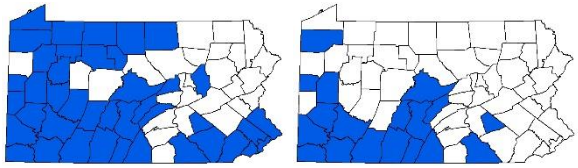
all records 2000-2014

Glyphyalinia wheatleyi



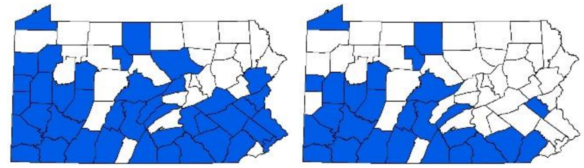
all records 2000-2014

Guppya sterkii



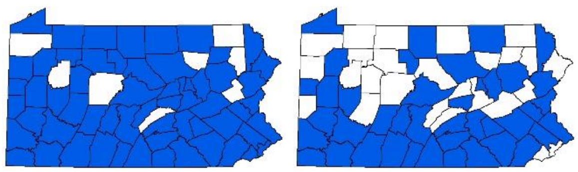
all records 2000-2014

Haplotrema concavum



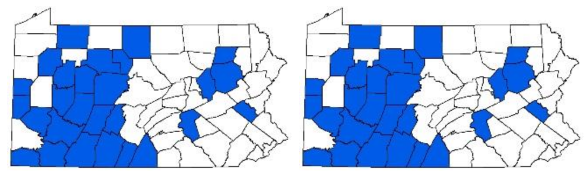
all records 2000-2014

Hawaiia minuscula



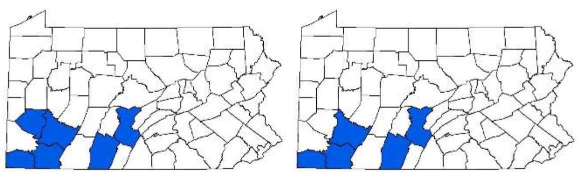
all records 2000-2014

Helicodiscus parallelus



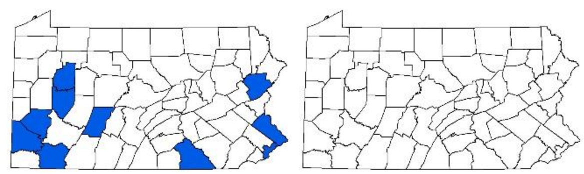
all records 2000-2014

Helicodiscus shimeki



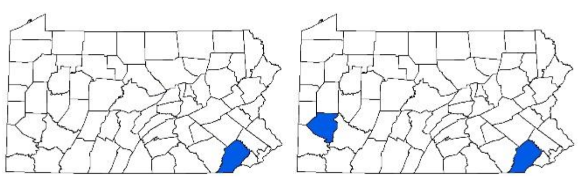
all records 2000-2014

Hendersonia occulta



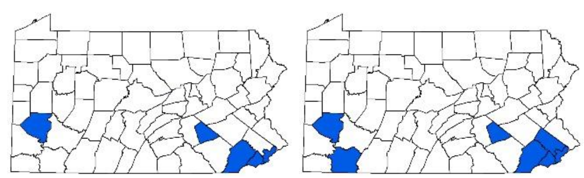
all records 2000-2014

Inflectarius inflectus



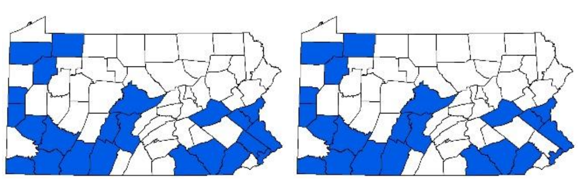
before 2000 2000-2014

Lehmannia valentiana
(introduced)



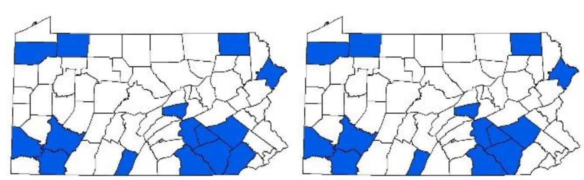
before 2000 2000-2014

Limax maximus
(introduced)



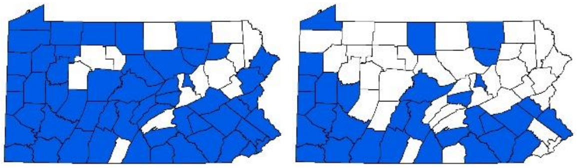
all records 2000-2014

Lucilla singleyana



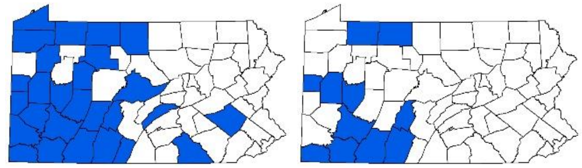
all records 2000-2014

Megapallifera mutabilis



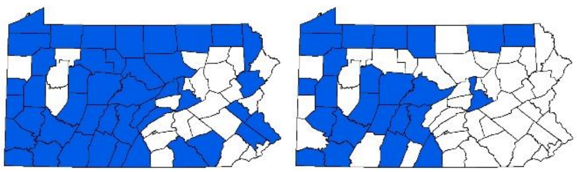
all records 2000-2014

Mesodon thyroidus



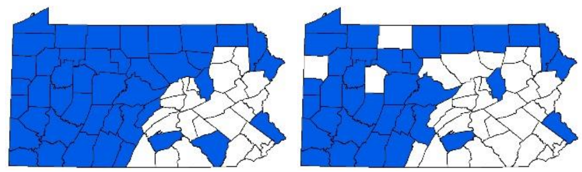
all records 2000-2014

Mesodon zaletus



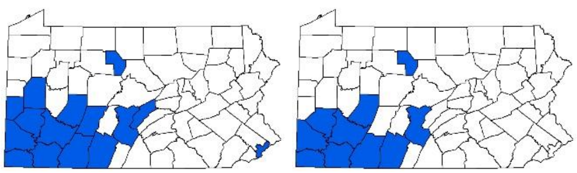
all records 2000-2014

Mesomphix cupreus



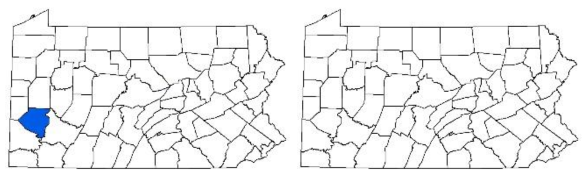
all records 2000-2014

Mesomphix inornatus



all records 2000-2014

Mesomphix perlaevis

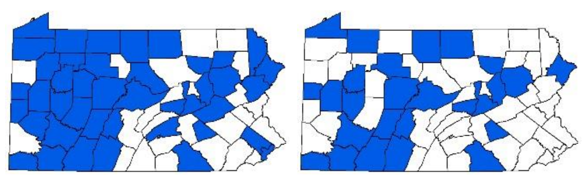


before 2000 2000-2014

Milax gagates
(introduced)

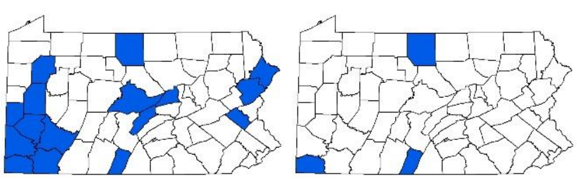
all records 2000-2014

Neohelix albolabris



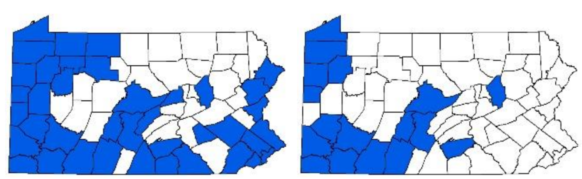
all records 2000-2014

Neohelix dentifera



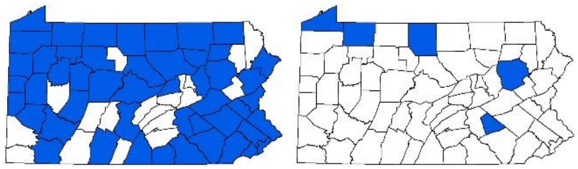
all records 2000-2014

Nesovitrea binneayana



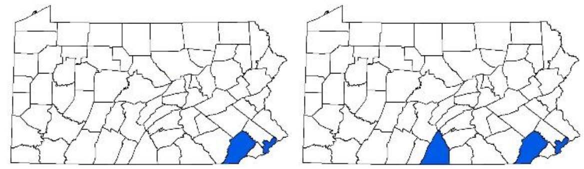
all records 2000-2014

Nesovitrea electrina



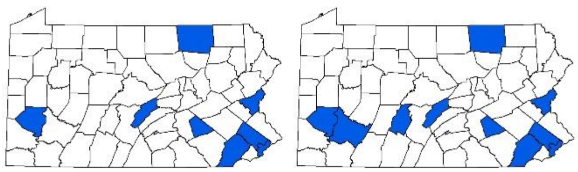
all records 2000-2014

Novisuccinea ovalis



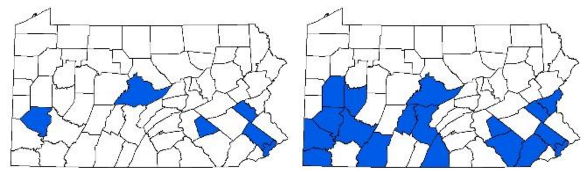
before 2000 2000-2014

Oxychilus alliarius
(introduced)



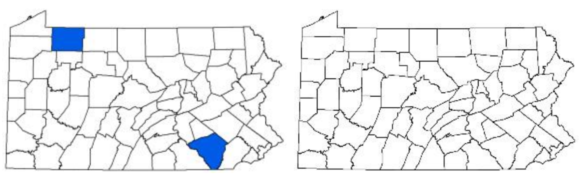
before 2000 2000-2014

Oxychilus cellarius
(introduced)



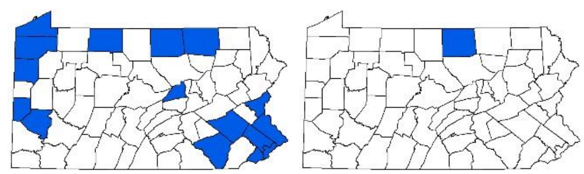
before 2000 2000-2014

Oxychilus draparnaudi
(introduced)



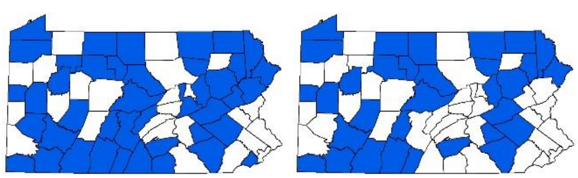
all records 2000-2014

Oxyloma gouldi



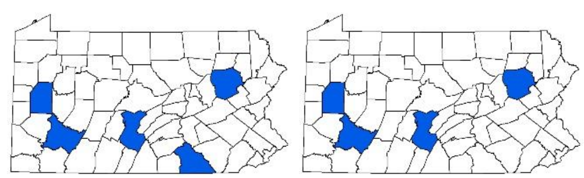
all records 2000-2014

Oxyloma retusum



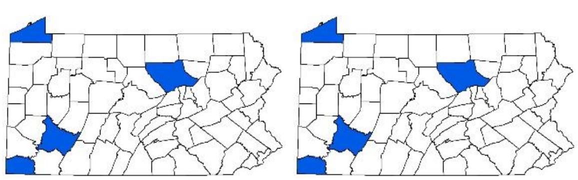
all records 2000-2014

Pallifera dorsalis



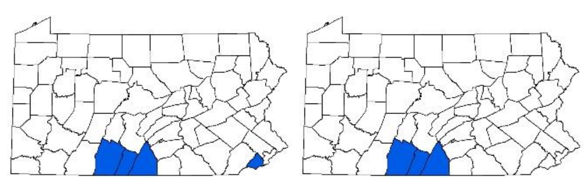
all records 2000-2014

Pallifera fosteri



all records 2000-2014

Pallifera ohioensis

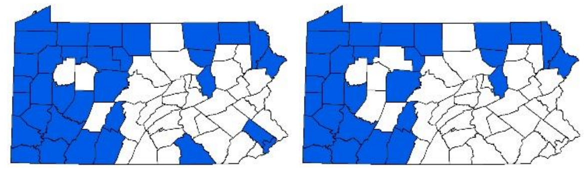


all records 2000-2014

Pallifera secreta

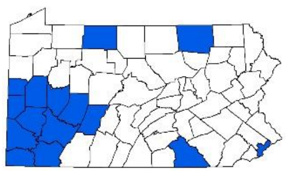
all records 2000-2014

Pallifera varia



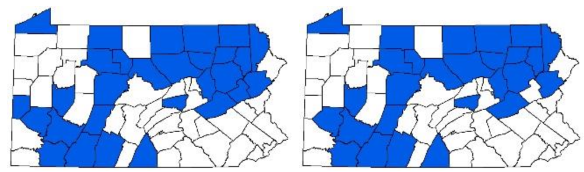
all records 2000-2014

Paravitrea multidentata



all records 2000-2014

Patera pennsylvanica

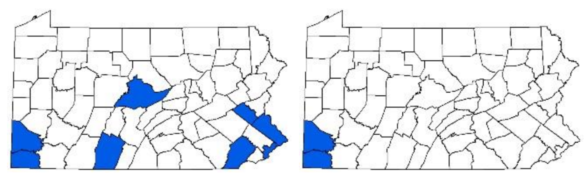


all records 2000-2014

Philomycus flexuolaris

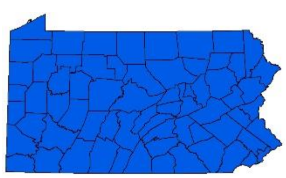
all records 2000-2014

Philomycus togatus



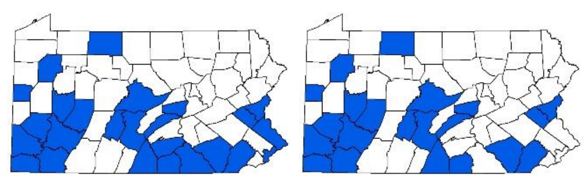
all records 2000-2014

Pomatiopsis lapidaria



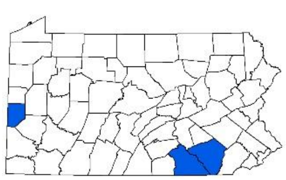
all records 2000-2014

Punctum minutissimum



all records 2000-2014

Punctum vitreum



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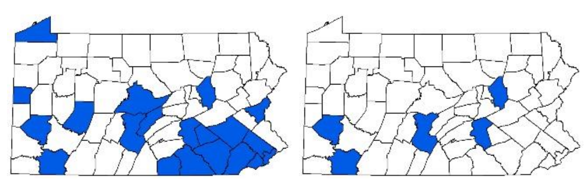
Pupilla muscorum



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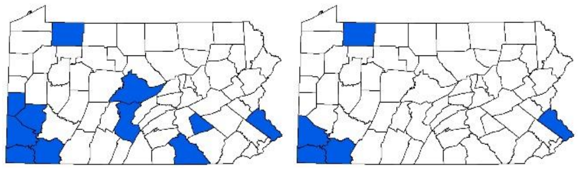

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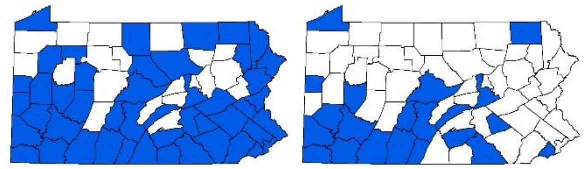
Stenotrema barbatum



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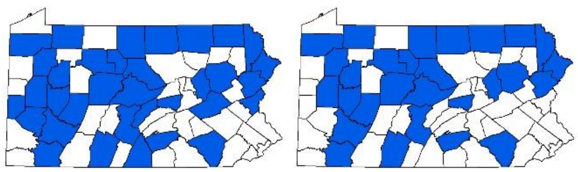

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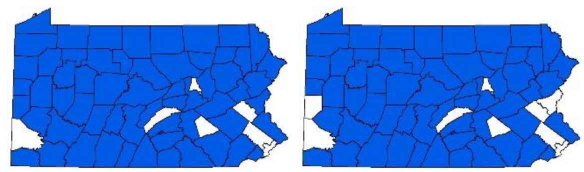
Striatura exigua



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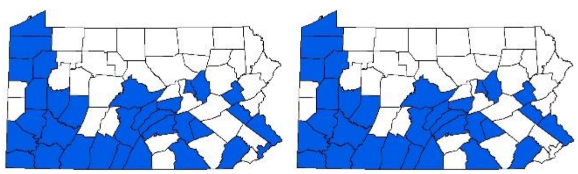

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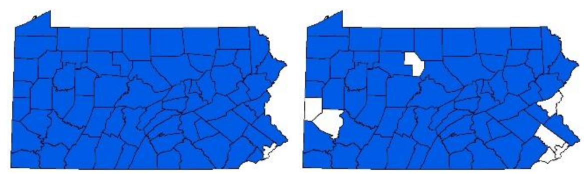
Striatura meridionalis



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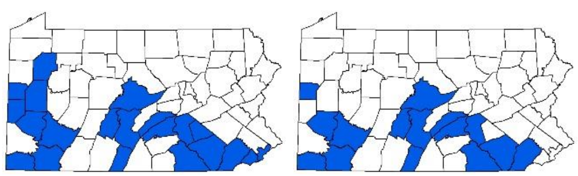
Striatura milium



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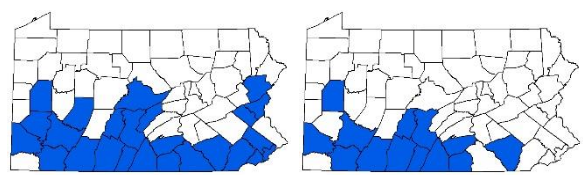
Strobilops aeneus



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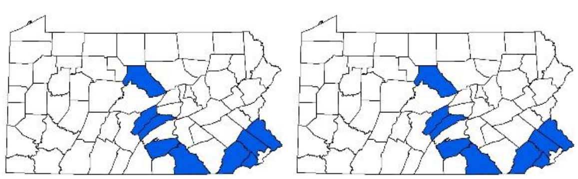
Strobilops labyrinthicus



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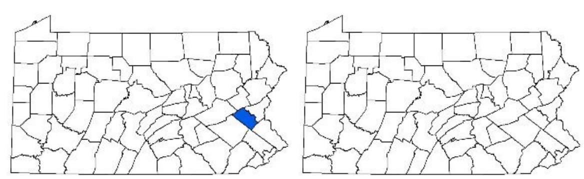
Strobilops texasianus



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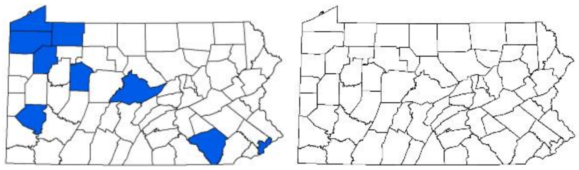
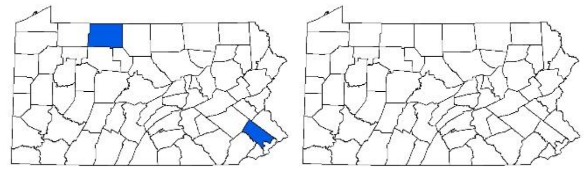
Succinea grosvenori



all records 2000-2014

Succinea indiana



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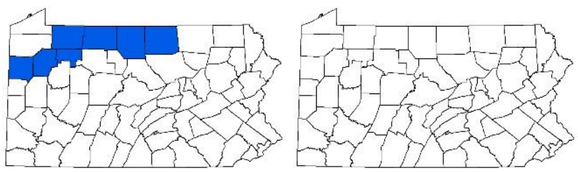
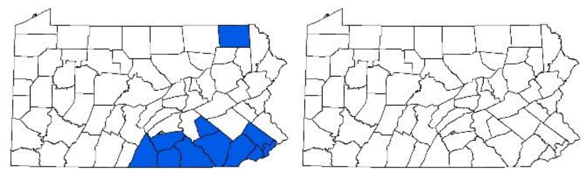
Succinea pennsylvanica



before 2000 2000-2014

Succinea putris
(introduced)



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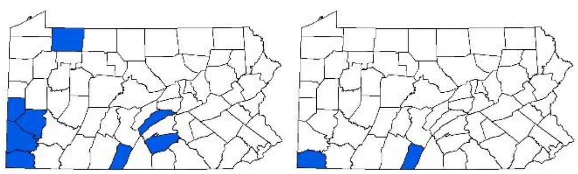
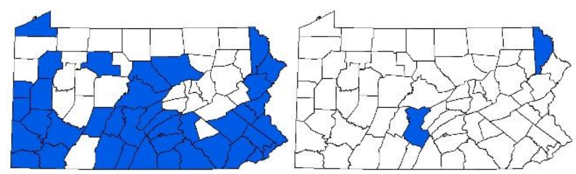
Triodopsis fallax



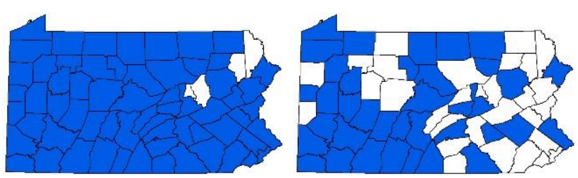
all records 2000-2014

Triodopsis fraudulenta



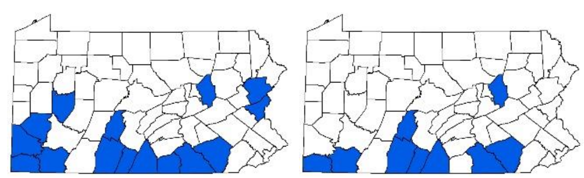
all records 2000-2014

Triodopsis juxtidens



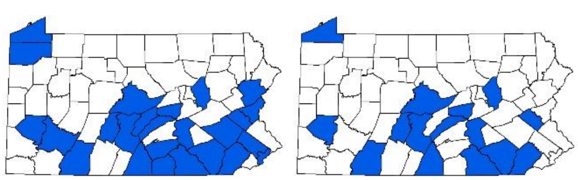
all records 2000-2014

Triodopsis tridentata



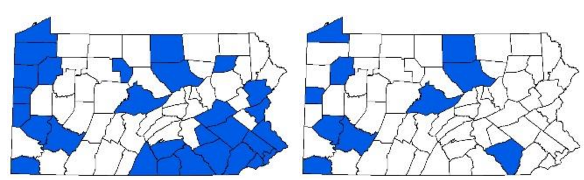
all records 2000-2014

Triodopsis vulgata



all records 2000-2014

Vallonia costata



all records 2000-2014

Vallonia excentrica

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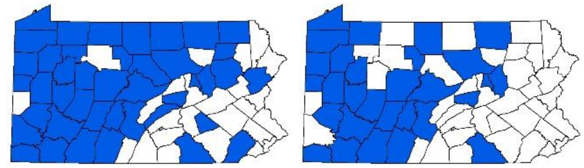
Vallonia pulchella



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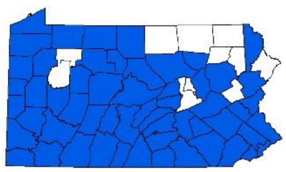
Ventridens intertextus



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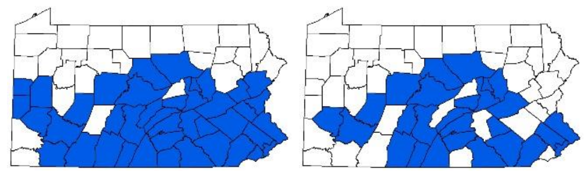
Ventridens ligera

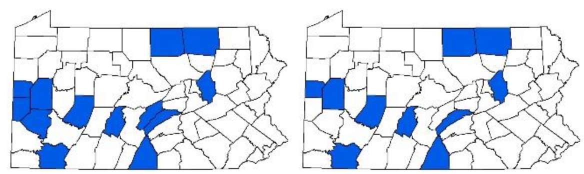


all records 2000-2014

Ventridens suppressus

all records 2000-2014

Ventridens virginicus

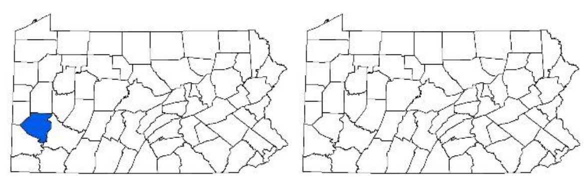


all records 2000-2014

Vertigo bollesiana

all records 2000-2014

Vertigo cristata



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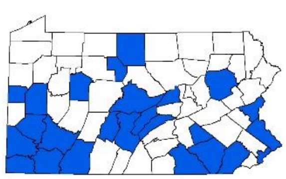
Vertigo elatior



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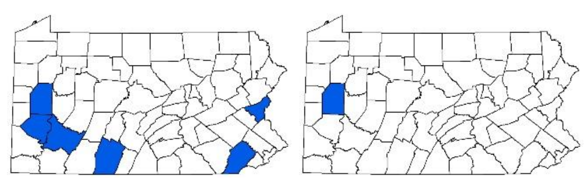
Vertigo gouldii



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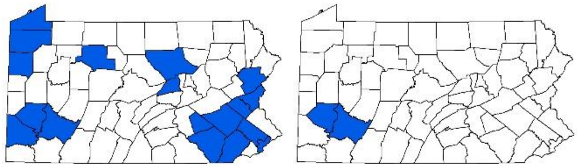
Vertigo milium



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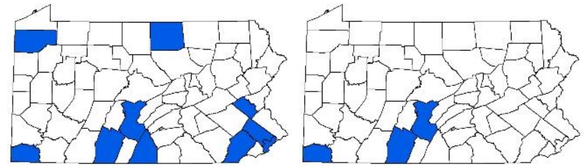
Vertigo ovata



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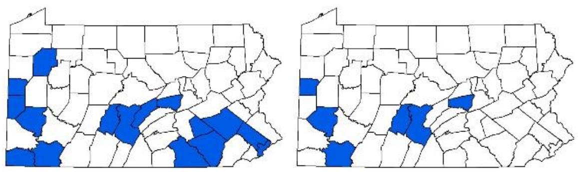
Vertigo pygmaea



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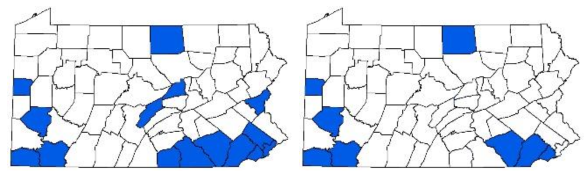
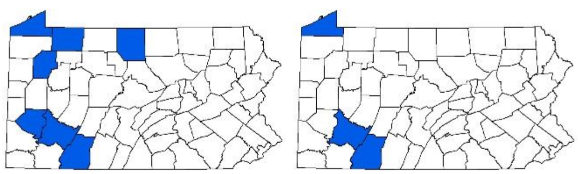
Vertigo tridentata



all records 2000-2014

Vertigo ventricosa



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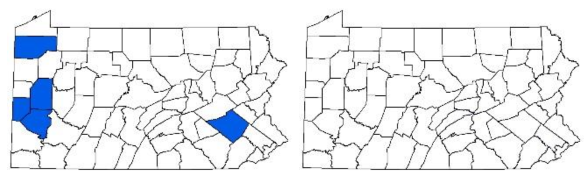
Vitrina angelicae



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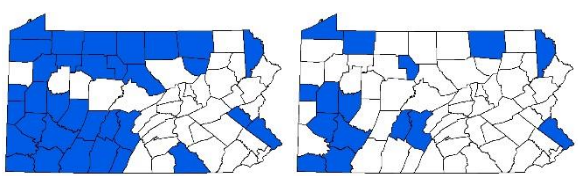
Webbhelix multilineata



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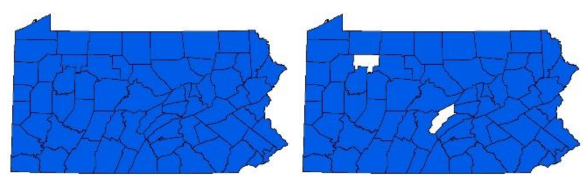
Xolotrema denotatum



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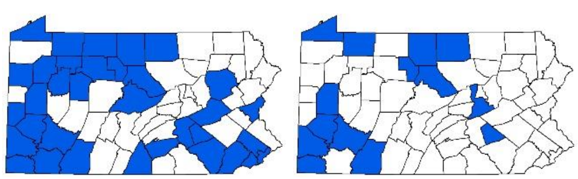
Zonitoides arboreus



all records 2000-2014

Zonitoides nitidus

Appendix 3. Imperilment ranks for Pennsylvania land snails. S1=critically imperiled, S2=imperiled, S3=vulnerable, S4=apparently secure, S5=secure, SNA=state not applicable, SNR=state not ranked.

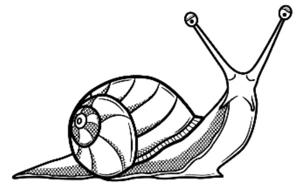
Species	**Rank**	**Species**	**Rank**	**Species**	**Rank**
Allogona profunda	S2	*Gastrocopta procera*	SNR	*Oxyloma retusum*	SNR
Anguispira alternata	S3	*Gastrocopta similis*	SNR	*Oxyloma effusum*	SNR
Anguispira fergusoni	S1	*Gastrocopta tappaniana*	S1	*Pallifera dorsalis*	S4
Anguispira kochi	S3	*Gastrodonta interna*	SH	*Pallifera fosteri*	S3
Appalachina sayana	S2	*Glyphyalinia carolinensis*	SNR	*Pallifera ohioensis*	S3
Arion circumscriptus	SNA	*Glyphyalinia cumberlandiana*	SNR	*Pallifera pennsylvanica*	SNR
Arion distinctus	SNA	*Glyphyalinia indentata*	S5	*Pallifera secreta*	S2
Arion hortensis	SNA	*Glyphyalinia raderi*	S2	*Pallifera varia*	S3
Arion intermedius	SNA	*Glyphyalinia rhoadsi*	S4	*Paravitrea multidentata*	S4
Arion rufus	SNA	*Glyphyalinia virginica*	SNR	*Patera pennsylvanica*	S2
Arion silvaticus	SNA	*Glyphyalinia wheatleyi*	S4	*Philomycus carolinianus*	SNR
Arion subfuscus	SNA	*Guppya sterkii*	S4	*Philomycus flexuolaris*	S4
Carychium exiguum	S3	*Haplotrema concavum*	S4	*Philomycus togatus*	S4
Carychium exile	S4	*Hawaiia alachuana*	SNR	*Pomatiopsis lapidaria*	S2
Carychium minimum	SNA	*Hawaiia minuscula*	S4	*Punctum minutissimum*	S5
Carychium nannodes	S1	*Helicodiscus parallelus*	S4	*Punctum vitreum*	S4
Catinella vermeta	SNR	*Helicodiscus shimeki*	S4	*Pupilla muscorum*	S1
Cecilioides acicula	SNA	*Hendersonia occulta*	S2	*Pupoides albilabris*	S2
Cepaea nemoralis	SNA	*Inflectarius inflectus*	SNR	*Stenotrema barbatum*	S3
Cochlicopa lubrica	S4	*Lehmannia valentiana*	SNA	*Stenotrema hirsutum*	S4
Cochlicopa lubricella	S4	*Limax maximus*	SNA	*Striatura exigua*	S4
Cochlicopa morseana	S4	*Lucilla singleyana*	S4	*Striatura ferrea*	S5
Columella columella	S1	*Megapallifera mutabilis*	S3	*Striatura meridionalis*	S4
Columella simplex	S4	*Mesodon clausus*	SNR	*Striatura milium*	S4
Deroceras laeve	S3	*Mesodon elevatus*	SNR	*Strobilops aeneus*	S4
Deroceras reticulatum	SNA	*Mesodon mitchellianus*	SNR	*Strobilops labyrinthicus*	S3
Discus catskillensis	S3	*Mesodon thyroidus*	S4	*Strobilops texasianus*	S3
Discus patulus	S3	*Mesodon zaletus*	S3	*Succinea grosvenori*	SNR
Discus rotundatus	SNA	*Mesomphix cupreus*	S4	*Succinea indiana*	SNR
Discus whitneyi	SNR	*Mesomphix inornatus*	S4	*Succinea pennsylvanica*	SNR
Euchemotrema fraternum	S4	*Mesomphix perlaevis*	S4	*Succinea putris*	SNA
Euchemotrema leai	S2	*Milax gagates*	SNA	*Triodopsis fallax*	SNR
Euconulus dentatus	S1	*Neohelix albolabris*	S4	*Triodopsis fraudulenta*	S3
Euconulus fulvus	S3	*Neohelix dentifera*	S4	*Triodopsis juxtidens*	S1
Euconulus polygyratus	S4	*Nesovitrea binneyana*	S2	*Triodopsis tridentata*	S4
Gastrocopta armifera	S3	*Nesovitrea electrina*	S4	*Triodopsis vulgata*	S3
Gastrocopta clappi	SNR	*Novisuccinea ovalis*	SNR	*Vallonia costata*	S5
Gastrocopta contracta	S4	*Oxychilus alliarius*	SNA	*Vallonia excentrica*	S5
Gastrocopta corticaria	S3	*Oxychilus cellarius*	SNA	*Vallonia pulchella*	S5
Gastrocopta cristata	SNR	*Oxychilus draparnaudi*	SNA	*Ventridens demissus*	SNR
Gastrocopta pentodon	S4	*Oxyloma gouldi*	SNR	*Ventridens gularis*	SNR

Appendix 3 (continued).

Species	**Rank**	**Species**	**Rank**	**Species**	**Rank**
Ventridens intertextus	S4	*Vertigo elatior*	SNR	*Vertigo ventricosa*	S3
Ventridens ligera	S5	*Vertigo gouldii*	S4	*Vitrina angelicae*	S2
Ventridens suppressus	S4	*Vertigo milium*	S1	*Webbhelix multilineata*	SH
Ventridens virginicus	S3	*Vertigo ovata*	S2	*Xolotrema denotatum*	S4
Vertigo bollesiana	S3	*Vertigo pygmaea*	S3	*Zonitoides arboreus*	S5
Vertigo cristata	S3	*Vertigo tridentata*	S3	*Zonitoides nitidus*	S3

Appendix 4. Educational fact sheet about land snails of Pennsylvania.

Fact Sheet:
Pennsylvania Land Snails



What are snails and slugs?

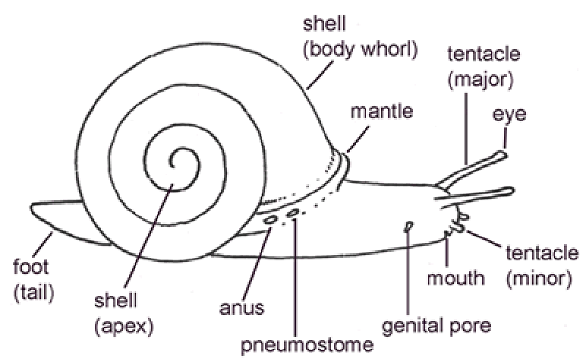
- Snails (including slugs) are phylum Mollusca, class Gastropoda
- Snails live on land, in freshwater, and in the sea
- Snails make a calcium carbonate (lime) shell, usually coiled
- Land snails are like leaky bags of water that survive on dry land
- Slugs descended from snails by reducing the size of the shell and internalizing it
- Slugs look like snails without shells, but most slugs have plate-like shells inside their bodies
- Intermediate forms called semi-slugs have an external shell too small to accommodate the body
- Pennsylvania has 129 species of land snails and slugs

How do they grow and reproduce?

- To grow a larger shell, snails add calcium carbonate to the shell edge and continue the spiral (in contrast, hermit crabs – which are not mollusks – find and use abandoned snail shells)
- Most Pennsylvania land snails and slugs are hermaphrodites (male and female at the same time)
- Only two land snails in Pennsylvania have separate sexes
- Unlike hermaphrodites, those with separate sexes have an operculum (door for closing the shell)
- All Pennsylvania land snails lay eggs; the shell begins to form within the egg
- The smallest snails in Pennsylvania are 1 mm (1/25 inch), the size of Lincoln's nose on a penny
- The largest land snails in Pennsylvania are 25 mm (1 inch) in diameter

Biology: How do they perceive the world, what do they eat, where do they live?

- The two upper tentacles usually have eyes on the tips
- They use the lower pair for smelling and tasting (to find food and mates)
- Snails cannot hear; they use an ear stone for balance
- Many land snails eat leaf litter, probably getting nutrition from the bacteria and fungus on it
- Other land snails eat green leaves, and some are carnivorous, eating other snails
- Many live in woods while some live in drier areas such as meadows, but they all need moisture
- Snails require calcium to build shells; consequently, they are abundant in limestone areas
- Tiny snails are slow (a few mm or 1/8 inch/minute); leopard slugs crawl 20 cm (8 in.)/ 90 seconds



Why should we care?

- Land snails recycle nutrients by eating dead leaves
- Many animals eat them: chipmunks and mice, birds, salamanders, and insects including fireflies
- Nesting female birds obtain calcium carbonate for their eggshells by eating snail shells
- Archaeologists use shells to discover ancient trade routes, habitats, and climates
- Some species are crop pests and others transmit parasites that cause diseases
- Can snails migrate or adapt fast enough to survive rapid changes in weather or deforestation?

by Timothy A. Pearce, Carnegie Museum of Natural History, February 2015