PENNSYLVANIA
WILDLIFE ACTION PLAN

Appendix 1.1

Species Conservation Status Assessment Reports

A. Birds
B. Mammals
C. Fishes
D. Amphibians and Reptiles
E. Crayfishes
F. Freshwater Mussels
G. Terrestrial and other aquatic Invertebrates

How to cite individual assessment reports:

[Assessment author last name, first initial, additional author(s) first initial and last name, as applicable]. [Year of the assessment]. [Assessment report title] *in* PGC-PFBC (Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission). Pennsylvania Wildlife Action Plan, 2025-2035. C. Haffner, D. Day, and N. Welte, editors. Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, Harrisburg, Pennsylvania.

Example: Leppo, B., M. Walsh, and P. Woods. 2025. A Comprehensive Status Assessment of Pennsylvania's Invertebrates for the 2025-35 Pennsylvania Wildlife Action Plan (exclusive of freshwater molluscs-bivalves and crayfishes) *in* PGC-PFBC (Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission). Pennsylvania Wildlife Action Plan, 2025-2035. C. Haffner, D. Day, and N. Welte, editors. Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, Harrisburg, Pennsylvania.

A Comprehensive Status Assessment of Pennsylvania's Birds for the 2025 State Wildlife Action Plan Update

Sean P. Murphy, Ph.D.[1], Patricia Barber[1], Stefan Karkuff[1], Joshua Johnson, Ph.D.[2], Catherine D. Haffner[3], Nathan J. Zalik[3]

Pennsylvania Game Commission, [1]Wildlife Recovery Division, Protected Birds Section; [2]Administration Division, Statistical Support Section; [3]Wildlife Recovery Division, Planning and Grants Administration Section

12 June 2026

Table of Contents

Introduction 2
Methods 2
- Species Selection 3
- Data Sources 4
- Spatial Analysis 4
- Migration Significance 6
- Winter Significance 7
- Population Estimate 9
- Trends 9
- Threats Assessment 12

Results 13
Discussion 14
- Considerations for future assessments 16

Acknowledgements 18
Literature Cited 18
Appendix A 20
- R Code for Spatial and Trends Analyses 20

Appendix B 23

Introduction

We completed a comprehensive status assessment of Pennsylvania's bird species to inform the 2025-2035 Pennsylvania Wildlife Action Plan (PA WAP) in 2024. This assessment evaluated breeding, migratory, and wintering birds to identify conservation priorities and support consistent, science-based decision-making across taxa.

Methods

Following the general guidelines provided by NatureServe (Faber-Langendoen et al. 2012, Master et al. 2012), we conducted analyses for 218 bird species and three time-periods including breeding, migration, and nonbreeding. Outputs included spatial and temporal metrics for inclusion in NatureServe Rank Calculators used in part to determine subnational conservation status rank (i.e., S-rank). The calculator applies a standardized decision framework that integrates available data and expert input on key factors, including population size, population trend, geographic range within Pennsylvania, habitat condition, and known or inferred threats. It uses parameterized input ranges to reflect uncertainty in available data and produces repeatable, transparent status determinations across species.

We assigned S-ranks ranging from S1 (critically imperiled) to S5 (secure; Table 1), following established NatureServe definitions. These ranks describe the relative risk of extirpation within Pennsylvania and provide a consistent basis for comparing conservation status among species.

Table 1. Rank Calculator subnational (S-rank) categories (Faber-Langendoen et al. 2012) assigned to Pennsylvania bird species in this assessment.

S-rank	Description
S1	*Critically Imperiled*—At very high risk of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.
S2	*Imperiled*—At high risk of extirpation in the jurisdiction due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
S3	*Vulnerable*—At moderate risk of extirpation in the jurisdiction due to a restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
S4	*Apparently Secure*—At a fairly low risk of extirpation in the jurisdiction due to an extensive range and/or many populations or occurrences, but with possible cause for some concern because of local recent declines, threats, or other factors.
S5	*Secure*—At very low or no risk of extirpation in the jurisdiction due to a very extensive range, abundant populations or occurrences, with little to no concern from declines or threats.

The resulting S-ranks support identification of Species of Greatest Conservation Need and guide habitat management, monitoring priorities, and conservation actions included in the 2025-35 PA WAP update.

Species Selection

In modern times, four hundred fifty-seven (457) bird species have been documented in Pennsylvania (https://pabirds.org/porc-pennsylvania-bird-list/), of which 290 are considered to be "regularly occurring" by the Pennsylvania Ornithological Records Committee [PORC]. We only considered those species with sufficient data for reviewing, and largely confined the assessments to native, regularly occurring species with two exceptions—King Rail (*Rallus elegans*) and Black Rail (*Laterallus jamaicensis*)—the only two non-regular species that breed in Pennsylvania. We defined native species as an extant, or historically present, breeding or migratory species occurring in Pennsylvania without human assistance. We reviewed 218 bird species for at least one assessment period (breeding, migration, or wintering). Most of the 218 species were placed into one of eight primary habitat guilds: aerial insectivores (8 species), conifer-northern forest (36 species), deciduous-mixed forest (43 species), wetlands-waterbodies-shores (61 species), streams-islands-bottomlands (11 species), successional-shrubland-young forest (28 species), grassland-obligate (17 species), farmland generalists (7 species), and ledges-bare soil-structures (4 species). The handful of remaining species that did not fit neatly in those seven primary habitat guilds were placed in a catch-all group: special cases of habitat use (3 species). Dividing species into guilds based on habitat requirements provided a parsimonious framework to assess threats affecting individual species. Species were subdivided into guilds using the modeling results of the PABBA (Wilson et al. 2012) and additional expert opinion. We only used these guilds during the threat assessment component.

Breeding Assessment. We assessed 181 native species that breed in Pennsylvania as identified by Wilson et al. (2012), including two non-regular breeding species: King and Black Rails.

Migration Assessment. Rather than assess every migrant species, we developed a suite of criteria to identify those species of conservation concern in Pennsylvania and adjacent regions. We assessed 92 species that migrate through or within Pennsylvania that met at least one of the following criteria:

1. Threatened or endangered under the U.S. Endangered Species Act (http://www.fws.gov/endangered/) or state threatened or endangered in Pennsylvania (https://www.pa.gov/agencies/pgc/wildlife/discover-pa-wildlife/endangered-and-threatened)
2. 2015-25 Pennsylvania Species of Greatest Conservation Need (PGC-PFBC 2015)
3. Listed as special concern, threatened, or endangered under Canada's Species at Risk Act (S.C. 2002, c 29; https://laws-lois.justice.gc.ca/eng/acts/s-15.3/page-10.html#h-435647)
4. Northeast Regional Species of Greatest Conservation Need (Northeast Fish and Wildlife Diversity Technical Committee 2023; https://northeastwildlifediversity.org/rsgcn)
5. Tipping Point Species (Road to Recovery 2022; https://r2rbirds.org/tipping-point-species/)
6. "Conservation Species" in the U.S. Fish and Wildlife Service North Atlantic-Appalachian Region At-Risk Species (2021)
7. "High-risk" (red) or "moderate-risk" (orange) in the Raptors at Risk list compiled by the Raptor Population Index (Oleyar et al. 2025)

8. Birds of Conservation Concern (USFWS 2021) within Bird Conservation Regions 12, 13, 14, 28, 29, 30 or at the Continental scale.

Wintering Assessment. We identified 50 Pennsylvania wintering species for review by using the same criteria as the migration assessment.

Data Sources

The primary sources of bird occurrence data were obtained from the following: eBird (Sullivan et al. 2009), Biotics (PNHP 2023), Wildlife Action Plan Conservation Opportunity Area Tool (COA Tool; PGC et al. 2023), Pennsylvania Game Commission annual reports (Barber 2022, Barber and Murphy 2022, Huck 2023, McMorris et al. 2022, Mummert et al. 2022, Murphy 2022a,b), U.S. Geological Survey North American Breeding Bird Survey (BBS; Ziolkowski 2023), Raptor Population Index (RPI; www.hawkcount.org), and Christmas Bird Count (CBC; National Audubon Society 2022).

Though the 2013 conservation status assessment made extensive use of the 2nd Pennsylvania Breeding Bird Atlas (PABBA; Wilson et al. 2012) for spatial and trends analyses (Hill 2014), at the time of this analysis, a 3rd PABBA had not yet been completed. We incorporated breeding season safe dates from 2nd PABBA in analysis, but we excluded spatial and trend data.

Breeding Assessment. For each species, we used breeding observations from the data sources that fell within the PABBA “safe dates” (Appendix G of Wilson et al. 2012). The safe dates for a species indicate the beginning and end date within the calendar year where an individual observed is likely on a breeding territory. BBS data (Ziolkowski 2023) were also an important source of statistical data for species assessments. Secondary data sources for the breeding assessment included PIF Landbird Population Estimates Database Version 3.1 (Partners in Flight 2020) and Pennsylvania Game Commission Survey results for: colonial waterbirds, wetland birds, waterfowl monitoring, Peregrine Falcons, Bald Eagles, Osprey, and American Barn Owls (Pennsylvania Game Commission, unpublished data). Using the PIF database and eBird Status and Trends, we calculated the proportion of the North American population that exists in Pennsylvania.

Migration Assessment. We conducted migration assessments for 90 species using the same methods as in the Breeding Assessment. The only difference was the time-period used to extract records from the eBird and Biotics datasets. We defined migration periods using dates developed by Hill (2014) and supplemented them with dates from eBird Status and Trends (Fink et al. 2023).

Wintering Assessment. We conducted nonbreeding assessments for 46 species, including species classified as year-round residents in Pennsylvania. Using records from the eBird, COA Tool, and CBC datasets, we applied the same analytical methods used in the Breeding and Migration Assessments. We defined the wintering period using dates developed by Hill (2014) and supplemented them with dates from eBird Status and Trends (Fink et al. 2023).

Spatial Analysis

We followed methods presented by Hill (2014) to calculate range extent, area of occupancy, and number of occurrences. The range extent is meant to be a broad-scale estimate of the range of a species within Pennsylvania. A species' range will include areas of Pennsylvania where that species has not been detected and may include areas of unsuitable habitat (Master et al. 2012). Species with smaller ranges are likely more susceptible to localized disturbances and possibly have smaller populations than species with large ranges. Therefore, increasing the range extent for a species in the rank calculator has the general effect of raising its S-ranking (e.g., S2 to S3).

The area of occupancy is the area within a species extent of occurrence that is occupied by that species (Master et al. 2012). In essence, the area of occupancy is a finer scale estimate of the range extent of a species across Pennsylvania. Species with smaller areas of occupancy are likely more susceptible to localized disturbances and possibly have smaller populations than species with large areas of occupancy. Therefore, increasing the area of occupancy for a species has the general effect of raising its S-ranking.

An occurrence is an area of land and/or water in which a species is present. The number of occurrences for a species is analogous to the number of populations of that species in Pennsylvania—which will rarely be known for vertebrates. In general, species with a greater number of occurrences have higher S-rankings (e.g., S5) because the Pennsylvania population of that species is spread out over many subpopulations and is likely less susceptible to localized disturbance and extinction events.

Breeding Assessment. We assessed 181 bird species, including those classified as year-round residents in Pennsylvania. We used the R package 'ConR' (Dauby 2020; R Core Team 2022) to estimate range extent, area of occupancy (AOO), and number of occurrences for each species. Following the convex hull method, we calculated range extent in square kilometers (Bruce Young, personal communication). To estimate AOO, we calculated the area occupied within a 2-km grid. The analyses produced AOO values in square kilometers which we converted to the number of occupied 2-km × 2-km (4-km^2) grid cells for entry into the NatureServe Rank Calculator version 3.2 Excel workbook. Last, we calculated the number of occurrences as the number of occupied cells within a 10-km grid. The r-script can be found in Appendix A.

For 20 species (e.g., Northern Cardinal), the number of observations was so large that R crashed before completing the analysis. For these species, we iteratively removed data one year at a time, beginning with 2013, until R completed the analysis without crashing.

The PGC State Ornithologist reviewed the results for all species before they were entered into the NatureServe Rank Calculator.

Migration Assessment. We conducted migration assessments for 226 species using the same methods as the breeding assessment. The only difference was the period used to extract records from the eBird and Biotics datasets. We defined migration periods using dates developed by Hill (2014), supplemented by dates used in eBird Status and Trends (Fink et al. 2023).

Wintering Assessment. We conducted nonbreeding assessments for 46 species, including those categorized as year-round residents in Pennsylvania due to differing threats during the winter period. We based the analyses on records from the eBird, COA Tool, and CBC datasets and conducted them using the same methods as the breeding and migration assessments. We defined the nonbreeding period using dates developed by Hill (2014) and supplemented them with dates used in eBird Status and Trends (Fink et al. 2023).

Migration Significance

Similar to Wilson (2014) methods used for the 2015-25 PA WAP migratory season analyses, we assessed eBird data for the importance of Pennsylvania as a bird migratory corridor. We used relative abundance estimates from eBird Status and Trends (Fink et al. 2023) to assess the importance of Pennsylvania as a migration corridor for birds during spring and fall migration. Relative abundance estimates represent the expected number of individuals occurring within a standardized area and provide a consistent basis for comparing species distributions across geographic regions.

For each species, we obtained relative abundance estimates during spring and fall migration for six states in Mississippi and Atlantic Flyways spanning the primary migration corridor at the latitude of Pennsylvania: New Jersey, Pennsylvania, Ohio, Indiana, Illinois, and Iowa. To estimate the total number of migrants occurring within each state, we adjusted the relative abundance value by the state's land area. This adjustment accounts for differences in the geographic extent of the states and converts relative abundance estimates into an index of the total migratory population present within each state during a given migration season.

We then calculated Pennsylvania's proportion of the regional migratory population by dividing the area-adjusted estimate for Pennsylvania by the sum of the area-adjusted estimates across all six states. This value provides an estimate of the proportion of migrants occurring within Pennsylvania relative to the total population using the regional migration corridor during spring and fall migration.

As an example, a species may exhibit similar relative abundance values in Pennsylvania and neighboring states. However, because Pennsylvania is larger than several states within the study region, the area-adjusted estimate may indicate that Pennsylvania supports a greater proportion of the total migratory population. The resulting proportions therefore reflect both the density of migrants and the geographic extent of available habitat within each state.

To identify species for which Pennsylvania is particularly important as a migration corridor, we compared the estimated proportion of migrants occurring within Pennsylvania to the proportion expected based on state area alone. Pennsylvania is 18.4% (119,279 km^2) of the area of the two flyways, hence, if we estimate that >36.8% of the population passes through Pennsylvania, we thereby assess that the species is a Pennsylvania priority migrant.

We assessed migration status for 226 species. Species were excluded when migration periods could not be clearly distinguished from breeding or wintering distributions or when relative abundance values within the study region were insufficient for reliable interpretation. A full list of assessed species can be found in Appendix B.

Of the 226 species we assessed for migration status, 26 occurred in Pennsylvania at greater than expected proportions (>18.4%) during spring migration, of which 10 occurred at more than twice the expected proportion (>36.8%) (Table 1). During fall migration, 24 species occurred in Pennsylvania at greater than expected proportions, of which 13 exceeded twice the expected proportion. In total, 30 species occurred in Pennsylvania at greater than expected proportions during at least one migration season, and 16 species met the criterion of occurring at more than twice the expected proportion. In fact, 18 species occurred at greater than expected, and 6 more than twice, in both fall and spring migration seasons. These species represent those for which Pennsylvania appears to be particularly important as a migratory corridor (Table 1).

Table 1. Species for which Pennsylvania is an especially important as a migratory corridor within the Atlantic and Mississippi flyways.

Common name	Spring (%)	Fall (%)	Max spring/fall (%)
Golden Eagle	100.0	100.0	100.0
Ruffed Grouse	100.0	100.0	100.0
Evening Grosbeak	93.3	100.0	100.0
Northern Saw-whet Owl	95.7	0.0	95.7
Veery	53.9	54.7	54.7
Black-billed Cuckoo	31.7	54.4	54.4
Scarlet Tanager	51.8	41.7	51.8
Connecticut Warbler	50.6	0.0	50.6
Cape May Warbler	49.2	33.2	49.2
Canada Warbler	23.5	46.3	46.3
Eastern Whip-poor-will	0.0	46.2	46.2
Wood Thrush	43.8	34.4	43.8
Cerulean Warbler	40.0	25.0	40.0
Black-capped Chickadee	38.3	38.3	38.3
Louisiana Waterthrush	36.9	33.1	36.9
Sharp-shinned Hawk	36.5	36.8	36.8

Winter Significance

Similar to the migration analyses, we used eBird Status and Trends population estimates (Fink et al. 2023) to assess the importance of Pennsylvania for wintering birds. For each of 226 species, we obtained estimates of the total winter population occurring within Pennsylvania and compared these values to the estimated winter population across North America.

Because many species have substantial portions of their global populations occurring outside North America during winter, we adjusted estimates to reflect only the North American wintering population. This approach provides a more biologically meaningful assessment of Pennsylvania's contribution to continental winter populations and avoids underestimating the importance of Pennsylvania for species with large non-North American distributions.

For each species, we calculated the proportion of the North American wintering population occurring within Pennsylvania by dividing the estimated Pennsylvania winter population by the estimated North American winter population. When necessary, the Pennsylvania proportion was adjusted to account for the fraction of the global population occurring within North America. For example, if Pennsylvania supported 10% of the global winter population of a species and North America contained 50% of the global winter population, Pennsylvania's contribution to the North American winter population would be adjusted upward to 20%.

To identify species for which Pennsylvania is particularly important during winter, we designated species as winter priorities when at least 10% of the North American wintering population occurred within the state. This threshold was selected to identify species with a substantial concentration of their continental winter population in Pennsylvania.

We assessed winter abundance for 226 species. No species met or exceeded the 10% threshold, indicating that Pennsylvania does not support a disproportionately large share of the North American wintering population for any assessed species. Although numerous species winter regularly within the state, none occurred in Pennsylvania at levels suggesting exceptional continental importance based on the criteria used in this analysis.

Population Estimate

We acquired Pennsylvania breeding bird population estimates from the PIF Landbird Population Estimates Database Version 3.1 (Partners in Flight 2020), eBird, and PGC surveys. PIF estimates are derived by essentially multiplying the estimated density of a species at BBS routes by the range of that species within the state of Pennsylvania. These density estimates are then corrected for the time of the count (counts conducted later in the morning typically have fewer detections) and for the difference in detection probability between the sexes of a species. This “pair adjustment” correction allows PIF to estimate the population size of both sexes combined in Pennsylvania, even when the BBS counts are dominated by individuals of one sex (typically males, who are generally more vocal).

Breeding Assessment. For the previous Wildlife Action Plan, PABBA population estimates were considered more reliable than PIF Landbird Population Estimates because they were derived from substantially more point counts within Pennsylvania. For the 2025 assessment, however, we relied on PIF estimates because the PABBA data are now more than a decade old and no longer represent current population conditions as effectively. The PIF dataset was updated in 2023. For some species (e.g., rare and infrequently detected species) no population estimate of any kind was available from PIF. In those incidents, we searched for other sources of population estimates, including the data presented in the PABBA species accounts along with expert opinion, and Pennsylvania Game Commission survey data (unpublished data). We used the PIF database or eBird data products to estimate the proportion of the North American Population that resides in Pennsylvania.

Migration Assessment. No population estimates were available exclusively for the number of migrants in Pennsylvania.

Wintering Assessment. No population estimates were available exclusively for the number of wintering individuals in Pennsylvania.

Trends

We conducted trend assessments for two timeframes: short-term trends, which covered the most recent 10 years of available data, and long-term trends, which spanned from 1966 to the most recent year of available data. We assessed both short- and long-term trends during three biological periods: breeding, migration, and nonbreeding. As with the spatial analyses, we defined these periods using dates provided by PABBA and eBird.

To quantify percent change over each timeframe, we used an approach similar to that described by Hill (2014). We obtained trend estimates directly from the Breeding Bird Survey (BBS) website or calculated them using data from Pennsylvania Game Commission annual reports, the Raptor Population Index, and the Christmas Bird Count. For datasets other than BBS, we first compiled the data and standardized them by survey effort and year.

We modeled trends using three approaches: linear, exponential, and second-order polynomial regression. We selected the model with the highest R^2 (or quasi-R^2) value to estimate percent change from the first to the final year of analysis, unless that model projected a population decline of 100% or greater by the final year. In those cases, we selected the model with the next-highest R^2 value. Reported percent changes reflect values predicted by the selected model rather than the raw data.

Following review by PGC biologists, we entered trend estimates and the results of spatial analyses into the Rank Calculator.

Breeding Assessment. Consistent with the 2015–25 PA WAP, we used short- and long-term trend estimates from the USGS Breeding Bird Survey (BBS) website when species were assigned to the blue or yellow reliability categories. We did not use trend estimates in the red category because those data were considered unreliable. Of the species evaluated, 71 were categorized as blue, 43 as yellow, 46 as red, and 58 lacked BBS trend estimates. For 8 of the 46 species in the red category, we calculated trends using Pennsylvania Game Commission (PGC) annual report data. For an additional 4 of the 58 species without BBS trend estimates, we also calculated trends using PGC annual report data. We assessed short-term trends for 2013–2022 and long-term trends for 1966–2022.

We were able to calculate long- and short-term breeding trends for 161 and 156 species, respectively, breeding in Pennsylvania. Most bird species in Pennsylvania (for which we have data) have stable or increasing long-term trends (83 species) and stable or increasing short-term trends (52 species). Thirty-one species have experienced long-term declines >50% and six species experienced >90% declines (Table 3).

Table 3. Pennsylvania breeding bird species with the five largest and five most negative long-term trends.

Common name	Scientific name	Long-term trend (%)	Trend type
Golden-winged Warbler	*Vermivora chrysoptera*	-98	BBS
Upland Sandpiper	*Bartramia longicauda*	-98	BBS
Henslow's Sparrow	*Centronyx henslowii*	-98	BBS
Vesper Sparrow	*Pooecetes gramineus*	-97	BBS
Yellow-breasted Chat	*Icteria virens*	-95	BBS
Carolina Wren	*Thryothorus ludovicianus*	2,623	BBS
Common Merganser	*Mergus merganser*	2,707	BBS
Red-bellied Woodpecker	*Melanerpes carolinus*	2,750	BBS
Bald Eagle	*Haliaeetus leucocephalus*	4,817	BBS
Canada Goose	*Branta canadensis*	7,967	BBS

While short- and long-trends were significantly and positively related to each other ($\rho = 0.37$, $P < 0.001$), 63 species showed a contrasting pattern with 45 suggesting a recent change from increasing to declining. Winter Wrens, for example, have increased by 1,413% overall in Pennsylvania since 1966, but have declined by 51% since 2013. Not surprisingly, several species with extreme long-term trends (Table 3) also had extreme short-term trends (Table 4).

Table 4. Pennsylvania breeding bird species with the five largest and five most negative short-term trends.

Common name	**Scientific name**	**Long-term trend (%)**	**Trend type**
Pine Siskin	*Spinus pinus*	-85	BBS
Bank Swallow	*Riparia riparia*	-78	BBS
Henslow's Sparrow	*Centronyx henslowii*	-71	BBS
Yellow-breasted Chat	*Icteria virens*	-68	BBS
Red-breasted Nuthatch	*Sitta canadensis*	-59	BBS
Bald Eagle	*Haliaeetus leucocephalus*	164	BBS
Black Vulture	*Coragyps atratus*	98	BBS
Hooded Merganser	*Lophodytes cucullatus*	80	BBS
Yellow-throated Vireo	*Vireo flavifrons*	76	BBS
Purple Martin	*Progne subis*	67	BBS

Worth noting, Hill (2014) found 102 (of 137) species had stable or increasing long-term trends, and 111 species exhibited short-term (2001-2011) stability or growth. While 21 species have experienced long-term declines >50% and a handful of species experienced >90% declines (Table 5).

Table 5. Changes in breeding bird population trend categories between 2015 and 2025 Pennsylvania Wildlife Action Plans (PA WAP). Values represent percentage of species in each category.

			Population trend		
Term length	**PA WAP year**	**No. of species**	**Stable or increasing**	**>50% decline**	**>90% decline**
Long-term	2015	137	74	15	4
	2025	161	52	19	4
Short-term	2015	137	81	1	0
	2025	156	33	6	0

Migration Assessment. For migratory species, we used data from the Raptor Population Index to model short-term (2013–2022) and long-term (1966–2022) trends for seven raptor species. We compiled data from 10 observation sites across Pennsylvania and standardized them for observer effort before analysis.

Nonbreeding Assessment. We conducted nonbreeding trend analyses for 46 species classified as nonbreeding or year-round residents in Pennsylvania. We used Christmas Bird Count (CBC) data to assess short-term (2012–2021) and long-term (1966–2021) trends. As in the breeding and migration assessments, we evaluated linear, exponential, and second-order polynomial models for each species and timeframe. We used the model with the highest R^2 value to calculate percent change over the assessment period.

Threats Assessment

For each species, we used the Rank Calculator to estimate an overall threat impact score during each assessment period (Master et al. 2012; Hill 2014). A panel of experts identified individual threats, scope, severity, and timing (immediacy) score to each threat using peer-reviewed literature where available. Individual threats roll up to an overall threat impact score (Master et al. 2012). A threat is any activity or process that is causing destruction, degradation, and/or impairment to a particular species (Salafsky et al. 2008). These threats can be natural processes (e.g., earthquakes and hybridization), but most threats are anthropogenic processes (e.g., development, agricultural activities, pollution and fire suppression). The scope is the proportion of the species that is likely to be affected by the threat within 10 years. Within the scope (as defined spatially and temporally), severity is the level of damage to the species from the threat that is likely to be expected within the next three generations. Timing, a measure of the immediacy of the threat, was recorded for each threat but it does not affect the overall threat score and was included entirely for reference. See Master et al. (2012) and Hill (2014) for more details.

An overall threat score (very high, high, medium, low) was assigned to each species for each assessment period it occurred in based on the rank calculator threat worksheet (Master et al. 2012; Hill 2014).

Breeding Assessment: Threats during the breeding assessment period were identified, assigned, and scored for each species as described above.

Migration Assessment: Threats during the migration assessment period were identified, assigned, and scored for each species as described above.

Wintering Assessment: Threats during the wintering assessment period were identified, assigned, and scored for each species as described above.

Results

The Rank Calculator generates S-ranks based on expert's inputs who referenced best available data for that assessment period and for that species. Most breeding species were ranked as vulnerable (S3) or higher (i.e., S4 [apparently secure] or S5 [secure]) (Figure 1), but 31 species were deemed either critically imperiled (S1, 17%) and 12 species imperiled (S2, 7%). Migratory and wintering S-ranks (Figure 2) showed an overall similar pattern to the breeding S-ranks, but with fewer critically imperiled species. For the migration assessment, two species, Loggerhead Shrike (*Lanius ludovicianus*) and Dunlin (*Calidris alpina*), were designated as unrankable (SU) due to a lack of data in Pennsylvania during fall and spring migration periods.

Figure 1. Count of breeding bird subnational ranks (S-ranks) for each S-rank category as determined from the Rank Calculator for 181 Pennsylvania bird species. The S2 category contains Nashville Warbler (*Leiothlypis ruficapilla*) which was calculated as "S2S3". The S3 category includes Virginia Rail (*Rallus limicola*) which was calculated as "S3?".

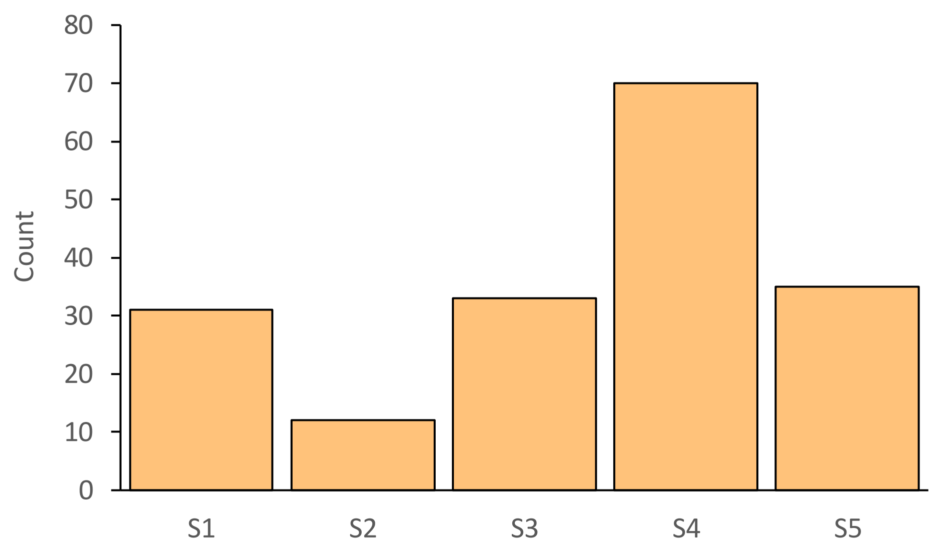


Figure 2. Count of migratory bird subnational ranks (S-ranks) (left panel) and wintering bird S-ranks (right panel) as determined from the Rank Calculator for 90 migratory and 50 wintering Pennsylvania bird species. Note the different scales between panels.

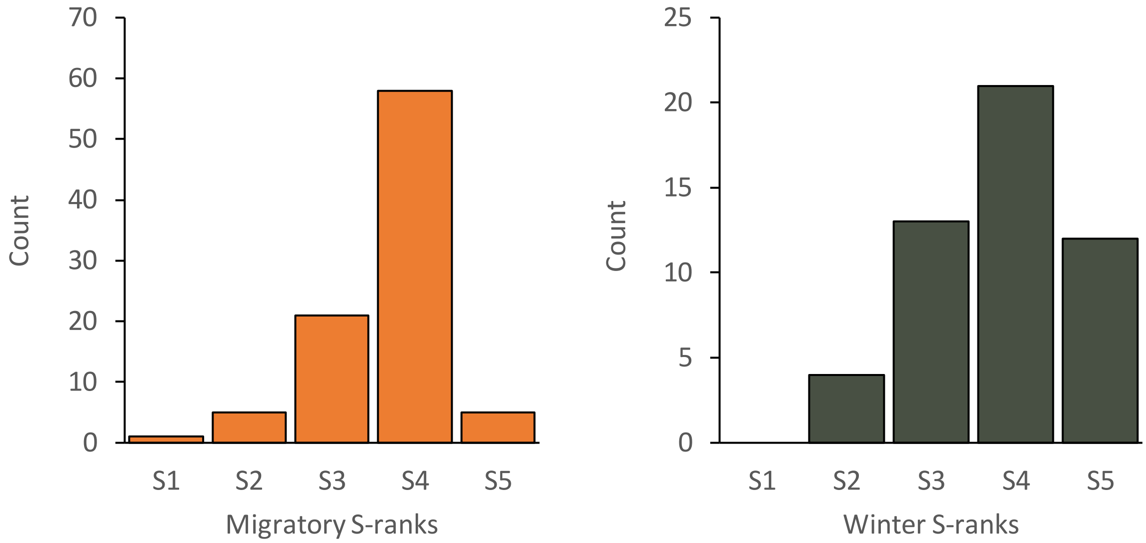
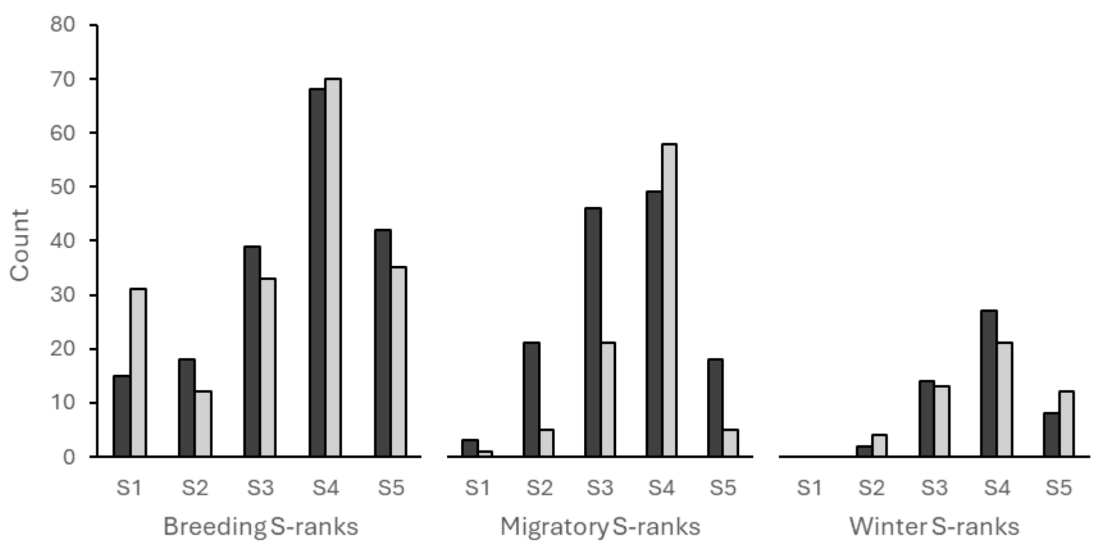


Figure 3. Count of bird species subnation rank (S-rank; S1-S5) during breeding, migratory, and winter periods in Pennsylvania in 2014 (dark gray) and 2024 (light gray). Bars show the number of species assigned to each rank during each assessment year.



Discussion

The 2024 assessment provides an updated and more comprehensive evaluation of the conservation status of Pennsylvania's birds using the best available biological data and the current NatureServe conservation status assessment framework. As in the previous assessment completed for the 2015-25

PA WAP, most breeding, migratory, and wintering species were assigned subnational ranks of S3 (Vulnerable), S4 (Apparently Secure), or S5 (Secure), indicating that the majority of Pennsylvania's avifauna remains relatively widespread and resilient. However, several important changes emerged when comparing results between assessment periods.

Breeding Assessments. Most notable was the increase in the number of breeding species assigned an S1 rank (critically imperiled). Hill (2014) assessed 16 breeding species as critically imperiled, whereas 31 species received an S1 rank in the current assessment. This shift does not necessarily indicate that all affected species experienced dramatic biological declines during the intervening decade. Rather, several factors likely contributed to the increase.

First, the current assessment incorporated substantially more occurrence data from eBird and other monitoring programs than were available during the previous assessment. Increased data availability often allows more accurate delineation of species distributions, population trends, and threats. In some cases, improved information revealed that species occupy smaller areas, occur in fewer locations, or face greater conservation challenges than previously recognized.

Across the two reporting periods, the 2015 and 2025 PA WAPs, Pennsylvania's breeding bird assemblage shows a shift from an overall pattern of broad stability and long-term recovery in many species to a more complex picture characterized by increasing short-term volatility and emerging recent declines in a subset of species (Table 5). While the earlier framework (1966–2014) suggested that most species were either stable or increasing and that only a relatively small fraction experienced severe long-term declines, the more recent assessment indicates that these long-term trajectories do not consistently predict current conditions. Instead, a growing number of species exhibit divergent long- versus short-term trends, including apparent reversals from long-term increases to recent declines.

Additionally, several species continue to exhibit long-term declines associated with habitat loss, habitat degradation, changing land-use practices, and other widespread stressors. Species associated with grasslands, early successional habitats, wetlands, and aerial insectivore guilds remain among the groups of greatest conservation concern. Hill (2014) emphasized that a high portion of the wetlands-open water-shores habitat guild species were deemed critically imperiled (S1, n = 6 species). In the 2024 assessments, 17 wetlands-open water-shores species were identified as critically imperiled (S1) including species like Prothonotary Warbler which moved from S3 (vulnerable) to S1 (critically imperiled). Continued declines within these habitat groups likely contributed to lower conservation status ranks for some species.

The apparent increase in the number of species showing short-term declines may partly reflect true ecological change as well as improved detectability of trend shifts due to longer time series and more sensitive analytical methods. However, the consistency of directional reversals across multiple species suggests that this pattern is unlikely to be purely methodological.

Taken together, these results indicate that Pennsylvania's bird populations are entering a period in which long-term historical trends are an incomplete predictor of current population dynamics. While past decades were characterized by recovery for many species, recent years suggest increasing environmental pressures are reshaping those trajectories. Continued monitoring will be essential to determine whether these short-term declines represent temporary fluctuations, the beginning of new long-term declines, or ongoing fluctuations.

Last, the NatureServe Rank Calculator has undergone revisions since the previous assessment. Corrections to calculator algorithms and improvements to the treatment of uncertainty may have influenced rank outcomes independently of biological changes. Consequently, differences between 2014 and 2024 rankings should not be interpreted solely as changes in species status but also as improvements in assessment methodology.

Migration Assessments. The migration assessment evaluated fewer species than the previous review. The 2014 assessment reviewed 137 migratory species, whereas the current assessment focused on 90 species selected through updated conservation-priority criteria. This reduction reflects a more targeted approach that emphasizes species with elevated conservation concern rather than a decline in the importance of migration through Pennsylvania.

Migration Significance. Our results further demonstrated Pennsylvania's importance as a migratory corridor. Several species occurred within the Commonwealth at proportions substantially greater than expected based on regional land area, indicating that Pennsylvania provides disproportionately important migratory habitat for these species. Species such as Golden Eagle, Veery, Scarlet Tanager, Canada Warbler, Cerulean Warbler, and Wood Thrush were among those for which Pennsylvania appears particularly important during migration. These findings reinforce the significance of habitat conservation efforts that support stopover and migratory connectivity throughout the state.

Wintering Assessments. Our assessments of the winter period generally exhibited patterns like those observed during the breeding period, although fewer species were classified as critically imperiled. This outcome is not unexpected because many wintering species occupy broader geographic areas, concentrate in suitable habitats, or are less constrained by breeding habitat requirements. Nevertheless, wintering populations remain vulnerable to habitat alteration, climate-driven changes in distribution, and degradation of critical winter habitats both within and beyond Pennsylvania.

Overall, the 2024 assessment reflects both real conservation concerns and substantial improvements in available information. The increased use of large-scale datasets, refined analytical methods, updated monitoring programs, and improved conservation status assessment tools has produced a more robust and defensible evaluation of Pennsylvania's bird populations. While many species remain secure, the increase in critically imperiled breeding species highlights the continued importance of conservation actions directed toward declining habitat specialists and species with restricted distributions.

Considerations for future assessments

Future assessments would benefit from continued emphasis on standardized, repeatable methods and transparent documentation of analytical decisions. Several recommendations emerged during this review:

1. **Incorporate Third Pennsylvania Bird Atlas (2024-2029) data when available.** The absence of a recent Pennsylvania breeding bird atlas limited the ability to evaluate long-term changes in

occupancy and distribution using methods comparable to the 2014 assessment. Atlas data will substantially improve estimates of range extent, area of occupancy, occurrences, and distributional change. Moreover, the third atlas includes a winter survey period to learn about the distribution and abundance of birds in Pennsylvania in winter which is understudies and will significantly contribute to future winter assessments.

2. **Maintain archived analytical workflows.** All scripts, spatial layers, species lists, migration dates, and calculator inputs should be archived with detailed metadata. Reproducible workflows will reduce effort and improve consistency in future assessment cycles.
3. **Continue refining migration assessments.** The migration-significance analysis developed for this assessment provides a useful framework for identifying species that rely disproportionately on Pennsylvania during migration. As migratory connectivity data continues to advance, future assessments should evaluate opportunities to expand this analysis geographically and incorporate additional measures of stopover importance.
4. **Improve population estimates for poorly monitored species.** Reliable population estimates remain unavailable for some rare, colonial, nocturnal, marsh-dependent, and secretive species. Developing targeted surveys or model-based population estimates (e.g., secretive marsh birds) would reduce uncertainty in future rank determinations.
5. **Document expert-review decisions.** Expert judgment remains an important component of the NatureServe ranking process, particularly threat assessments. Future conservation status assessments should maintain written records explaining departures from calculated values or unusual ranking outcomes to ensure transparency and consistency among assessment cycles.
6. **Track methodological changes between assessment cycles.** Changes in analytical methods, data sources, and NatureServe calculator versions can affect rank outcomes. Maintaining a formal change log will help future reviewers distinguish biological change from methodological change.
7. **Evaluate emerging data sources.** eBird Status and Trends products, community science datasets, automated acoustic monitoring, and occupancy-modeling approaches continue to improve rapidly and may provide additional information for future conservation status assessments.
8. **Periodically review threat frameworks.** Threat scores should be revisited regularly to ensure that emerging issues—including climate change, invasive species, disease, renewable energy development, and changing land-use practices—are consistently evaluated across species and habitat guilds. Like the 2014 effort to assign threats, future assessments should return to the 2014 methods— each threat (and its associated scope and severity) were assigned to an entire guild, and then a reviewer made individual adjustments for each species in that guild based on that species' susceptibility to that threat. This process ensured that threats were assessed similarly for species occurring in the same habitat, and yet this approach allowed individual species to be assessed independently from other species in that guild.

Through detailed documentation, analytical transparency, incorporating new monitoring data, and maintaining consistent assessment methods, future reviews will be better positioned to distinguish true biological change from changes in data availability or analytical approaches.

Acknowledgements

We thank Pennsylvania Biological Survey Ornithological Technical Committee (OTC) members for their contributions to the threats assessment and conservation status results review for accuracy and completeness: *Terry Master, Ph.D.* (OTC Chair), *Dan Brauning, Matt Marshall, Ph.D., Bob Mulvihill, Jeff Stratford, Ph.D., Kim Van Fleet, Justin Vreeland, David Yeany II.*

Literature Cited

Barber, P. M. 2022. Colonial Waterbird Nesting Study. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Barber, P. M., and S. P. Murphy. 2022. Wetland Nesting Bird Surveys. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Dauby, G. 2020. ConR: Computation of parameters used in preliminary assessment of conservation status. R package 1.3.0. Available at https://CRAN.R-project.org/package=ConR.

Faber-Langendoen, D., J. Nichols, L. Master, K. Snow, A. Tomaino, R. Bittman, G. Hammerson, B. Heidel, L. Ramsay, A. Teucher, and B. Young. 2012. NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe, Arlington, VA.

Fink, D., T. Auer, A. Johnston, M. Strimas-Mackey, S. Ligocki, O. Robinson, W. Hochachka, L. Jaromczyk, C. Crowley, K. Dunham, A. Stillman, I. Davies, A. Rodewald, V. Ruiz-Gutierrez, C. Wood. 2023. eBird Status and Trends, Data Version: 2022; Released: 2023. Cornell Lab of Ornithology, Ithaca, New York.

Hill, J. M. 2014. A comprehensive status assessment of Pennsylvania's avifauna for application to the State Wildlife Action Plan update 2015. Unpublished report for Pennsylvania Game Commission, Harrisburg, PA.

Huck, N. 2023. Waterfowl Population Monitoring. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Master, L.L., D. Faber-Langendoen, R. Bittman, G.A. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe, Arlington, VA.

McMorris, F.A., P.M. Barber, S.P. Murphy, and D.W. Brauning. 2022. Peregrine Falcon Investigations. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Mummert, D., M. Giazzon, T. Colt, R. Fritsky, C. Lutz, and S. Wolbert. 2022. Barn Owl Conservation Initiative. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Murphy, S.P. 2022a. Bald Eagle Breeding Surveys. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Murphy, S.P. 2022b. Osprey Research/Management and Surveys. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

National Audubon Society. 2022. The Christmas Bird Count Historical Results [Online]. Available at http://www.christmasbirdcount.org. Accessed on 1 September 2023.

Northeast Fish and Wildlife Diversity Technical Committee. 2024. Northeast Regional Species of Greatest Conservation Need (RSGCN) Database, version 4.1. Prepared for the Northeast Association of Fish and Wildlife Agencies by Terwilliger Consulting, Inc. https://www.northeastwildlifediversity.org.

Oleyar, D., D. Ethier, L. Goodrich, D. Brandes, J. Brown, and J. Sodergren. 2025. The Raptor Population Index: 2023 Analyses and Assessments. Available at https://www.rpi-project.org/raptors-at-risk/.

Partners in Flight. 2020. Population Estimates Database, version 3.1. Available at http://pif.birdconservancy.org/PopEstimates.

Pennsylvania Game Commission, Pennsylvania Fish and Boat Commission, and Western Pennsylvania Conservancy (unpublished data). 2023. Wildlife Action Plan Conservation Opportunity Area Tool. Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, Harrisburg, PA.

Pennsylvania Natural Heritage Program. 2023. Biotics 5. Western Pennsylvania Conservancy Natural Heritage Program, Pittsburgh, PA.

R Core Team. 2023. R: A language and environment for statistical computing. Version 4.3.1. R Foundation for Statistical Computing, Vienna, Austria. Available at http://www.R-project.org.

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H.M., Collen, B., Cox, N., Master, L.L., O'Connor, S. and Wilkie, D. 2008. A Standard Lexicon for Biodiversity Conservation: Unified Classifications of Threats and Actions. *Conservation Biology* **22**: 897-911.

Sullivan, B.L., C.L. Wood, M.J. Iliff, R.E. Bonney, D. Fink, and S. Kelling. 2009. eBird: a citizen-based bird observation network in the biological sciences. *Biological Conservation* **142**: 2282-2292.

U.S. Fish and Wildlife Service. 2021. Birds of Conservation Concern 2021. United States Department of the Interior, U.S. Fish and Wildlife Service, Migratory Birds, Falls Church, VA. Available at http://www.fws.gov/birds/management/ managed-species/birds-of-conservation-concern.php.

Wilson, A.M. 2014. Assessment of eBird data for the importance of Pennsylvania as a bird migratory corridor. Unpublished report for Pennsylvania Game Commission, Harrisburg, PA.

Wilson, A.M., D.W. Brauning, and R.S. Mulvihill. 2012. Second Atlas of Breeding Birds of Pennsylvania. Penn State University Press. 612 pp.

Ziolkowski, D.J., Lutmerding, M., English, W.B., Aponte, V.I., and Hudson, M.A.R. 2023. North American Breeding Bird Survey Dataset 1966-2022: U.S. Geological Survey. Available at https://doi.org/10.5066/P9GS9K64.

Appendix A

R Code for Spatial and Trends Analyses

```
# R packages needed for analysis
ConR
dplyr
lubridate
MASS
modelr
rnaturalearth
rnaturalearthdata
tidyverse

### Code for Spatial analysis of Breeding season data; code for other seasons would be similar
# Generic code for importing raw observation data
data <- read.delim("Mammals.txt", sep='\t', header=T)
data$LAT <- as.numeric(data$LAT)
data$LONG <- as.numeric(data$LONG)

# Subset data excluding all but past 10 years of Breeding season data (raw data already labeled with
column that indicated which season they were recorded)
Breed <-data %>% filter(data$Season=="b")
Breed <- Breed %>% filter (Breed$Year > 2013 & Breed$Year < 2024)

# Dates in raw eBird data were converted to day-of-year in Excel for subsetting seasons based on safe
dates. Example is generic subset for Migration season analysis
Migr <- Breed %>% filter (Breed$DOY > 318 & Breed$DOY < 367 | Breed$DOY > 0 & Breed$DOY < 61)

# Extract a certain species for analysis
BreedSp <-Breed %>% filter(Breed$SCI.NAME=="Perimyotis subflavus")

# package ConR requires only Latitude, Longitude, and Species name for analysis
BreedSp2 <- BreedSp[,c(5,6,1)]

# Function that outputs EOO, AOO, Numbers of Locations, &c.
IUCN.eval(BreedSp2)

### Code for Trends analysis
# Import dataset
data <- read.delim("Gametake.txt", sep='\t', header=T)

# Subset data to extract a particular species

data2 <- data %>% filter (data$Species=="PESU")

# Separate data into 2 time periods; 1 subset for long-term analysis, 1 subset for short-term analysis
data2 <- data2 %>% filter(data2$Year < 2024)
```

```
data2s <- data2 %>% filter(data2$Year > 2012)

# Plot long-term and short-term data for visual inspection
plot(Harvest.effort~Year, data=data2)
plot(Harvest.effort~Year, data=data2s)

# Model long-term and short-term data via linear regression
linl <- lm (Harvest.effort~Year, data=data2)
summary(linl)
lins<- lm (Harvest.effort~Year, data=data2s)
summary(lins)
# Model long-term and short-term data via 2nd order polynomial regression
polyl <- lm(Harvest.effort~poly(Year, 2), data=data2)
summary(polyl)
polys <- lm(Harvest.effort~poly(Year, 2), data=data2s)
summary(polys)

# Model long-term and short-term data via exponential regression
expl <- nls(Harvest.effort~exp(a+b*Year), data=data2, start=list(a=0,b=0))
summary(expl)
modelr::rsquare(expl, data=data2)
exps <- nls(Harvest.effort~exp(a+b*Year), data=data2s, start=list(a=0,b=0))
summary(exps)
modelr::rsquare(exps, data=data2s)

# Choose model with highest r-square value and fit the model to the data to estimate percent increase
or decrease over the given time period

# Linear long-term model
(linl$coef[1]+linl$coef[2]*max(data2$Year))/(linl$coef[1]+linl$coef[2]*min(data2$Year))

# Say the model above results in a value of 9.21, the population has increased by 821% [(9.21-1)*100]

# Linear short-term model
(lins$coef[1]+lins$coef[2]*max(data2s$Year))/(lins$coef[1]+lins$coef[2]*min(data2s$Year))

# Say the model above returns a value of 0.4855, then population has declined by ~51% over the given
time period.

# 2nd order polynomial long-term model
polyp <- lm(Harvest.effort ~ poly(Year, 2), data = data2); polyp.datc <- data.frame(Year =
seq(min(data2$Year), max(data2$Year), by = 1))
polyp.datc$yhat <- predict(polyp, polyp.datc)
View(polyp.datc)

# In the following code, insert the modelled value from the 1st year in the given time period (0.5015 in
this example)
polyp.datc$yhat[length(polyp.datc$yhat)]/(0.5015)
```

```
# The code above produces an output value of 0.6152, which indicates a population decrease of 38.5%
 (0.615-1)*100 = -38.5%.

# 2nd order polynomial short-term model
polyp <- lm(Harvest.effort ~ poly(Year, 2), data = data2s)
polyp.datc <- data.frame(Year = seq(min(data2s$Year), max(data2s$Year), by = 1))
polyp.datc$yhat <- predict(polyp, polyp.datc)
View(polyp.datc)

# In the following code, the modelled value [1] from the 1st year in the given time period is inserted into
the following calculation
polyp.datc$yhat[length(polyp.datc$yhat)]/(polyp.datc$yhat[1])

# The code above produces a value of say, 0.1286; so 1 – 0.1286 = 0.8714, so a ~87% reduction over the
give time period

# Exponential long-term model

explp <-nls(Harvest.effort~exp(a+b*Year),data=data2,start=list(a=0,b=0))
explp.coef<-coef(explp)

# First and last years of modelled values are inserted into the following formula to calculate percent
increase or decrease in population over a given time period
(predict(explp, list(x = data2$Year))[55])/(predict(explp, list(x = data2$Year))[1])

# Exponential short-term model
expsp <-nls(Count.effort~exp(a+b*Year), data=CBCdata2s, start=list(a=0,b=0))
expsp.coef<-coef(expsp)

# First year modelled value is inserted into the following formula to calculate percent increase or
decrease in population over a given time period
tail(predict(expsp, list(x = CBCdata2s$Year)), n=1)/(predict(expsp, list(x = CBCdata2s$Year))[1])
```

Appendix B

Full list of species assessed for migratory significance, in alphabetical order. Green indicates >20.7% of the Atlantic and Mississippi Flyway populations estimated to pass through Pennsylvania, orange indicates >36.8% of population estimated to pass though Pennsylvania.

Common name	Fall (%)	Spring (%)	Max spring/fall (%)
Acadian Flycatcher	11.2	15.2	15.2
American Black Duck	8.9	13.2	13.2
American Golden-Plover	1.2	0.0	1.2
American Kestrel	12.4	12.8	12.8
American Woodcock	**32.3**	**26.2**	**32.3**
Bank Swallow	6.7	0.0	6.7
Barn Swallow	10.5	11.8	11.8
Bay-breasted Warbler	16.6	**26.7**	**26.7**
Belted Kingfisher	**23.4**	**25.3**	**25.3**
Black-bellied Plover	3.1	0.0	3.1
Black-billed Cuckoo	**31.7**	**54.4**	**54.4**
Black-capped Chickadee	**38.3**	**38.3**	**38.3**
Blue-winged Warbler	**26.7**	**26.4**	**26.7**
Bobolink	14.8	17.2	17.2
Canada Warbler	**23.5**	**46.3**	**46.3**
Cape May Warbler	**49.2**	**33.2**	**49.2**
Cerulean Warbler	**40.0**	**25.0**	**40.0**
Chimney Swift	18.3	17.6	18.3
Common Nighthawk	11.9	12.0	12.0
Common Tern	**22.9**	6.3	**22.9**
Connecticut Warbler	**50.6**	0.0	**50.6**
Eastern Meadowlark	2.3	3.9	3.9
Eastern Towhee	**30.6**	**30.1**	**30.6**
Eastern Whip-poor-will	0.0	**46.2**	**46.2**
Eastern Wood-Pewee	13.6	15.1	15.1
Evening Grosbeak	**93.3**	**100.0**	**100.0**
Field Sparrow	18.3	17.9	18.3
Golden Eagle	**100.0**	**100.0**	**100.0**
Golden-winged Warbler	0.3	10.9	10.9
Grasshopper Sparrow	7.7	12.7	12.7
Great Black-backed Gull	0.0	0.0	0.0
Greater Yellowlegs	2.6	1.0	2.6
Henslow's Sparrow	2.6	3.5	3.5

Common name	Fall (%)	Spring (%)	Max spring/fall (%)
Horned Grebe	10.2	**24.2**	**24.2**
Kentucky Warbler	0.4	5.0	5.0
Least Bittern	10.5	9.1	10.5
Lesser Yellowlegs	1.6	0.6	1.6
Louisiana Waterthrush	**36.9**	**33.1**	**36.9**
Northern Harrier	2.4	3.4	3.4
Northern Pintail	0.0	1.8	1.8
Northern Saw-whet Owl	**95.7**	0.0	**95.7**
Olive-sided Flycatcher	6.5	7.1	7.1
Osprey	15.3	**27.3**	**27.3**
Pectoral Sandpiper	0.2	0.0	0.2
Prairie Warbler	**22.6**	**23.5**	**23.5**
Prothonotary Warbler	0.0	0.4	0.4
Red-headed Woodpecker	1.0	1.6	1.6
Rose-breasted Grosbeak	**21.2**	16.2	**21.2**
Rough-legged Hawk	0.0	2.1	2.1
Ruddy Turnstone	0.0	0.8	0.8
Ruffed Grouse	**100.0**	**100.0**	**100.0**
Rusty Blackbird	4.6	5.6	5.6
Sanderling	1.6	0.0	1.6
Scarlet Tanager	**51.8**	**41.7**	**51.8**
Semipalmated Sandpiper	0.0	0.5	0.5
Sharp-shinned Hawk	**36.5**	**36.8**	**36.8**
Short-eared Owl	0.9	7.1	7.1
Veery	**53.9**	**54.7**	**54.7**
Wood Thrush	**43.8**	**34.4**	**43.8**
Yellow-billed Cuckoo	12.4	17.7	17.7
Yellow-breasted Chat	0.0	2.5	2.5

A Comprehensive Status Assessment of Pennsylvania's Mammals for the 2025 State Wildlife Action Plan Update

Michael Scafini[1], Gregory Turner[1], Katelyn Otterbein, Ph.D.[1], Joshua Johnson, Ph.D.[2], Catherine D. Haffner[3], Nathan J. Zalik[3]

Pennsylvania Game Commission, [1]Wildlife Recovery Division, Protected Mammals Section; [2]Administration Division, Statistical Support Section; [3]Wildlife Recovery Division, Planning and Grants Administration Section

12 June 2026

Table of Contents

Introduction 1
Methods 2
  Data Sources 4
  Species Selection 4
  Range Extent 4
  Area of Occupancy 5
  Number of Occurrences 5
  Population Estimate 6
  Trends 6
  Threats Assessment 7
Results 8
  Special cases 12
Discussion 13
  Considerations for future assessments 14
Literature Cited 14
Appendix A 16

Introduction

The Pennsylvania Game Commission (PGC) manages and protects wildlife and their habitats, while promoting hunting and trapping, for this and future generations. To do this effectively, it is necessary to evaluate comprehensively at regular intervals wildlife population conservation statuses (or securement) in the state using well-established methods. In support of 2025-2035 Pennsylvania Wildlife Action Plan development, PGC worked with the Pennsylvania Biological Survey (PABS) Mammal Technical Committee (MTC) to review and comprehensively revise, as needed, conservation status assessments for all native, regularly occurring mammals in Pennsylvania.

Methods

We used NatureServe's Rank Calculator Version 3.2 (June 2020) for this analysis. NatureServe has developed two manuals critical to correctly using the rank calculator which covers the methodology and determination factors used by the calculator:

- NatureServe Conservation Status Assessments: Methodology for Assigning Ranks (Faber-Langendoen et al. 2012).
- NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk (Master et al. 2012).

Version 3.2 of the rank calculator weighs three primary factors in calculating the S-ranks: rarity, threats, and trends.

This method is meant to be as consistent and objective as possible, and applicable to all elements run through an assessment tool known as the Rank Calculator. We used Rank Calculator Version 3.2 to: 1) update mammal S-ranks for Pennsylvania Biological Survey (PABS) Mammal Technical Committee (MTC) discussion and vote, and 2) provide outputs for the 2025-2035 Pennsylvania Wildlife Action Plan (PA WAP) update (scheduled for completion in 2026).

The Rank Calculator is a Microsoft Excel-based spreadsheet which uses decision factors to determine extirpation or extinction risk. The Rank Calculator is designed to be used at multiple levels across a species' range, with those being at global, national, or subnational (state) level.

The Rank Calculator requires a minimum number of factors to be entered for a status rank to be assigned. Although more data yields stronger confidence in the calculator output, there is no confidence interval on the front end of the calculator, only a display showing whether the minimum number of factors have been entered. Although not all factors are *required* to produce a status rank, we used the best information readily available to conduct these analyses. We used the American Society of Mammalogist's Mammal Diversity Database to assign species taxonomic nomenclature, and then used multiple datasets, consulted with various PGC and other species experts, and used white and grey literature (favoring Pennsylvania-specific publications and reports) to help meet the minimum number of factors to evaluate Pennsylvania's mammal species with the Rank Calculator.

Rank Calculator Outputs and S-Rank Definitions

Five primary S-rank definitions are used by NatureServe to describe an elements risk of extirpation from a subnation (state):

S-rank	Description
S1	Critically Imperiled—At very high risk of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.
S2	Imperiled—At high risk of extirpation in the jurisdiction due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
S3	Vulnerable—At moderate risk of extirpation in the jurisdiction due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
S4	Apparently Secure—At a fairly low risk of extirpation in the jurisdiction due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
S5	Secure—At very low or no risk of extirpation in the jurisdiction due to a very extensive range, abundant populations or occurrences, with little to no concern from declines or threats.

Five other S-rank definitions are used where exceptions on species status are not covered by the primary factors:

SX = extirpated (virtually no likelihood of rediscovery).

SH = possibly extirpated (known only from historical occurrences, but still some hope of rediscovery).

- S#S# = range rank (used to indicate uncertainly about status, no more than 2 degrees of separation is considered valid).
- SU – unrankable (lack of data or conflicting information about status or trends).
- SNA = not applicable (species is not a suitable target for conservation activities. This is where non-native, or transient species should be assigned).

Merritt (1987) was used as the primary source for determining the subspecies of mammals found in Pennsylvania. Taxonomic changes (lumping) have occurred since Merritt was published, and therefore fewer subspecies were recognized for this revision than are recognized in Merritt (1987).

Following the general guidelines provided by NatureServe (Faber-Langendoen et al. 2012, Master et al. 2012), we considered spatial and trends analyses for 85 mammalian species and infraspecies (and for bat hibernacula). Data were available for 56 species; however, we determined that data for only 17 of these species were suitable for analysis. Previous data (PNHP 2013) were carried forward into this assessment for all other species. There were three time-periods under consideration (including breeding and year-round, migration, and nonbreeding) in which species could be categorized. Outputs included spatial and temporal metrics for inclusion in NatureServe Rank Calculators used in part to determine conservation status rank (i.e., S-rank).

Data Sources

For spatial and temporal analyses, we used either solely, or a combination of, the following data sources: Biotics (PNHP 2023), Pennsylvania Game Commission annual reports for specific species or communities (Boyd 2022, Nolder et al. 2022, Scafini 2022a,b), PGC Game Take and Furtaker surveys (Johnson 2022), PGC and academic institution research, and PGC bat and terrestrial mammal databases (Pennsylvania Game Commission, unpublished data). If data were either not available, insufficient, or resulted in spurious outcomes, we carried forward results from the 2013 conservation status assessment (Eichelberger and Wisgo 2014).

- Breeding Assessment: A combination of the above was used for the breeding assessment.
- Migration Assessment: A combination of the above was used for the migration assessment.
- Wintering Assessment: A combination of the above was used for the wintering assessment.

Species Selection

Breeding Assessment

In total, we assessed 83 year-round/breeding mammals to determine their status in Pennsylvania. For all species, the most recent ten years of data were used, e.g., 2014-2024. In addition, we conducted spatial analyses for four of these species, which included Allegheny woodrat, Appalachian cottontail, elk, and snowshoe hare. Allegheny woodrat data were from PGC and academic research/monitoring efforts. Appalachian cottontail and snowshoe hare data were from camera and live-trapping, fecal pellet genetics analysis, track transects (snowshoe hare only), and radio-telemetry research (snowshoe hare only). Elk data were from Pennsylvania Game Commission's elk management plan. Results for all species were reviewed by the PGC State Mammalogist before being entered into the Rank Calculator.

Migration Assessment

The status of all nine bat species known to occur within Pennsylvania was analyzed. This included six cave bats and three tree bats. However, we did not conduct spatial analyses for the migration period for any mammalian species due to insufficient data.

Wintering Assessment

The status of eight bat species known to occur within Pennsylvania during the winter was analyzed. This included all bat species except for Lasiurus cinereus (Hoary bat). In addition, we conducted spatial analyses for the nonbreeding period for the six cavernicolous bat species. Data was from the most recent ten years available (2014-2024). Spatial analyses were based on hibernacula locations.

Range Extent

Breeding Assessment

We used R package ConR (Dauby 2020, R Core Team 2022) to evaluate range extent for each species except elk. Elk spatial data were taken directly from the elk management plan (Banfield and Rosenberry 2020). Range extent in square kilometers was calculated via convex hull method (Bruce Young, personal communication). Results for all species were reviewed by the PGC State Mammalogist before being entered into the Rank Calculator.

Migration Assessment

We did not conduct spatial analyses for the migration period for any mammalian species due to insufficient data.

Wintering Assessment

We conducted spatial analyses for the nonbreeding period for six cavernicolous bat species using data from the most recent ten years (2013-2022). Spatial analyses were based on hibernacula locations.

Area of Occupancy

Breeding Assessment

We used R package ConR (Dauby 2020, R Core Team 2022) to evaluate area of occupancy (AOO) for each species except elk. Elk spatial data were taken directly from the elk management plan (Banfield and Rosenberry 2020). Area of occupancy was computed by calculating the area covered by the number of occupied cells of a 2-km grid. Analysis results were output as square kilometers and converted to numbers of 2-km (4-km^2) grid cells occupied for entry in the NatureServe Rank Calculator version 3.2 Excel workbook. Results for all species were reviewed by the PGC State Mammalogist before being entered into the Rank Calculator.

Migration Assessment

We did not conduct spatial analyses for the migration period for any mammalian species due to insufficient data.

Wintering Assessment

We conducted spatial analyses for the nonbreeding period for six cavernicolous bat species using data from the most recent ten years (2013-2022). Spatial analyses were based on hibernacula locations.

Number of Occurrences

Breeding Assessment

We used R package ConR (Dauby 2020, R Core Team 2022) to evaluate numbers of locations for each species except elk. Number of locations was calculated as the number of occupied cells in a 10-km grid. Results for all species were reviewed by the PGC State Mammalogist before being entered into the Rank Calculator.

Migration Assessment

We did not analyze any data for the number of occurrences during the migration period for any mammalian species due to insufficient data.

Wintering Assessment

We conducted analyses related to the number of occurrences during the nonbreeding period for six cavernicolous bat species using data from most recent ten years (2013-2022). Interior hibernacula count totals by species were used to determine the number of occurrences.

Population Estimate

Breeding Assessment: This information is typically not available for Pennsylvania's mammals, and no assessments included this factor.

Migration Assessment: This information is typically not available for Pennsylvania's mammals, and no assessments included this factor.

Wintering Assessment: This information is typically not available for Pennsylvania's mammals, and no assessments included this factor.

Trends

For most species, the short-term trend included data from the most recent 10 years data were available (2012–2023). Long-term trends were based on data from the most recent year for which data were available (2022 or 2023) to the oldest year for which data were available (1984 to 1990). Data sources included the Game Commission Game Take and Furtaker Surveys (both of which were compiled and standardized by effort and year; Johnson 2022), Allegheny woodrat site occupancy (calculated as the percent of sites surveyed within a given period that were occupied; Scafini 2022a), PGC bat hibernacula counts (Scafini 2022b), and the PGC elk management plan (Banfield and Rosenberry 2020). For Game Take and Furtaker survey data, along with Allegheny woodrat, we use a similar approach to Hill's (2014) assessment of avian species trends. We used three approaches to model trend data: linear, exponential, and 2nd-order polynomial. We used the model with the highest r-squared (or quasi-r-squared) value to calculate percent change over time (first year of analysis to final year of analysis) unless the model predicted ≥100% population decline by the final year of analysis. In those cases, the model with the next highest r-squared value was used. Percent change reflects modelled data values, not actual data inputs. For American black bear, elk, and bat hibernacula data, we used the percent difference between the most recent and the oldest count or estimate in the timeframe being considered. Following review by PGC biologists, trend data were entered into the Rank Calculator along with results of spatial analyses.

Breeding Assessment

The breeding and year-round period trends assessments included 13 species from Game Take and Furtaker surveys, and Allegheny woodrat. For the 13 species covered by Game Take and Furtaker surveys, the short-term trend analysis was based on harvest per unit effort from 2013-2022, with exception of porcupine, which was a more recent addition to the Game Take Survey in 2011. Porcupine short-term trend analysis was based on 2011-2022 data. Timeframe of short-term trends in Allegheny woodrat was 2013-2022. No long-term trends were calculated for species covered by the Furtaker Survey, as there are no long-term data to use to standardize harvest data. Long-term trend timeframe for species covered by the Game Take Survey was 1990-2022. Long-term trend timeframe for Allegheny woodrat was 1985-2022.

Migration Assessment

We did not conduct trends assessments for the migration period for any mammalian species.

Wintering Assessment

The nonbreeding assessment for trends analysis was limited to bat species, particularly hibernaculum counts for six caverniculous species. The primary data source for this analysis was PGC annual reports (Scafini 2022b). Short-term trends included data from 2013-2022. Long-term trends included data from 1985-2022. We used hibernaculum count data to calculate differences between the most recent year of count data and first year of count data for each of the two timeframes for each of the six species.

Threats Assessment

This factor category can be assessed through two routes; the threats table or a less rigorous intrinsic vulnerability level. The preferred method is to use the associated threats table to assess the scope, severity, and timing of threats to a species. Eleven threat categories may be evaluated for each species, including:

1) Residential and commercial development
2) Agriculture and aquaculture
3) Energy production and mining
4) Transportation and service corridors
5) Biological resource use
6) Human intrusions and disturbance
7) Natural system modifications
8) Invasive and other problematic species and genes
9) Pollution
10) Geologic events
11) Climate change and severe weather

These eleven categories are used to calculate an overall threat impact, ranging from *very high* to *low*. Each of these threat categories has a more specific set of factors beneath it. For example, energy production and mining threats (threat category 3) can be separately evaluated for potential impacts from the oil and gas industry, mining and quarrying, and/or renewable energy, and then averaged to get a threat assessment for the whole threat category.

The *scope* of the potential threat is to reflect what portion of a certain species population in Pennsylvania could be affected by a particular threat, and the *severity* of the threat is to reflect how serious the impact of that threat could be to those affected populations. Uncertainty ranges for scope and severity are also available in the calculator and used where professional opinions conflicted or there was a greater level of uncertainty. The threats table portion of the calculator incorporates a level of "best professional judgment", and this portion of the calculator was based on previous data, experiences, and realistic potential threats and population changes of experienced mammalogists (G. Turner and M. Scafini of PGC). Timing is considered an optional input in the threat assessment and proved to have little influence on the calculated overall threat impact output. We did not consistently use the timing input since it did not appear to have a significant influence (either positive or negative) on the calculated overall threat impact. Only one threat factor category needs to be completed to assign an overall threat impact. The most severe threat is the primary driver to the overall threat impact. For example, White-nose Syndrome (WNS) in the little brown bats (*Myotis lucifugus*) in Pennsylvania, was assigned a scope level of pervasive (affecting 71-100% of the population), and the severity level of extreme (causing mortality in 71-100% of the impacted population). Because WNS is so devastating to the little brown bat, the other threats that had lesser scope and severity could not alter the calculated overall threat impact of "very high". For those species that have no immediate known threats (the most severe threat has a scope or severity level considered "negligible"), the rank calculator does not provide a calculated overall threat impact. To force the rank calculator to provide a calculated overall threat impact, species for which the scope or severity of the most severe threat fit the definition of "negligible", were increased to "small", calculating the lowest available overall threat impact of "low".

Results

Taxonomy

Taxonomy changes occur for various reasons, such as new genetic information or maybe a more thorough review of species distribution or morphological differences. In some cases, changes may be suggested in a particular piece of literature but may not be more formally accepted yet by the broader community of scientists. We pursued taxonomic changes only where the broad community seemed to support and secondarily were noted as such in the mammal diversity database published by the American Society of Mammalogists. There are several species that have potential to change soon, but we took a conservative approach for changes listed in this document.

Taxonomic changes for Pennsylvania mammals in 2025 assessment:

Common Name	**2015 Scientific Name**	**2025 Scientific Name**
Fisher	*Martes pennanti*	*Pekania pennanti*
Southern red-backed vole	*Myodes gapperi*	*Clethrionomys gapperi*
American mink	*Neogale vison*	*Mustela vison*
Maryland shrew	*Sorex cinereus fontinalis*	*Sorex fontinalis*
Masked shrew	*Sorex cinereus cinereus*	*Sorex cinereus*
Eastern water shrew	*Sorex palustris albibarbis*	*Sorex albibarbis*
West Virginia water shrew	*Sorex palustris punctulatus*	*Sorex punctulatus*
Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*	*Ictidomys tridecemlineatus*

Notably, the water shrew (*Sorex palustris*) had two subspecies in Pennsylvania in 2015, with both *S.p. albibarbis (*Northern water shrew*)* and *S.p. punctulatus* (West Virginia water shrew) assessed. In 2025, the two had changes for both the scientific and common nomenclature, and each elevated to separate species status, so we assessed as such using the calculator. The scientific nomenclature has removed 'palustris' from its name. The Northern water shrew is now known as the Eastern water shrew (*Sorex albibarbis*), and the West Virgina water shrew is now known as *Sorex* *punctulatus.* There is some debate about this species and whether the newly suggested common name is accepted, so we left the common name as reported in 2015. A major part of the original reasoning for two subspecies in PA was due to the large distance between the two known areas harboring the species. However, field work in the past 15 years has identified many new locations and closed the gap from greater than 100 miles to less than 20 miles, clouding the picture. Recent work suggests the nomenclature change and further suggests they are two separate species. The question remaining is whether Pennsylvania truly has both, or just one. On-going work is currently examining genetic and morphological differences, but this work is not yet completed by the time of this publication, so both species are included in this plan. The work underway does seem to suggest that the West Virigina water shrew (S. punctulatus) does not actually exist within Pennsylvania, and the next assessment may likely remove this species from Pennsylvania.

Pennsylvania had three subspecies of the Fox Squirrel assessed in 2015, being *Sciurus niger* (Delmarva Fox Squirrel, *S.n. rufiventer* (Western Fox Squirrel) and *S. n. vulpinus* (Eastern Fox Squirrel) with all assessed through the rank calculator. *S. n. cinereus* (Delmarva Fox Squirrel), which was extirpated but experimentally reintroduced in the 1980's, has not been recorded in the state in over 40 years. This reintroduction effort is now thought to have failed, and the species is thought to now be extirpated (Dunn, 1989, Mike Steele, pers. comm.). We did not access the status of this twice extirpated species.

The MTC agreed at their 2013 Nov 16 meeting that the distinct morphological and ecological traits of the Prairie Deer Mouse (*Peromyscus maniculatus bairdii* sensu Merritt, 1987) warrant a separate status assessment for the subspecies. Accordingly, the MTC agreed to recognize the two other subspecies of Deer Mouse (*P.m. gracilis* and *P.m. nubiterrae*) following Merritt. In 2025, we have found no actual evidence that substantiates this claim, where the potential sub-species may occur, and thus no ecological value or management can target the species, so we concluded that an assessment was not warranted at this time.

<u>Conservation Statuses</u>

In the 2015 assessment, Wilson and Reeder's review of the Maryland Shrew (*Sorex fontinalis* sensu Merritt 1987) relegated this former species to a subspecies of the Masked Shrew (Sorex cinereus). The Mammal Diversity Database in 2025 changed these to distinct species as the Maryland Shrew (S. fontinalis) and the Masked Shrew (S. cinereus), and we assessed in 2025 as such. Lastly, the subspecies of elk native to Pennsylvania, previously considered to be *Cervus elaphus canadensis*, has long been considered extinct in Pennsylvania. However, the current consensus by elk biologists in the east (Padilla et al. 2023) now consider elk in Pennsylvania to be *Cervus elaphus*.

Status changes for this 2025 assessment had only minor changes since the last (Figure 1). There was a slight increase in the number of S3 and S4 species. This was attributed to *Myotis leibii*, *Myotis lucifugus*, *Perimyotis subflavus*, *Sylvilagus obscurus, Sylvilagus floridanus,* and *Neogale frenata* all becoming S3, and to *Condylura cristata* and *Mustela vison* changing rank to S4.

For Pennsylvania bat species, bat hibernacula changed from S1 to S2, become more secure as the threat from WNS lessens; big brown bats changed from S4 to S5, also becoming more secure; *Myotis leibii* went from S2 to S3, *Myotis lucifugus* from S1 to S2, and *Perimyotis subflavus* from S1 to S2, all becoming more secure by one rank. In contrast *Myotis septentrionalis* and *Myotis sodalis* both stayed as S1. In addition, *Nycticeius humeralis* (evening bat) was previously listed as an S2 in Pennsylvania but was changed to SNA since it is considered a non-native or transient species within the state. All three migratory bat species remained at their previous rank: *Lasionycteris noctivagans* (silver-haired bat) stayed as S1, while the Lasiurus borealis (eastern red bat) and *Lasiurus cinereus* (hoary bat) stayed at S4.

Additional species that changed ranks include: Peromyscus maniculatus bairdii (prairie deer mouse; S3S4 to S3S5) due to the uncertainty of its existence within the state and if subspecies status is warranted; *Lepus americanus* (snowshoe hare; S4 to S2), accounting for the largest rank change in all mammal species assessed; *Sylvilagus floridanus* (eastern cottontail; S1S2 to S3); *Sylvilagus obscurus* (Appalachian cottontail; S1S2 to S3); *Mustela frenata* (long-tailed weasel; S5 to S4); and *Spilogale putorius* (eastern spotted skunk; S2 to S1).

Breeding Assessment

Condylura cristata (star-nosed mole): changed from S5 to S4. This is due to many additional low-impact threats being considered for this species. *Cryptotis parva* (North American least shrew) stayed as an S1 between assessments. This species has a very limited range, only known to occur in southcentral PA, where its largest threat included predation by native species including raptors, Blarina spp., mesopredators, and snakes. Lesser threats include feral cat predation, fire suppression leading to succession of their preferred habitats, along with farming and development reducing available habitat. Extirpation risk of *Lepus americanus* (snowshoe hare) has increased from S4 (apparently secure) to S2 (imperiled). The largest threat to this species is climate change, with less snow in winter leading to color morph mismatch (Zimova et al. 2016), and declines in suitable habitats increasing their predation risk (Wilson et al. 2019). Other threats to this species include RHDV2 exposure, loss of early successional habitat (naturally or via removal by development, mining, etc.), and hunting pressure since they are included as a game species. *Sylvilagus obscurus* (Appalachian cottontail) has changed from an S1S2 to S3, which was a large improvement since the last assessment. The major threats to this species that remain include hunting, since they are lumped in with other cottontail species when it comes to bag limits, loss of suitable habitat from succession and other natural forces, and the introduction of other cottontails into Pennsylvania. *Peromyscus maniculatus bairdii* (prairie deer mouse) changed from S3S4 to S3S5. This S-rank range is due to little being known about this species, including its location, numbers, and presence within PA. *Spilogale putorius* (Alleghanian spotted skunk) changed from S2 to S1, with threats that include farming and mortality on roadways. This species is only known from one single location in Pennsylvania.

Migration Assessment

The threat considered to have the largest negative impact on our three migratory bat species *Lasionycteris noctivagan*s (silver-haired bat), *Lasiurus borealis (*eastern red bat), and *Lasiurus cinereus* (hoary bat) was determined to be renewable energy. Utility-scale wind projects are causing mortality in large numbers to these three species, plus mining and other energy development, such as utility-scale solar development, are reducing the availability of roosts. Various forms of development (housing, transportation corridors, commercial/industrial areas) were rated as having a negative impact on our five species of cave bats (non-migratory).

<u>*Wintering Assessment*</u>

We also evaluated threats to those five bat species that reside within Pennsylvania hibernacula during the winter months. It was determined that invasive/non-native species or diseases has the highest scope (pervasive) and severity (extreme or 71-100% population decline). This was attributed to the introduction of white-nose syndrome in the winter of 2008/09. This threat assessment was determined through a combination of personal observations and severe declines as noted in our winter bat hibernacula database. Of our cave bats, three species became more secure by changing their rank by one level: *Myotis leibii (*eastern small-footed bat*)*: S2 to S3, *Myotis lucifugus* (little brown bat*)*: S1 to S2, and *Perimyotis subflavus* (tricolored bat): S1 to S2). This is because of white-nose syndrome having stabilized after many years of extreme declines. These *Myotis* species and *Perimyotis subflavus* have shown some increases in numbers through summer maternity counts, mist-net captures and/or acoustics during summer, and winter hibernacula counts. *Lasiurus cinereus* (hoary bat), although staying as an S4 from last assessment, is at an unusually high incident rate of rabies (60% nationwide). Both species of flying squirrel stayed at their existing ranks (no change), however for *Glaucomys sabrinus macrotus* (N. Flying squirrel) invasive and other problematic species, genes, and diseases remain their largest threat. This includes hemlock wooly adelgid destroying their preferred hemlock forest habitats and increased hybridization and competition from S. flying squirrels (*Glaucomys volans*) as they move northward into *G.s.macrotus* habitat.

After this 2024 assessment, the most imperiled species in Pennsylvania, with S1 ranks, are currently:

Northern flying squirrel (*Glaucomys sabrinus*)

Least shrew *(Cryptotis parva*)

Northern long-eared bat (*Myotis septentrionalis*)

Indiana bat (*Myotis sodalis*)

Silver-haired bat (*Lasionycteris noctivagans*)

Alleghanian spotted skunk (*Spilogale putorius*)

The 2nd tier of most at-risk species (those now considered S2 rank) include:

Snowshoe hare (*Lepus americanus*)

Little brown bat (*Myotis lucifugus*)

Tricolored bat (*Perimyotis subflavus*)

Allegheny woodrat (*Neotoma magister*)

Eastern fox squirrel (*Sciurus niger*)

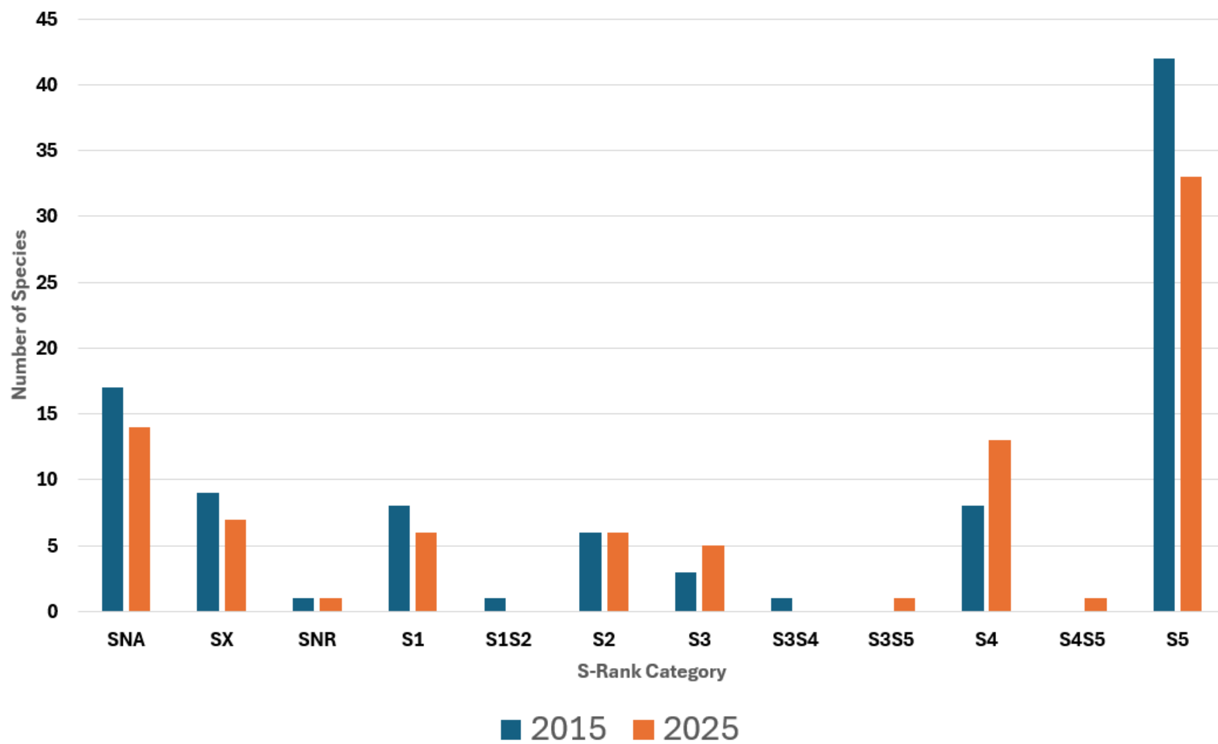


Figure 1. Number of Mammalian state conservation status (i.e., S-Rank) for 2015 and 2025.

Note: Specific information is available within completed Rank Calculator spreadsheets, on file with PGC and Pennsylvania Natural Heritage Program.

Special cases

For those species now thought to be extirpated from Pennsylvania, we entered Z (zero) for species range and number of occurrences, which assigns the appropriate S-rank of SX (extirpated). This list of extirpated species primarily followed Williams et al. (1985) except for those where reintroduction efforts have been successful (i.e. beaver, fisher). For those species considered transients (evening bat), waifs (West Indies manatee), deliberate non-native introductions (thirteen-lined ground squirrel), or invasive species (house mouse), an S-rank of SNA (not applicable) was assigned as these species should not be the target of conservation efforts. With concurrence from the Mammal Technical Committee, PNHP will update mammal conservation statuses in NatureServe Explorer.

Breeding Assessment

Cervus elaphus (elk) was not considered a different species than the western subspecies (*C. e. canadensis* and *C. e nelsoni*), and therefore those subspecies were not considered in this assessment. *Corynorhinus townsendii* (Townsend's big-eared bat) has no evidence of being present in the state and therefore was not assessed. *Puma concolor* (cougar) was not considered since it a western species and not found within Pennsylvania, with only the eastern subspecies (*Puma concolor couguar*) being considered extirpated in the state. Work by Hope et al. (2014) evaluated the taxonomy of North American water shrews (genus *Sorex*). The research led to the genetic validation of distinct, species-level clades previously grouped under the broad umbrella of *Sorex palustris.* Within Pennsylvania, when analyzing two of these subspecies, the overarching species was ignored and thus not assessed. This applied to the instance of *Sorex albibarbis* and *Sorex punctulatus*, which were analyzed for this WAP, but Sorex palustris was not. PGC research suggests that Pennsylvania does not have *S. punctulatus* (West Viriginia water shrew), but this research was not published in time for use in this assessment and was therefore included. This work suggests that we only have *S. albibarbis* within the state.

Migratory Assessment

For our long-distance migratory bat species, the ranks stayed the same as in 2015 due to the same persisting threats as last assessment. For all Pennsylvania bat species (both short and long-distance migratory movements) pressure due to increased development (residential, commercial, road, mining, etc.) continues to play a major role in their status assessment, reducing available habitat for these species.

Wintering Assessment

Although the threats from White-nose syndrome have lessened since its introduction into Pennsylvania in 2008/09, it persists in bat hibernacula and reinfects bats each winter. Although bats have learned to 'cope' with WNS to an extent (inhabiting colder areas of hibernacula where the Pd fungus does not grow as quickly) it is still a very real consideration, which is why we have continued to treat important hibernacula with polyethylene glycol (PEG)-8000 during this reporting period, as well as manipulate hibernacula to cool internal temperatures to give bats those preferred habitats where the Pd fungus does not grow as prolifically.

Discussion

The conservation status of all native Pennsylvanian mammals has previously been assessed using novel approaches (see Genoways 1985, Kirkland & Krim 1989, Kirkland & Krim 1990, Wright & Kirkland 1998), which are no longer supported. The strength of the NatureServe methodology comes from its continual evolution based on the best available science, and its ability to assess overall conservation status for all species, not just those closer to the risk of extinction. The NatureServe Rank Calculator is not meant to be a replacement for PGC's regulatory methodology for listing and delisting of species, rather it complements the detailed assessments completed by PABS using IUCN methodology for listing proposals. With a guiding principle of the Pennsylvania Wildlife Action Plan being to "keep common native species common," NatureServe S-ranks play an important role in evaluating the conservation status of all the state's native mammal species. In addition, NatureServe corrected an error in the previous (2014) calculator, which may explain some differences seen today.

Some interesting changes between the 2015 and 2025 assessments include:

- Two *Myotis* species (*Myotis lucifugus* and *Myotis leibii*), have both increased one level, from S1 to S2, and S2 to S3, respectively, along with *Perimyotis subflavus* (S1 to S2). This is largely due in part to slight increases in numbers as revealed in winter and summer counts, but also because of white-nose syndrome having passed its epidemic phase, and survivor bats finding ways to persist in the landscape.

- Snowshoe hare was the only mammal species to change two levels (S4 to S2), becoming much less secure within Pennsylvania, due to the threats mentioned above. However, *Sylvilagus floridanus* (eastern cottontail) and *Sylvilagus obscurus* (Appalachian cottontail) both changed from ‘critically imperiled/imperiled’ to ‘vulnerable’ (S1S2 to S3).

NatureServe’s Status Assessment methodology was originally developed in 1978, and has been continually refined since then, with the input factors being weighted at different levels based on the most current published scientific literature regarding species extinction risks. Version 3.2 places more of an emphasis on trends than previous versions of the rank calculator (G. Hammerson, pers. comm.).

Pennsylvania’s S-ranks for mammals had not been thoroughly assessed using this methodology prior to 2014; this methodology was used to assess species conservation status in preparation for the 2015-2025 Pennsylvania Wildlife Action Plan (PGC-PFBC 2015). Before that year, S-ranks appear to have been set by the MTC using other status assessment methodology and finding the closest match for the categories/definitions.

Considerations for future assessments

Future assessments should prioritize standardized methods, transparent documentation, and the integration of new data sources. Recommendations include incorporating data from PGC’s online SQL databases (Appalachian Bat Count and Bat Net & Trap, which includes all survey and capture data including acoustics) for bats to improve analyses of distribution, occupancy, and winter bat populations. It is also important to maintain notes on the rank calculator and its use to make this process reproducible in the future, without recreating the wheel. Efforts should also focus on improving population estimates for poorly monitored species, documenting expert-review decisions, and maintaining formal records of methodological changes between assessment cycles. Emerging data sources in Pennsylvania, especially bat acoustic monitoring, should be evaluated for future use. Finally, threat assessment frameworks should be reviewed regularly and applied consistently across habitat guilds while allowing species-specific adjustments. Together, these practices will improve consistency, transparency, and the ability to distinguish true biological change from shifts in data availability or analytical methods.

Literature Cited

Banfield, J. E., and C. S. Rosenberry. 2020. Pennsylvania elk management plan (2020-2025). Pennsylvania Game Commission, Harrisburg, PA.

Boyd, E. S., 2022. Snowshoe hare and cottontail rabbit research/management. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Dauby, G. 2020. ConR: Computation of parameters used in preliminary assessment of conservation status. R package 1.3.0 https://CRAN.R-project.org/package=ConR

Dunn, J.P. 1989. Translocation of Delmarva fox squirrels to Chester County, PA. Pennsylvania Game Com mission, Harrisburg, Pennsylvania, 13 pp.

Eichelberger, C., and J. Wisgo. 2014. A comprehensive status assessment of Pennsylvania's mammals, utilizing NatureServe ranking methodology and Rank Calculator Version 3.1 for application to the State Wildlife Action Plan update 2015. Unpublished report for Pennsylvania Game Commission, Harrisburg, PA.

Faber-Langendoen, D., J. Nichols, L. Master, K. Snow, A. Tomaino, R. Bittman, G. Hammerson, B. Heidel, L. Ramsay, A. Teucher, and B. Young. 2012. NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe, Arlington, VA.

Genoways, H.H., ed. 1985. Mammals *in* Genoways, H.H., and F.J. Brenner, eds. Species of special concern in Pennsylvania. Carnegie Mus. Nat. Hist., Pittsburgh, Pennsylvania, USA. 430 pp.

Hill, J. M. 2014. A comprehensive status assessment of Pennsylvania's avifauna for application to the State Wildlife Action Plan update 2015. Unpublished report for Pennsylvania Game Commission, Harrisburg, PA.

Hope, A. G., N. Panter, J. A. Cook, S. L. Talbot, D. W. Nagorsen. 2014. Multilocus phylogeography and systemic revision of North American water shrews (genus: *Sorex*). Journal of Mammalogy 95: 722-738

Johnson, J. B. 2022. Game take, furtaker, and spring turkey hunters surveys. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Kirkland, G.L., Jr., and J.A. Hart. 1999. Recent records for ten species of small mammals in Pennsylvania. Northeastern Naturalist 6:1-18.

Kirkland, G.L., Jr. and P.M. Krim. 1989. Survey of the statuses of the mammals of Pennsylvania. Final Report submitted to the Pennsylvania Wild Resource Conservation Fund, Harrisburg, Pennsylvania, USA. 194 pp.

Kirkland, G. L., Jr. and P.M. Krim. 1990. Survey of the statuses of the mammals of Pennsylvania. Journal of the Pennsylvania Academy of Science. 64:33-45.

Master, L. L., D. Faber-Langendoen, R. Bittman, G.A. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe, Arlington, VA.

Merritt, J. F. 1987. Guide to the mammals of Pennsylvania. University of Pittsburgh Press, Pittsburgh, Pennsylvania, USA. 408 pp.

Nolder, A., M. Scafini, and G. Turner. 2022. Summer bat concentration survey/Appalachian bat count. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Padilla, B. J., J. E. Banfield, A. Corondi, and J. L. Larkin. 2023. Seasonal variation and size and composition of elk (*Cervus canadensis*) home range in central Appalachia. Canadian Journal of Zoology 00:1-14.

Pennsylvania Natural Heritage Program (PNHP). 2023. Biotics 5. Western Pennsylvania Conservancy Natural Heritage Program, Pittsburgh, PA.

R Core Team. 2023. R: A language and environment for statistical computing. Version 4.3.1. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org

Scafini, M. 2022a. Allegheny woodrat surveys. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Scafini, M. 2022b. Indiana bat hibernacula surveys. Bureau of Wildlife Management Annual Report. Pennsylvania Game Commission, Harrisburg, PA.

Wilson, E.C., A.A. Shipley, B. Zuckerberg, M.Z. Peery, and J.N. Pauli. 2019. An experimental translocation identifies habitat features that buffer camouflage mismatch in snowshoe hares. Conservation Letters, Vol. 12, Issue 2, id.e12614, 8 pp,

Zimova, M., L.S. Mills, and J. J. Nowak. High fitness costs of climate change-induced camouflage mismatch. 2016. Ecology Letters, 19(3):299-307.

Appendix A

R Code for Spatial and Trends Analyses for Birds and Mammals

```
# R packages needed for analysis
ConR
dplyr
lubridate
MASS
modelr
rnaturalearth
rnaturalearthdata
tidyverse

### Code for Spatial analysis of Breeding season data; code for other seasons would be similar
# Generic code for importing raw observation data
data <- read.delim("Mammals.txt", sep='\t', header=T)
data$LAT <- as.numeric(data$LAT)
data$LONG <- as.numeric(data$LONG)

#Subset data excluding all but past 10 years of Breeding season data (raw data already labeled with column that indicated which season they were recorded)
Breed <-data %>% filter(data$Season=="b")
Breed <- Breed %>% filter (Breed$Year > 2012 & Breed$Year < 2024)

#Extract a certain species for analysis
BreedSp <-Breed %>% filter(Breed$SCI.NAME=="Perimyotis subflavus")

# Dates in raw eBird data were converted to day of year in Excel for subsetting seasons based on safe dates. Example is generic subset for Migration season analysis
Migr <- Breed %>% filter (Breed$DOY > 318 & Breed$DOY < 367 | Breed$DOY > 0 & Breed$DOY < 61)

#package ConR requires only Latitude, Longitude, and Species name for analysis, in that order
BreedSp2 <- BreedSp[,c(5,6,1)]

#Function that outputs EOO, AOO, Numbers of Locations, etc for spatial analysis
IUCN.eval(BreedSp2)


### Code for Trends analysis
# Import dataset
data <- read.delim("Gametake.txt", sep='\t', header=T)
```

```
#Subset data to extract a particular species

data2 <- data %>% filter (data$Species=="SYFL")

#Separate data into 2 time periods; 1 subset for long-term analysis, 1 subset for short-term analysis
data2 <- data2 %>% filter(data2$Year < 2024)
data2s <- data2 %>% filter(data2$Year > 2012)

#Plot long-term and short-term data for visual inspection
plot(Harvest.effort~Year, data=data2)
plot(Harvest.effort~Year, data=data2s)

#Model long-term and short-term data via linear regression
linl <- lm (Harvest.effort~Year, data=data2)
summary(linl)
lins<- lm (Harvest.effort~Year, data=data2s)
summary(lins)

# Model long-term and short-term data via 2nd order polynomial regression
polyl <- lm(Harvest.effort~poly(Year, 2), data=data2)
summary(polyl)
polys <- lm(Harvest.effort~poly(Year, 2), data=data2s)
summary(polys)

#Model long-term and short-term data via exponential regression
expl <- nls(Harvest.effort~exp(a+b*Year), data=data2, start=list(a=0,b=0))
summary(expl)
modelr::rsquare(expl, data=data2)

exps <- nls(Harvest.effort~exp(a+b*Year), data=data2s, start=list(a=0,b=0))
summary(exps)
modelr::rsquare(exps, data=data2s)

#Choose model with highest r-square value and fit the model to the data to estimate population percent increase or decrease over the given time period

#Linear long-term model
(linl$coef[1]+linl$coef[2]*max(data2$Year))/(linl$coef[1]+linl$coef[2]*min(data2$Year))

#Say the model above results in a value of 9.21, the population has increased by 821% [(9.21-1)*100]

#Linear short-term model
(lins$coef[1]+lins$coef[2]*max(data2s$Year))/(lins$coef[1]+lins$coef[2]*min(data2s$Year))

#Say the model above returns a value of 0.4855, then population has declined by ~51% over the given time period.
```

```
#2nd order polynomial long-term model
polyp <- lm(Harvest.effort ~ poly(Year, 2), data = data2); polyp.datc <- data.frame(Year =
seq(min(data2$Year), max(data2$Year), by = 1))
polyp.datc$yhat <- predict(polyp, polyp.datc)
View(polyp.datc)

#In the following code, insert the modelled value from the 1st year in the given time period (0.5015 in
this example)

polyp.datc$yhat[length(polyp.datc$yhat)]/(0.5015)

#The code above produces an output value of 0.6152, which indicates a population decrease of 38.5%
 (0.615-1)*100 = -38.5%.

#2nd order polynomial short-term model
polyp <- lm(Harvest.effort ~ poly(Year, 2), data = data2s)
polyp.datc <- data.frame(Year = seq(min(data2s$Year), max(data2s$Year), by = 1))
polyp.datc$yhat <- predict(polyp, polyp.datc)
View(polyp.datc)

#In the following code, the modelled value [1] from the 1st year in the given time period is inserted into
the following calculation
polyp.datc$yhat[length(polyp.datc$yhat)]/(polyp.datc$yhat[1])

#The code above produces a value of say, 0.1286; so 1 – 0.1286 = 0.8714, so a ~87% decrease over the
give time period

#Exponential long-term model

explp <-nls(Harvest.effort~exp(a+b*Year), data=data2, start=list(a=0,b=0))
explp.coef<-coef(explp)

#First and last years of modelled values are inserted into the following formula to calculate percent
increase or decrease in population over a given time period

(predict(explp, list(x = data2$Year))[55])/(predict(explp, list(x = data2$Year))[1])

#Exponential short-term model
expsp <-nls(Harvest.effort~exp(a+b*Year), data=data2s, start=list(a=0,b=0))
expsp.coef<-coef(expsp)

#First year modelled value is inserted into the following formula to calculate percent increase or
decrease in population over a given time period
tail(predict(expsp, list(x = data2s$Year)), n=1)/(predict(expsp, list(x = data2s$Year))[1])
```

A Comprehensive Status Assessment of Pennsylvania's Fishes for the 2025-35 Pennsylvania Wildlife Action Plan

Robert W. Criswell and Douglas P. Fischer

Pennsylvania Fish and Boat Commission
Division of Environmental Services
Natural Diversity Section

31 October 2025

Table of Contents

Introduction **2**
Methods **2**
Data Sources 4
Species Selection 4
Range Extent 4
Area of Occupancy 4
Number of Occurrences 5
Population Estimate 5
Trends 5
Threats Assessment 6
Results **6**
Discussion **7**
Considerations for future assessments 13
Literature Cited **13**

Introduction

Considerable effort has been invested over the past two decades toward the development of improved status determination and listing processes for Pennsylvania's species of conservation concern (Hassinger 2002). These processes, as they relate to fishes, have metamorphosed into a procedure whereby the Pennsylvania Biological Surveys (PABS) Fishes Technical Committee (FTC) provides status change recommendations to the Pennsylvania Fish and Boat Commission (PFBC), the agency with responsibility for conserving and managing the Commonwealth's fish taxa. These recommendations are based upon reviews of individual species and include consideration of expert opinion and objective criteria (PABS 2013). Status change recommendations are subsequently reviewed by PFBC and considered for further action.

As the fish listing process evolved, an increased emphasis has been placed on the use of objective criteria, such as those employed by the International Union for Conservation of Nature (Anonymous 2000). Along with objective listing criteria and federal or state regulatory conservation status classifications (i.e., endangered, threatened, candidate), the development and use of national (N-ranks) and subnational ("state") conservation ranks (S-ranks) have become an important element for conservation-related decision making and resource allocation. These S-rank designations are analogous to global conservation ranks (G-ranks) but consider a species' status within a specific political boundary rather than its global range (NatureServe 2012).

Our objectives were to review the current S-ranks of Pennsylvania's fishes and subsequently update rankings where necessary to reflect a change in a species' status. These S-ranks serve as the current status of fishes for use in the 2025-35 Pennsylvania Wildlife Action Plan (PA WAP).

Methods

Each fish species was evaluated using NatureServe Conservation Status Assessments: Rank Calculator Version 3.2 (https://www.natureserve.org/products/conservation-rank-calculator/download), henceforth referred to as "calculator."

This calculator was developed to increase the repeatability and transparency of the conservation ranking process. It considers ten status factors grouped within rarity, threats, and trend categories. The calculator computes a numeric score, based on weightings assigned to each factor and some conditional rules, which are then translated to a calculated status rank. This calculated rank is reviewed and adjusted if deemed appropriate (with justification for the reasons for adjustment) before it is recorded as the final assigned conservation status rank, or S-rank (Master et al. 2012). For the remainder of this report, rankings will be discussed in the context of "state" or S-ranks rather than "subnational" unit ranks.

In addition to the rank determinations provided by the calculator, expert opinion provided by PABS FTC members were considered in a few instances where additional unpublished/undocumented information was lacking.

Table 1: National (N) and Subnational (S) Conservation Status Ranks (Master et al. 2012)

Status	Definition

NX **SX**	**Presumed Extirpated**—Species or ecosystem is believed to be extirpated from the jurisdiction (i.e., nation, or state/province). Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered. [Equivalent to "Regionally Extinct" in IUCN Red List terminology]
NH **SH**	**Possibly Extirpated**—Known from only historical records but still some hope of rediscovery. There is evidence that the species or ecosystem may no longer be present in the jurisdiction, but not enough to state this with certainty. Examples of such evidence include (1) that a species has not been documented in approximately 20-40 years despite some searching and/or some evidence of significant habitat loss or degradation; (2) that a species or ecosystem has been searched for unsuccessfully, but not thoroughly enough to presume that it is no longer present in the jurisdiction.
N1 **S1**	**Critically Imperiled**—At very high risk of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.
N2 **S2**	**Imperiled**—At high risk of extirpation in the jurisdiction due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
N3 **S3**	**Vulnerable**—At moderate risk of extirpation in the jurisdiction due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
N4 **S4**	**Apparently Secure**—At a fairly low risk of extirpation in the jurisdiction due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
N5 **S5**	**Secure**—At very low or no risk of extirpation in the jurisdiction due to a very extensive range, abundant populations or occurrences, with little to no concern from declines or threats.

Variant National and Subnational Conservation Status Ranks

Rank	Definition
N#N# **S#S#**	**Range Rank**—A numeric range rank (e.g., S2S3 or S1S3) is used to indicate any range of uncertainty about the status of the species or ecosystem. Ranges cannot skip more than two ranks (e.g., SU is used rather than S1S4).
NU **SU**	**Unrankable**—Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.
NNR **SNR**	**Unranked**—National or subnational conservation status not yet assessed.
NNA **SNA**	Not Applicable—A conservation status rank is not applicable because the species or ecosystem is not a suitable target for conservation activities.[1]
Not Provided	Species or ecosystem is known to occur in this nation or state/province. Contact the relevant NatureServe network program for assignment of conservation status.

[1] A conservation status rank may not be applicable for some species, including long distance aerial and aquatic migrants, hybrids without conservation value, and non-native species or ecosystems

Data Sources

For species assessments and determinations, we used two primary sources: 1) the PFBC comprehensive fish collection database, which includes all fish records collected by PFBC staff (both game and non-game fishes) and Scientific Collector's Permit reports; and 2) review of *The Fishes of Pennsylvania* (Stauffer et al. 2016), published after submission of the 2015-25 PA WAP. This volume includes all records noted above (#1) through 2015 and provided a baseline for status comparisons between the two WAPs, along with maps detailing collections divided into three time periods – pre-1940, 1940-1989, and 1990-2015.

Data for anadromous fishes of the Delaware River and Delaware Estuary, as well as two Lake Erie species, were obtained primarily from fish stock status reports by multi-agency commissions. Lake Whitefish *Coregonus clupeaformis* and Burbot *Lota lota* data were obtained from the Lake Erie Coldwater Task Group report (2021). American Shad *Alosa sapidissima* data were obtained from the Atlantic States Marine Fisheries Commission (ASMFC) 2020 stock assessment. Data for river herrings – Alewife *Alosa pseudoharengus* and Blueback Herring *A. aestivalis* – were obtained from a river herring benchmark stock assessment report (ASMFC 2024). Data for Striped Bass *Morone saxatilis* were obtained from a 2022 Atlantic Striped Bass stock assessment update report (ASMFC 2023).

Species Selection

Only native occurrences, insofar as they could be identified and delimited, were considered in the ranking calculations. For example, Emerald Bowfin *Amia ocellicauda* is native to northwest Pennsylvania and is expanding in the Allegheny River (Stauffer et al. 2016). These occurrences are considered native (although the origin of the riverine specimens is open to debate); however, populations existing outside this original range and resulting from stocking, were not considered native.

A few native species, notably Lake Trout *Salvelinus namaycush* and Paddlefish *Polyodon spathula*, are extant but do not currently reproduce in Pennsylvania. Individuals or occurrences of both species are maintained by stocking. These species are ranked as SX (extirpated).

Range Extent

Due to the primarily lineal nature of fish occurrences in the commonwealth's waterways, the "range extent" factor was seldom utilized. A more accurate assessment of a species' status was available through the employment of the "area of occupancy" species grid cell counts. Range extent was only used in cases where "Z – no occurrences" or "U – unknown" applied.

Area of Occupancy

Factors used primarily within the rarity group included "area of occupancy" and "percent of area occupied with good viability/ecological integrity." The default measure of occupancy for lineal species (fishes) is 1 km^2 grid cells (Master et al. 2012).

There are many gaps in survey effort on the state's waterways. These data gaps result from topography (i.e., inaccessibility due to remoteness or terrain), legal access (i.e., posting, fencing), limited resources, and weather and water conditions during survey periods. Many species are more-or-less continuously distributed in many waterways and systems, yet even comprehensive surveys may fail to reflect this species distributional characteristic on a map or spreadsheet; therefore, it was necessary to make assumptions.

Generally, for a distribution gap >10 km, occurrences were measured separately; however, when such gaps were observed on a range map and it was obvious the species occurred throughout the section of waterway under consideration, a continuous measurement was made. Where gaps or single location records existed, the species was placed within one of the "movement group" classifications within PFBC's Core Polygon Specifications (D. Fischer in lit.) for upstream/downstream home range and movement, and the corresponding length was used as the area of occupancy measure.

Area of occupancy estimates were derived primarily from the data sources noted above. Where known data gaps existed, additional sources – including literature and experts familiar with a problematic species – were consulted. Estimates were based upon these consultations or our own field work.

Number of Occurrences

Two factors in this group include "Number of occurrences with good viability/ecological integrity" and "Percent area occupied with good viability/ecological integrity" both of which are equally weighted. Since there are practically no absolute numbers or population estimates available for Pennsylvania fish occurrences, only the second factor was employed.

Assignments were made based on informed opinion relating to environmental conditions, extant or expected threats, watershed conditions/health, land use practices, amount of protected land (state/national forests, state game lands, public and private park lands, etc.), and the apparent health of particular populations of fishes.

Population Estimate

No population estimates were available or attempted.

Trends

Population trends have the potential to exert significant influence on the outcome of a conservation rank. The calculator considers both short- and long-term trends. Short-term trends consider changes to a species' rarity factors within the past 10 years or three generations, whichever is longer. The long-term trend factor considers changes over the past *circa* 200 years.

For Pennsylvania's fishes, there are few standardized data collection programs or events that can be used to make a clear trend determination for either the past ten years or three generations. Additionally, many short-lived fishes experience significant variation in year-to-year abundance, further confounding the analysis of uncoordinated survey data (Trautmann 1981). Therefore, occurrence data generated as far back as 2010 were considered to identify short-term trends for individual species.

Determining long-term population trends for Pennsylvania fishes is challenging due to a lack of early records or reports. Historically, barriers to conducting comprehensive survey work were monumental and included a paucity or lack of transportation, effective sampling gear, efficient means of recording, preservation, and curating of specimens, financial resources, and trained personnel. As a result, early survey work was spotty, sporadic, and largely confined to developed areas and transportation corridors.

Short-term trend scores were assigned based on consultation with maps in Stauffer et al. (2016) compared with recent records in the PFBC database, consultations with experts currently or recently conducting survey work on certain species, and our own knowledge which included unpublished field data on fish species of concern that have been targeted in the past decade.

Most long-term trend assignments were either “G – relatively stable” or “U – unknown.” Informed assumptions regarding the historical 200-year lookback prescribed in the calculator and pre-colonial distributions of some species were considered, particularly those that remain common to abundant today, and those that were known to be common but suffered obvious catastrophic declines due to construction of dams, rampant, extended pollution, etc. Reports by Rafinesque (1820), Cope (1883), and Bean (1892) provided some limited insight into pre-1900 distributions.

Threats Assessment

Threat categories largely follow Salafsky et al. (2008).

Results

For this evaluation we considered a total of 228 taxa including 222 recognized species, two undescribed forms, and four subspecies (as well as their nominate forms). Of this total, 20 species were determined to be introduced into Pennsylvania waters and were therefore classified as SNA (not applicable).

Further, problematic records exist from the Pennsylvania portion of the Delaware River Estuary. The 26 species accounting for these records are primarily marine and/or estuarine forms that move up and down the estuary depending on chloride concentrations generally dictated by river flow rates river (Horwitz 1986). A determination was made that only one of these species, Inland Silversides *Menidia beryllina* is a regular spawner in Pennsylvania waters and is accorded an S-rank. The other taxa are considered irregular, accidental, or non-breeders, and thus beyond the Commonwealth’s ability to apply any significant conservation measures. These species were designated as SNA.

The remaining taxa were evaluated using the rank calculator.

Generally, threats did not impact rankings for species that are common and widespread, and apparently secure, unless they were serious. However, for some species threat determination was slightly more problematic.

Water temperature increases have the potential to impact nearly all of Pennsylvania’s fauna. Predictions on the timing and severity of impacts vary considerably (Issak and Rieman 2013; Kaushal et al. 2010; Pennsylvania State University 2013; and Sievert et al. 2022). The scope of consideration for threats for the calculator is 10-20 years (Master et al. 2012), but some latitude is available for the climate change factor. Considering the fact that S-ranks are updated frequently, a 25-year benchmark was utilized during this project. This temporal perspective, along with more moderate recent predictions, resulted in low or, rarely, moderate threat levels, and then only to fishes requiring cold-water habitats at lower elevations and/or headwaters. It is believed that predicted changes during this time period may reduce flows and/or elevate temperatures to a level that would negatively impact or extirpate some populations.

To assess decadal changes, we compared the 2014 S-rank results with the current (2024) assessments (Table 2).

Table 2. Comparison of 2014 and 2024 Pennsylvania fishes S-ranks.

RANK	S1	S1S2	S2	S2S3	S3	S3S4	S4	S4S5	S5	SU	SH	SX	SNA	SNR
2014	16	0	10	0	6	0	46	2	69	14	1	20	47	0

2024	14	2	8	0	8	2	43	0	74	4	0	29	44	0

Discussion

There are few notable changes in fish S-ranks between 2014 and 2024 (Table 2). These results differ from prior changes observed between the 2004 and 2014 assessments, when the number of S1 through S2S3 species decreased from 42 to 26. The prior improvement illustrated a true reduction in endangerment for Pennsylvania fishes, reflecting improved water quality (particularly in the impounded sections of the Ohio River drainage), increased sampling effort, and an improved status determination process (Criswell 2014). The total number of species assigned ranks S1 through S3 (n = 32) remains unchanged from 2014-2024 and appears to indicate stable overall conditions.

The most critically imperiled fishes in Pennsylvania continue to be the Northern Brook Lamprey *Ichthyomyzon fossor* and Longnose Sucker *Catostomus catostomus*. The former occupies a very small range confined to Conneaut Creek and a single tributary in Erie County. The Northern Brook Lamprey is threatened by continued periodic lampricide treatments along sections of its historical distribution (Stauffer et al. 2016; PFBC data).

The Longnose Sucker has apparently continued to decline in its spotty distribution in the Casselman River drainage. This species is under potential threat from agricultural and forestry effluents, as well as increased water temperatures (Stauffer et al. 2016; PFBC data).

Table 3. S-ranks for species assessed in 2014 and 2024. Nomenclature follows Page et al. (2023).

S-Rank 2014	S-Rank 2024	Scientific Name	Common Name	Family
S4	S4	*Ichthyomyzon bdellium*	Ohio Lamprey	Petromyzontidae
S1	S1	*Ichthyomyzon fosor*	Northern Brook Lamprey	Petromyzontidae
S4	S4	*Ichthyomyzon greeleyi*	Mountain Brook Lamprey	Petromyzontidae
SU	SX	*Ichthyomyzon unicuspis*	Silver Lamprey	Petromyzontidae
S4	S4	*Lampetra aepyptera*	Least Brook Lamprey	Petromyzontidae
S4	S4	*Lethenteron appendix*	American BrooK Lamprey	Petromyzontidae
S4	S5	*Petromyzon marinus*	Sea Lamprey	Petromyzontidae
S2	S2	*Acipenser brevirostrum*	Shortnose Sturgeon	Acipenseridae
S1	S1	*Acipenser fulvescens*	Lake Sturgeon	Acipenseridae
S2	S2	*Acispenser oxyrinchus*	Atlantic Sturgeon	Acipenseridae
SX	SX	*Scaphirynchus platorynchus*	Shovelnose Sturgeon	Acipenseridae
SX	SX	*Polyodon spathula*	Paddlefish	Polyodontidae
S1	S1	*Lepisosteus oculatus*	Spotted Gar	Lepisosteidae
S5	S5	*Lepisosteus osseus*	Longnose Gar	Lepisosteidae
SX	SX	*Lepisosteus platostomus*	Shortnose Gar	Lepisosteidae
S4	S4	*Amia ocellicauda*	Emerald Bowfin	Amiidae
SNA	SNA	*Elops saurus*	Ladyfish	Elopidae
S5	S4	*Anguilla rostrata*	American Eel	Anguillidae

SX	SX	*Hiodon alosoides*	Goldeye	Hiodontidae
S4	S4	*Hiodon tergisus*	Mooneye	Hiodontidae
SNA	SNA	*Anchoa mitchilli*	Bay Anchovy	Engraulidae
S3	S3	*Alosa aestivalis*	Blueback Herring	Alosidae
S4	S4	*Alosa chrysochloris*	Skipjack Herring	Alosidae
S2	SU	*Alosa mediocris*	Hickory Shad	Alosidae
S3	S3	*Alosa pseudoharengus*	Alewife	Alosidae
S4	S3	*Alosa sapidissima*	American Shad	Alosidae
SNA	SNA	*Brevoortia tyrannus*	Atlantic Menhaden	Alosidae
S5	S5	*Dorosoma cepedianum*	Gizzard Shad	Dorosomatidae
S4	S4	*Carpiodes carpio*	River Carpsucker	Catostomidae
S5	S5	*Carpiodes cyprinus*	Quillback	Catostomidae
SU	SX	*Carpiodes velifer*	Highfin Carpsucker	Catostomidae
S1	S1	*Catostomus catostomus*	Longnose Sucker	Catostomidae
S5	S5	*Catostomus commersonii*	White Sucker	Catostomidae
SX	SX	*Cycleptus elongatus*	Blue Sucker	Catostomidae
S4	S4	*Eriomyzon elongatus*	Eastern Creek Chubsucker	Catostomidae
SX	SX	*Eriomyzon sucetta*	Lake Chubsucker	Catostomidae
S5	S5	*Hypentelium nigricans*	Northern Hogsucker	Catostomidae
S5	S5	*Ictiobus bubalus*	Smallmouth Buffalo	Catostomidae
S1	S1	*Ictiobus cyprinellus*	Bigmouth Buffalo	Catostomidae
SU	S4	*Ictiobus niger*	Black Buffalo	Catostomidae
S2	S2	*Minytrema melanops*	Spotted Sucker	Catostomidae
S5	S5	*Moxostoma anisurum*	Silver Redhorse	Catostomidae
S5	S5	*Moxostoma breviceps*	Smallmouth Redhorse	Catostomidae
S4	S5	*Moxostoma carinatum*	River Redhorse	Catostomidae
S5	S5	*Moxostoma duquesnii*	Black Redhorse	Catostomidae
S5	S5	*Moxostoma erythrurum*	Golden Redhorse	Catostomidae
S5	S5	*Moxostoma macrolepidotum*	Shorthead Redhorse	Catostomidae
SNA	SNA	*Carassius auratus*	Goldfish	Cyprinidae
SNA	SNA	*Cyprinus carpio*	Common Carp	Cyprinidae
SNA	SNA	*Ctenopharyngodon idella*	Grass Carp	Xenocyprinidae
SU	SX	*Alburnops blennius*	River Shiner	Leuciscidae
S1	S1	*Alburnops chalybaeus*	Ironcolor Shiner	Leuciscidae
G5	S5	*Campostoma anomalum*	Central Stoneroller	Leuciscidae
S1	S1	*Chrosomus eos*	Northern Redbelly Dace	Leuciscidae
S2	S2	*Chrosomus erythrogaster*	Southern Redbelly Dace	Leuciscidae
SNA	SNA	*Chrosomus oreas*	Mountain Redbelly Dace	Leuciscidae
S4	S4	*Clinostomus elongatus*	Redside Dace	Leuciscidae
S4	S4	*Clinostomus funduloides*	Rosyside Dace	Leuciscidae
S4	S4	*Cyprinella analostana*	Satinfin Shiner	Leuciscidae

S5	S5	*Cyprinella spiloptera*	Spotfin Shiner	Leuciscidae
S5	S5	*Ericymba buccata*	Silverjaw Minnow	Leuciscidae
S2	S1S2	*Ericymba dorsalis*	Bigmouth Shiner	Leuciscidae
S5	S5	*Erimystax dissimilis*	Streamline Chub	Leuciscidae
SU	SX	*Erimystax x-punctatus*	Gravel Chub	Leuciscidae
S4	S4	*Exoglossum laurae*	Tonguetied Minnow	Leuciscidae
S5	S5	*Exoglossum maxillingua*	Cutlip Minnow	Leuciscidae
S5	S5	*Hudsonius hudsonius*	Spottail Shiner	Leuciscidae
SNA	SNA	*Hybognathus hankinsoni*	Brassy Minnow	Leuciscidae
SNR	SX	*Hybognathus nuchalis*	Mississippi Silvery Minnow	Leuciscidae
S4	S4	*Hybognathus regius*	Eastern Silvery Minnow	Leuciscidae
S3	S3	*Hybopsis amblops*	Bigeye Chub	Leuciscidae
SNA	SNA	*Leucicus idus*	Ide	Leuciscidae
S5	S5	*Luxilus chrysocephalus*	Striped Shiner	Leuciscidae
S5	S5	*Luxilus cornutus*	Common Shiner	Leuciscidae
S2	S2	*Lythrurus umbratilis*	Redfin Shiner	Leuciscidae
S4	S4	*Macrhybopsis storeriana*	Silver Chub	Leuciscidae
S4	S4	*Margariscus margarita*	Allegheny Pearl Dace	Leuciscidae
S1	S1	*Miniellus heterodon*	Blackchin Shiner	Leuciscidae
S4	S3S4	*Miniellus procne*	Swallowtail Shiner	Leuciscidae
S5	S5	*Miniellus stramineus*	Sand Shiner	Leuciscidae
S1	S1	*Nocomis biguttatus*	Hornyhead Chub	Leuciscidae
S5	S5	*Nocomis micropogon*	River Chub	Leuciscidae
S5	S5	*Noteimgonus crysoleucas*	Golden Shiner	Leuciscidae
S4	S4	*Notropis amoenus*	Comely Shiner	Leuciscidae
SX	SX	*Notropis ariommus*	Popeye Shiner	Leuciscidae
S5	S5	*Notropis atherinoides*	Emerald Shiner	Leuciscidae
S1	S1	*Notropis bifrenatus*	Bridle Shiner	Leuciscidae
SU	S1	*Notropis heterolepis*	Blacknose Shiner	Leuciscidae
S5	S5	*Notropis photogenis*	Silver Shiner	Leuciscidae
S5	S5	*Notropis rubellus*	Rosyface Shiner	Leuciscidae
SU	S1	*Opsopoeodus emiliae*	Pugnose Minnow	Leuciscidae
SU	S3	*Paranotropis buchanani*	Ghost Shiner	Leuciscidae
S5	S5	*Paramotropis volucellus*	Mimic Shiner	Leuciscidae
S4	S4	*Paranotropis wickliffi*	Channel Shiner	Leuciscidae
S5	S5	*Pimephales notatus*	Bluntnose Minnow	Leuciscidae
S4	S4	*Pimephales promelas*	Fathead Minnow	Leuciscidae
SX	SX	*Pimephales vigilax*	Bullhead Minnow	Leuciscidae
S5	S5	*Rhinichthys atratulus*	Blacknose Dace	Leuciscidae
S5	S5	*Rhinichthys cataractae*	Longnose Dace	Leuciscidae
SNR	S5	*Rhinichthys obtusus*	Western Blacknose Dace	Leuciscidae

SNA	SNA	*Scardinius erythropthalmus*	Rudd	Leuciscidae
S5	S5	*Semotilus atromaculatus*	Creek Chub	Leuciscidae
S5	S5	*Semotilus corporalis*	Fallfish	Leuciscidae
S3	S3	*Ameiurus catus*	White Catfish	Ictaluridae
SU	SX	*Ameiurus melas*	Black Bullhead	Ictaluridae
S5	S5	*Ameiurus natalis*	Yellow Bullhead	Ictaluridae
S5	S5	*Ameiurus nebulosus*	Brown Bullhead	Ictaluridae
SX	SX	*Ictalurus furcatus*	Blue Catfish	Ictaluridae
S5	S5	*Ictalurus punctatus*	Channel Catfish	Ictaluridae
S4	S4	*Noturus eleutherus*	Mountain Madtom	Ictaluridae
S5	S5	*Noturus flavus*	Stonecat	Ictaluridae
S1	S1	*Noturus gyrinus*	Tadpole Madtom	Ictaluridae
S5	S5	*Noturus insignis*	Margined Madtom	Ictaluridae
S2	S2	*Noturus miurus*	Brindled Madtom	Ictaluridae
S4	S4	*Noturus stigmosus*	Northern Madtom	Ictaluridae
S5	S5	*Pylodictis olivaris*	Flathead Catfish	Ictaluridae
S4	S4	*Esox americanus americanus*	Redfin Pickerel	Esocidae
S4	S4	*Esox americanus vermiculatus*	Grass Pickerel	Esocidae
S4	S4	*Esox lucius*	Northern Pike	Esocidae
S4	S4	*Esox masquinongy*	Muskellunge	Esocidae
S5	S5	*Esox niger*	Chain Pickerel	Esocidae
SNA	SNA	*Esox reichertii*	Amur Pike	Esocidae
S4	S4	*Umbra limi*	Central Mudminnow	Esocidae
S3	S4	*Umbra pygmaea*	Eastern Mudminnow	Esocidae
SU	SX	*Coregonus artedi*	Cisco	Salmonidae
S4	S3S4	*Coregonus clupeaformis*	Lake Whitefish	Salmonidae
SNA	SNA	*Onchorhynchus gobuscha*	Pink Salmon	Salmonidae
SNA	SNA	*Onchorhynchus kisutch*	Coho Salmon	Salmonidae
SNA	SNA	*Onchorhynchus mykiss*	Rainbow Trout	Salmonidae
SNA	SNA	*Onchorhynchus nerka*	Sockeye Salmon (Kokanee)	Salmonidae
SNA	SNA	*Onchorrhynchus tshawytscha*	Chinook Salmon	Salmonidae
SNA	SNA	*Salmo salar*	Atlantic Salmon	Salmonidae
SNA	SNA	*Salmo trutta*	Brown Trout	Salmonidae
S4	S3S4	*Salvelinus fontinalis*	Brook Trout	Salmonidae
SX	SX	*Salvelinus namaycush*	Lake Trout	Salmonidae
SX	SX	*Osmerus mordax*	Rainbow Smelt	Osmeridae
S5	S5	*Percopsis omiscomaycus*	Trout-perch	Percopsidae
SX	SX	*Aphredoderus sayanus*	Pirate Perch	Aphredoderidae
S3	S3	*Lota lota*[a]	Burbot[a]	Gadidae
S2	S3	*Lota sp. of. lota*[a]	Allegheny Burbot[a]	Gadidae
SNA	SNA	*Opsanus tau*	Oyster Toadfish	Batrachoididae

SNA	SNA	*Pomatomus saltatrix*	Bluefish	Pomatomidae
SNA	SNA	*Gobiosoma bosc*	Naked Goby	Gobiidae
SNA	SNA	*Neogobius melanostomus*	Round Goby	Gobiidae
SNA	SNA	*Proterorhinus semilunaris*	Freshwater Tubenose Goby	Gobiidae
SNA	SNA	*Channa argus*	Northern Snakehead	Channidae
SNA	SNA	*Trachinotus carolinus*	Florida Pompano	Carangidae
SNA	SNA	*Scophthalmus aquosus*	Windowpane	Scophthalmidae
SNA	SNA	*Etropus microstomus*	Smallmouth Flounder	Cyclopsettidae
SNA	SNA	*Paralichthys dentatus*	Summer Flounder	Paralichthyidae
SNA	SNA	*Pseudopleuronectes americanus*	Winter Flounder	Pleuronectidae
SNA	SNA	*Trinectes maculatus*	Hogchoker	Achiridae
SNA	SNA	*Oreochromis aureus*	Blue Tilapia	Cichlidae
S5	S5	*Labidesthes sicculus*	Brook Silverside	Atherinopsidae
SNA	SNA	*Membras martinica*	Rough Silverside	Atherinopsidae
S4	S4	*Menidia beryllina*	Inland Silverside	Atherinopsidae
SNA	SNA	*Menidia menidia*	Atlantic Silverside	Atherinopsidae
S5	S5	*Fundulus diaphanus diaphanus*	Eastern Banded Killifish	Fundulidae
SU	SU	*Fundulus diaphanus menona*	Western Banded Killifish	Fundulidae
S5	S5	*Fundulus heteroclitus*	Mummichog	Fundulidae
SNA	SNA	*Fundulus majalis*	Striped Killifish	Fundulidae
SNA	SNA	*Cyprinodon variegatus*	Sheepshead Minnow	Cyprinodontidae
SNA	SNA	*Gambusia affinis*	Western Mosquitofish	Poeciliidae
SNA	SNA	*Gambusia holbrooki*	Eastern Mosquitofish	Poeciliidae
SNA	SNA	*Strongylura marina*	Atlantic Needlefish	Belonidae
SNA	SNA	*Tylosuarus ocus*	Atlantic Agujon	Belonidae
SX	SX	*Acantharchus pomotis*	Mud Sunfish	Centrarchidae
S5	S5	*Ambloplites rupestris*	Rock Bass	Centrarchidae
SX	SX	*Enneacanthus chaetodon*	Blackbanded Sunfish	Centrarchidae
S4	S4	*Enneacanthus gloriosus*	Bluespotted Sunfish	Centrarchidae
SH	SX	*Enneacanthus obesus*	Banded Sunfish	Centrarchidae
S5	S5	*Lepomis auritus*	Redbreast Sunfish	Centrarchidae
S5	S5	*Lepomis cyanellus*	Green Sunfish	Centrarchidae
S5	S5	*Lepomis gibbosus*	Pumpkinseed	Centrarchidae
S3	S4	*Lepomis gulosus*	Warmouth	Centrarchidae
SU	SU	*Lepomis humilis*	Orangespotted Sunfish	Centrarchidae
S5	S5	*Lepomis macrochirus*	Bluegill	Centrarchidae
S1	S1	*Lepomis megalotis*	Longear Sunfish	Centrarchidae
SNA	SNA	*Lepomis microlophus*	Redear Sunfish	Centrarchidae
SNR	SX	*Lepomis peltastes*	Northern Sunfish	Centrarchidae
S5	S5	*Micropterus dolomieu*	Smallmouth Bass	Centrarchidae
S4	S4	*Micopterus punctulatus*	Spotted Bass	Centrarchidae

S5	S5	*Micropterus nigricans*	Largemouth Bass	Centrarchidae
S5	S5	*Pomoxis annularis*	White Crappie	Centrarchidae
S5	S5	*Pomoxis nigromaculatus*	Black Crappie	Centrarchidae
S5	S5	*Cottus bairdii*	Mottled Sculpin	Cottidae
S4	S4	*Cottus caeruleomentum*	Blue Ridge Sculpin	Cottidae
S5	S5	*Cottus cognatus*	Slimy Sculpin	Cottidae
S4	S4	*Cottus girardi*	Potomac Sculpin	Cottidae
SX	SX	*Cottus ricei*	Spoonhead Sculpin	Cottidae
S2	S2	*Cottus sp. cf. cognatus*	Checkered Sculpin	Cottidae
SX	SX	*Myoxocephalus thompsonii*	Deepwater Sculpin	Psychrolutidae
S5	S5	*Morone americana*	White Perch	Moronidae
S5	S5	*Morone chrysops*	White Bass	Moronidae
S4	S4	*Morone saxatilis*	Striped Bass	Moronidae
S1	S1S2	*Ammocrypta pellucida*	Eastern Sand Darter	Percidae
S5	S5	*Etheostoma blennioides*	Greenside Darter	Percidae
S5	S5	*Etheostoma caeruleum*	Rainbow Darter	Percidae
S2	S1	*Etheostoma exile*	Iowa Darter	Percidae
S5	S5	*Etheostoma flabellare*	Fantail Darter	Percidae
SX	SX	*Etheostoma fusiforme*	Swamp Darter	Percidae
S5	S5	*Etheostoma nigrum*	Johnny Darter	Percidae
S5	S5	*Etheostoma olmstedi*	Tessellated Darter	Percidae
S5	S5	*Etheostoma variatum*	Variegate Darter	Percidae
S5	S5	*Etheostoma zonale*	Banded Darter	Percidae
S4S5	S4	*Nothonotus camurus*	Bluebreast Darter	Percidae
S4	S4	*Nothonotus maculatus*	Spotted Darter	Percidae
S4	S4	*Nothonotus tippecanoe*	Tippecanoe Darter	Percidae
S5	S5	*Perca flavescens*	Yellow Perch	Percidae
S1	S2	*Percina bimaculata*	Chesapeake Logperch	Percidae
S5	S5	*Percina caprodes caprodes*	Ohio Logperch	Percidae
SNR	S4	*Percina caprodes semifasciata*	Northern Logperch	Percidae
S5	S5	*Percina copelandi*	Channel Darter	Percidae
S4	S4	*Percina evides*	Gilt Darter	Percidae
S4	S5	*Percina macrocephala*	Longhead Darter	Percidae
S5	S5	*Percina maculata*	Blackside Darter	Percidae
SX	SX	*Percina oxyrhynchus*	Sharpnose Darter	Percidae
S5	S5	*Percina peltata*	Shield Darter	Percidae
S4	S4	*Percina shumardi*	River Darter	Percidae
S4	S4	*Sander canadensis*	Sauger	Percidae
S5	S5	*Sander vitreus vitreus*	Walleye	Percidae
SX	SX	*Sander vitreus glaucus*	Blue Pike	Percidae
SNA	SNA	*Lutjanus griseus*	Gray Snapper	Lutjanidae

S5	S5	*Aplodinotus grunniens*	Freshwater Drum	Sciaenidae
SNA	SNA	*Bairdiella chrysoura*	Silver Perch	Sciaenidae
SNA	SNA	*Cynoscion regalis*	Weakfish	Sciaenidae
SNA	SNA	*Leiostomus xanthurus*	Spot	Sciaenidae
SNA	SNA	*Micropogonias undulatus*	Atlantic Croaker	Sciaenidae
SU	SU	*Apeltes quadracus*	Fourspine Stickleback	Gasterosteidae
S4	S4	*Culaea inconstans*	Brook Stickleback	Gasterosteidae
S1	SX	*Gasterosteus aculeatus*	Threespine Stickleback	Gasterosteidae

N = Native **X = Native but extirpated** **I = Introduced**

[a]Synonyms: Burbot-Lake Erie Population, *Lota lota* population 3; Burbot-Allegheny River Population, *Lota lota* population 4 (NatureServe 2025).

S-ranks generated for this evaluation were reviewed by the PABS Fishes Technical Committee and accepted/approved with minor revisions by unanimous vote on 19 March 2024.

Considerations for future assessments

No comments are provided at this time.

Literature Cited

Anonymous. 2000. IUCN red list categories and criteria. Version 3.1. Second edition. International Union for Conservation of Nature, Geneva, Switzerland.

Atlantic States Marine Fisheries Commission (ASMFC). 2024. River herring benchmark stock assessment and peer review report. Atlantic States Marine Fisheries Commission, Arlington, VA.

Atlantic States Marine Fisheries Commission. 2023. 2022 Atlantic Striped Bass stock assessment update report. Atlantic States Marine Fisheries Commission, Arlington, VA.

Atlantic States Marine Fisheries Commission. 2020. 1010 American Shad benchmark stock assessment and peer review report. Atlantic States Marine Fisheries Commission, Arlington, VA.

Bean, T. H. 1892. The fishes of Pennsylvania, with descriptions of the species and notes on the common names, distribution, habits, reproduction, rate of growth, and mode of capture. Report of the State Commissioner of Fisheries (1889-1891). Official document 19. Harrisburg, PA.

Cope, E. D. 1883. The fishes of Pennsylvania. Report of the State Commissioner of Fisheries, for the years 1881 and 1882. Harrisburg, PA.

Criswell, R. W. 2014. A revision of the state conservation ranks of Pennsylvania's fishes. Unpublished report to PA Fish and Boat Commission and PA Game Commission.

Hassinger, J. 2002. Final Report – Status determination and regulatory listing. Grant WRCF-28-04/4100021222. Unpublished report to Wild Resource Conservation Fund.

Issak, D. J., and B. E. Rieman. 2013. Stream isotherm shifts from climate change and implications for distributions of ectothermic organisms. Global Change Biology 19:742-751

Kaushal, S. S., G. E. Likens, N. A. Jaworski, M. L. Pace, A. M. Sides, D. Seekell, K. T. Belt, S. H. Secor, and R. L. Wingate. 2010. Rising stream and rivers temperatures in the United States. Frontiers in Ecology and the Environment 8(9):461-466.

Lake Erie Coldwater Task Group. 2022. 2021 report of the Lake Erie Coldwater Task Group, March 2022. Presented to the Standing Technical Committee, Lake Erie Committee, Lake Erie Committee of the Great Lakes Fishery Commission, Ann Arbor, Michigan, USA.

Master, L. L., D. Faber-Langendoen, R. Bittman, G. A. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe, Arlington, VA.

NatureServe 2012. NatureServe Conservation Status Assessment: Rank Calculator Version 3.x. 2012. NatureServe, Arlington, VA. Online at www.natureserve.org/ explorer/ranking.htm.

NatureServe 2025. NatureServe Explorer. NatureServe, Arlington, VA. https://explorer.natureserve.org/Search, Accessed March 2025.

Page, L. M., and many authors. 2023. Common and scientific names of fishes from the United States, Canada, and Mexico, 8th edition. American Fisheries Society Special Publication 37.

Pennsylvania Biological Survey. 2013. The species listing process – status determination and regulatory listing in Pennsylvania. http://www.pabiologicalsurvey.org/the-species-listing-process.html

Pennsylvania State University. 2013. Pennsylvania Climate Impacts Assessment Update. Unpublished report to PA Dept. of Environmental Protection.

Rafinesque, C. S. 1820. Ichthyologia Ohioensis, or natural history of fishes inhabiting the Ohio River and its tributary streams, preceded by a physical description of the Ohio and its branches. W. G. Hunt, Lexington, KY.

Sievert, N., C. Paukert, J. Whittier, W. Daniel, D. Infante, and J. Stewart. 2022. Projected stream fish community risk to climate impacts in the Northeastern and Midwestern United States. Ecological Indicators 144 (2022) 109493.

Stauffer, J. R., Jr., R. W. Criswell, and D. P. Fischer. 2016. The Fishes of Pennsylvania. Cichlid Press, El Paso, TX. 556 pp.

A Comprehensive Status Assessment of Pennsylvania's Amphibians and Reptiles for the 2025-35 Pennsylvania Wildlife Action Plan

Brandon M. Ruhe[1,2], Christopher A. Urban[3], and Katharine D. Gipe[3]

[1] *The Mid-Atlantic Center for Herpetology and Conservation*

[2] *Terracon Consultants, Inc.*

[3] *Pennsylvania Fish and Boat Commission*
Division of Environmental Services
Natural Diversity Section

March 31, 2026

Table of Contents

Introduction 2
Methods 3
Data Sources 4
Species Selection 4
Range Extent 5
Area of Occupancy 5
Number of Occurrences 5
Population Estimate 5
Trends 6
Threats Assessment 6
Results 6
Discussion 6
Considerations for future assessments 8
Literature Cited 9

Introduction

The status of Pennsylvania's reptiles and amphibians is updated for the State Wildlife Action Plan (SWAP). Species status updates are vetted through taxonomic-specific technical committees of the Pennsylvania Biological Survey (PABS). PABS is a non-governmental committee of professional and amateur biologists that are experienced in dealing with Pennsylvania's floral and faunal biodiversity. Pennsylvania natural resource agencies use PABS as an independent scientific advisor for matters related to biodiversity. The Amphibian and Reptile Technical Committee (ARTC) will review these status updates and forward the document to the PFBC for consideration.

Listing efforts have modernized in recent decades with less reliance on arbitrary opinion and an increased reliance on objective criteria, particularly as guided by the International Union for Conservation of Nature (Anonymous 2000). Along with objective listing criteria and federal or state regulatory conservation status classifications (i.e., endangered, threatened, candidate), the development and use of national (N-ranks) and subnational ("state") conservation ranks (S-ranks) have become an important element for conservation-related decision making and resource allocation. These S-rank designations are analogous to global conservation ranks (G-ranks) but consider a species' status within a specific political boundary rather than its global range (NatureServe 2012).

Methods

Pennsylvania's herpetofauna status updates are generated through the compilation of information collected by the Pennsylvania Amphibian and Reptile Survey (PARS) and various historical and state sources of information, including data held by the Pennsylvania Natural Heritage Program. PARS is both a herpetological atlas project and a data repository maintained by The Mid-Atlantic Center for Herpetology and Conservation as a joint project with the Pennsylvania Fish and Boat Commission. Status updates for each species are generated by evaluation of PARS data via use of a NatureServe Conservation Status Assessments Rank Calculator (Version 3.2) tool (NatureServe 2020; Faber-Langendoen et al. 2012), henceforth referred to as "calculator."

This calculator was developed to increase the repeatability and transparency of the conservation ranking process. It considers ten status factors grouped within rarity, threats, and trend categories. The calculator computes a numeric score, based on weightings assigned to each factor and some conditional rules, which are then translated to a calculated status rank. This calculated rank is reviewed and adjusted if deemed appropriate (with justification for the reasons for adjustment) before it is recorded as the final assigned conservation status rank, or S-rank (Master et al. 2012). For the remainder of this report, rankings will be discussed in the context of "state" or S-ranks rather than "subnational" unit ranks (Table 1). In addition to the rank determinations provided by the calculator, expert opinion provided by PABS ARTC members were considered in a few instances where unpublished information was available or species information was lacking.

Table 1: National (N) and Subnational (S) Conservation Status Ranks (Master et al. 2012)

Status	Definition

NX **SX**	**Presumed Extirpated**—Species or ecosystem is believed to be extirpated from the jurisdiction (i.e., nation, or state/province). Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered. [Equivalent to "Regionally Extinct" in IUCN Red List terminology]
NH **SH**	**Possibly Extirpated**—Known from only historical records but still some hope of rediscovery. There is evidence that the species or ecosystem may no longer be present in the jurisdiction, but not enough to state this with certainty. Examples of such evidence include (1) that a species has not been documented in approximately 20-40 years despite some searching and/or some evidence of significant habitat loss or degradation; (2) that a species or ecosystem has been searched for unsuccessfully, but not thoroughly enough to presume that it is no longer present in the jurisdiction.
N1 **S1**	**Critically Imperiled**—At very high risk of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.
N2 **S2**	**Imperiled**—At high risk of extirpation in the jurisdiction due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
N3 **S3**	**Vulnerable**—At moderate risk of extirpation in the jurisdiction due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
N4 **S4**	**Apparently Secure**—At a fairly low risk of extirpation in the jurisdiction due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
N5 **S5**	**Secure**—At very low or no risk of extirpation in the jurisdiction due to a very extensive range, abundant populations or occurrences, with little to no concern from declines or threats.

Variant National and Subnational Conservation Status Ranks

Rank	Definition
N#N# **S#S#**	**Range Rank**—A numeric range rank (e.g., S2S3 or S1S3) is used to indicate any range of uncertainty about the status of the species or ecosystem. Ranges cannot skip more than two ranks (e.g., SU is used rather than S1S4).
NU **SU**	**Unrankable**—Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.
NNR **SNR**	**Unranked**—National or subnational conservation status not yet assessed.
NNA **SNA**	Not Applicable—A conservation status rank is not applicable because the species or ecosystem is not a suitable target for conservation activities.[1]
Not Provided	Species or ecosystem is known to occur in this nation or state/province. Contact the relevant NatureServe network program for assignment of conservation status.

Data Sources

The primary data source we used for the analysis was the PARS database (www.paherpsurvey.org). Since 2013, PARS has collected approximately 220,000 amphibian and reptile observations (including almost 33,000 Species of Greatest Conservation Need records) from over 3,000 citizen scientists via an active herpetofauna atlas. These high-quality data include clear voucher photographs and recordings, point locations, and are quality controlled via expert verification committees of herpetologists. The PARS database additionally includes historical Pennsylvania collections information from over 100 repositories around the world. As a result, PARS is the largest database for amphibian and reptile collections in the world. Prior to PARS, the standard for amphibian and reptile distribution in Pennsylvania was McCoy (1982). This source was consulted to ensure that historical distributions were accurately reflected in area calculations.

Species Selection

All Pennsylvania native reptile and amphibian species or infraspecies (subspecies, distinct population segments, etc.) were evaluated via the NatureServe Conservation Status Assessments: Rank Calculator Version 3.2 (calculator), as created by NatureServe (2020). Common and scientific names conform to the recommendations of the Society for the Study of Amphibians and Reptiles (2025). Species not native (e.g. Red-eared Slider) to Pennsylvania were not analyzed. Species that are native to Pennsylvania but suspected to have been moved outside of their natural range in the Commonwealth (e.g. Northern Map Turtle), were included in the analysis.

Range Extent

Range Extent, or Extent of Occurrence (EOO), is defined by IUCN (2001) as follows:

"*…the area contained within the shortest continuous imaginary boundary that can be drawn to encompass all the known, inferred, or projected sites of present occurrence of a taxon or ecosystem, excluding cases of vagrancy. While this measure may exclude discontinuities or disjunctions within the overall distribution of a taxon or type (e.g., large areas of obviously unsuitable habitat), such exclusions are discouraged except in extreme cases because these disjunctions and outlying occurrences accurately reflect the extent to which a large range size reduces the chance that the entire population of the taxon will be affected by a single threatening process. Risks are spread by the existence of outlying or disjunct occurrences irrespective of whether the range extent encompasses significant areas of unsuitable habitat*."

EOO is effectively the smallest created polygon in which all or an organism's populations are located within its entire geographic range. We calculated EOO by inputting amphibian and reptile point data into IUCN's Geospatial Conservation Assessment Tool (https://geocat.iucnredlist.org/) Range Extent tool.

Area of Occupancy

Area of Occupancy (AOO) is an arbitrarily-derived standard measurement created by IUCN to determine the minimum amount of area in a landscape required for an organism to persist (2001). AOO is utilized for core habitat designations and areas that are not utilized for core natural history functions are not included in the calculations. We calculated AOO by inputting amphibian and reptile point data into IUCN's Geospatial Conservation Assessment Tool (https://geocat.iucnredlist.org/) via creation of 4 km^2 grid cells.

For two aquatic species (Eastern Hellbender and Mudpuppy), we determined AOO by the creation of 1 km^2 linear cells as upland portions of the landscape are not useful as a distribution metric.

Number of Occurrences

The IUCN defines a location or occurrence of a taxon as a “geographically or ecologically distinct area where a single threatening event can affect all individuals of a species” (2001). An occurrence is not based upon the population biology of a taxon, but rather the susceptibility of a population, or populations, to a single threat such as a specific fire or drought. The number of occurrences was calculated using a GIS analysis that grouped observations based on the NatureServe species account separation distances prior to counting occurrences. The number of species occurrences were categorically assigned scores (e.g., “A” = 1-5 occurrences, “B” = 6- 20 occurrences, etc.) based upon NatureServe methodology (Master et al. 2012).

Population Estimate

Meaningful population estimates have not been conducted for amphibian and reptile species in Pennsylvania, and thus, were not used in this analysis.

Trends

Short- and long-term population trends are unknown for Pennsylvania’s herpetofauna; therefore, this factor was not used.

The PARS project significantly refined the process due to the amount of data available for review. Most species remained within the same ranking as found in 2014. Modest changes (e.g. S2S3 to S3) were noted for most species that had a rank status change. The SWAP analysis has indicated that several of Pennsylvania’s amphibians and reptiles continue on a trajectory towards critical imperilment or potential extirpation. Two frogs of the genus *Pseudacris* (*P. kalmi* and *P. triseriata*) are now considered historical species and may be extirpated from Pennsylvania, as are *Clonophis kirtlandii* and *Pseudotriton montanus montanus*.

Threats Assessment

Threats assessments largely followed those of Ruhe et al. (2015) and are taxa or habitat specific threats in most instances.

Results

Eighty-three Pennsylvania reptiles and amphibians were analyzed using the NatureServe rank calculator (Table 2). Changes from the previous (2014) analysis were noted in Table 3.

Table 2. S-ranks for species assessed in 2014 and 2024. Nomenclature follows SSAR (2025).

S-Rank 2014	S-Rank 2024	Scientific Name	Common Name
S1	S1	*Acris crepitans*	Eastern Cricket Frog

S3S4	S3S4	*Agkistrodon contortrix*	Copperhead
S3	S3S4	*Ambystoma jeffersonianum*	Jefferson Salamander
S1	S1S2	*Ambystoma laterale*	Blue-spotted Salamander
S4	S4	*Ambystoma maculatum*	Spotted Salamander
S3	S3	*Ambystoma opacum*	Marbled Salamander
SX	SX	*Ambystoma tigrinum*	Eastern Tiger Salamander
S5	S5	*Anaxyrus americanus americanus*	Eastern American Toad
S3S4	S2S3	*Anaxyrus fowleri*	Fowler's Toad
S2	S2	*Aneides aeneus*	Green Salamander
SX	SX	*Apalone mutica mutica*	Midland Smooth Softshell
S4	S4	*Apalone spinifera spinifera*	Northern Spiny Softshell
S2	S2S3	*Carphophis amoenus amoenus*	Wormsnake
S5	S5	*Chelydra serpentina*	North American Snapping Turtle
S5	S5	*Chrysemys picta marginata*	Midland Painted Turtle
S5	S5	*Chrysemys picta picta*	Eastern Painted Turtle
S3S4	S3	*Clemmys guttata*	Spotted Turtle
SH	SH	*Clonophis kirtlandii*	Kirtland's Snake
S5	S4S5	*Coluber constrictor constrictor*	Northern Black Racer
S3S4	S3S4	*Crotalus horridus*	Timber Rattlesnake
S2S3	S3	*Cryptobranchus alleganiensis alleganiensis*	Eastern Hellbender
S5	S5	*Desmognathus fuscus*	Northern Dusky Salamander
S3S4	S4	*Desmognathus monticola*	Northern Seal Salamander
S5	S5	*Desmognathus ochrophaeus*	Allegheny Mountain Dusky Salamander
S5	S5	*Diadophis punctatus edwardsii*	Northern Ring-necked Snake
S1	S3S4	*Dryophytes chrysoscelis*	Cope's Gray Treefrog
S4	S5	*Dryophytes versicolor*	Gray Treefrog
S1	S1	*Emydoidea blandingii*	Blanding's Turtle
S5	S5	*Eurycea bislineata*	Northern Two-lined Salamander
S5	S5	*Eurycea longicauda longicauda*	Long-tailed Salamander
S3S4	S3S4	*Glyptemys insculpta*	Wood Turtle
S2	S2	*Glyptemys muhlenbergii*	Bog Turtle
S4	S4	*Graptemys geographica*	Northern Map Turtle
S4	S4	*Gyrinophilus porphyriticus porphyriticus*	Northern Spring Salamander
S4	S5	*Hemidactylium scutatum*	Four-toed Salamander
S3S4	S3	*Heterodon platirhinos*	Eastern Hog-nosed Snake
S1	S1	*Kinosternon subrubrum subrubrum*	Southeastern Mud Turtle
SNA	SX	*Lampropeltis getula*	Eastern Kingsnake
S5	S5	*Lampropeltis triangulum*	Milksnake
S5	S5	*Lithobates catesbeianus*	North American Bullfrog
S5	S5	*Lithobates clamitans*	North American Green Frog
S1	S1	*Lithobates kauffeldi*	Atlantic Coast Leopard Frog

S5	S5	*Lithobates palustris*	Pickerel Frog
S2S3	S2S3	*Lithobates pipiens*	Northern Leopard Frog
S1	S1	*Lithobates sphenocephalus utricularius*	Coastal Plain Leopard Frog
S4	S4	*Lithobates sylvaticus*	Wood Frog
S3	S3S4	*Necturus maculosus*	Mudpuppy
S5	S5	*Nerodia sipedon sipedon*	Northern Watersnake
S5	S5	*Notophthalmus viridescens viridescens*	Red-spotted Newt
S1S2	S1	*Opheodrys aestivus*	Northern Rough Greensnake
S4	S4	*Opheodrys vernalis*	Smooth Greensnake
S5	S5	*Pantherophis alleghaniensis*	Central Ratsnake
S3	S3	*Plestiodon anthracinus anthracinus*	Northern Coal Skink
S4	S4	*Plestiodon fasciatus*	Eastern Five-lined Skink
S2	S2	*Plestiodon laticeps*	Broad-headed Skink
S5	S5	*Plethodon cinereus*	Eastern Red-backed Salamander
S2S3	S2S3	*Plethodon electromorphus*	Northern Ravine Salamander
S5	S5	*Plethodon glutinosus*	Northern Slimy Salamander
S4	S4	*Plethodon hoffmani*	Valley and Ridge Salamander
S4	S4	*Plethodon wehrlei*	Wehrle's Salamander
S2	S1S2	*Pseudacris brachyphona*	Mountain Chorus Frog
S5	S5	*Pseudacris crucifer*	Spring Peeper
S1	S1	*Pseudacris feriarum*	Upland Chorus Frog
S1	SH	*Pseudacris kalmi*	New Jersey Chorus Frog
S1	SH	*Pseudacris triseriata*	Western Chorus Frog
S2S3	S3	*Pseudemys rubriventris*	Northern Red-bellied Cooter
S1	SH	*Pseudotriton montanus montanus*	Eastern Mud Salamander
S5	S5	*Pseudotriton ruber ruber*	Northern Red Salamander
S3S4	S3S4	*Regina septemvittata*	Queensnake
S2S3	S2S3	*Scaphiopus holbrookii*	Eastern Spadefoot
S3	S4	*Sceloporus undulatus*	Eastern Fence Lizard
S1	S1	*Sistrurus catenatus*	Eastern Massasauga
S4	S4	*Sternotherus odoratus*	Eastern Musk Turtle
S5	S5	*Storeria dekayi*	Dekay's Brownsnake
S5	S5	*Storeria occipitomaculata*	Red-bellied Snake
S3S4	S3S4	*Terrapene carolina carolina*	Woodland Box Turtle
S4	S4	*Thamnophis brachystoma*	Short-headed Gartersnake
S3	S3	*Thamnophis sauritus*	Ribbonsnake
S3	S3	*Thamnophis sauritus sauritus*	Eastern Ribbonsnake
S3	S3	*Thamnophis sauritus septentrionalis*	Northern Ribbonsnake
S5	S5	*Thamnophis sirtalis sirtalis*	Eastern Gartersnake
S3	S3	*Virginia valeriae pulchra*	Mountain Earthsnake
S1	S1	*Virginia valeriae valeriae*	Eastern Smooth Earthsnake

Table 3. Comparison of 2014 and 2024 Pennsylvania amphibian and reptile S-ranks.

RANK	S1	S1S2	S2	S2S3	S3	S3S4	S4	S4S5	S5	SU	SH	SX	SNA	SNR
2014	13	1	5	5	9	9	13	0	24	0	1	2	1	0
2024	9	2	3	5	10	8	13	1	25	0	4	3	0	0

Discussion

Overall, the amphibian and reptile status list changed very little from 2014 to 2024. While a modest decrease in the number of S1 taxa was observed (from 13 to 9), this was, in part, due to the relegation of several species to an SH ranking (*Psuedacris kalmi, P. triseriata, Pseudotriton montanus montanus*).

Notes on increased status change decreasing imperilement within the last 10 years

Ambystoma jeffersonianum (S3 to S3S4). There are comparatively few sites relative to the other more common Ambystomid species in PA. They are a habitat specialist that reside in fishless ephemeral pools and occupied sites are typically isolated, scattered, and fragmented. However, *A. jeffersonianum* are not found in high densities like Spotted Salamanders and other S4 species.

Ambystoma laterale (S1 to S1S2). One more occurrence/metapopulation added in recent years of unknown quality and extent of population through all habitat areas. All occurrences remain under threat by roads, residential and commercial development, agriculture and recent illegal collection events documented.

Carphophis amoenus amoenus (S2 to S2S3). PARS records increased within the last 10 years. Records in new counties were documented, but overall, still relatively few records exist for the species statewide.

Cryptobranchus alleganiensis alleganiensis (S2S3 to S3). The number of PNHP and PARS records have doubled in the last 10 years, including many county records and recent confirmation of historical records; however, threats remain high.

Desmognathus monticola (S3S4 to S4). This species appears to be stable within a limited geographic range; previous concerns about declines due to natural gas exploration were not realized.

Hemidactylium scutatum (S4 to S5). Increased records and distribution for this species documented in the last 10 years mostly due to the active herp atlas (PARS).

Dryophytes chrysoscelis (S1 to S3S4). This is one of the largest increases in the 10-year analysis. This species was newly discovered in Pennsylvania in 2013 and occupied five 4-km^2 grids-. The number of occurrences have increased significantly since then (91 4-km^2 grid cells,2024). Part of the increase in number of occurrences can be attributed to a new awareness of the distinction of this species from *D. versicolor*, but *D. chrysoscelis* appears to be spreading in the east from Delaware.

Dryophytes versicolor (S4 to S5). This increase is likely due to an increase in information from the PARS project, e.g., 150 km^2 grid cells (2013) to 748 km^2 grid cells (2024).

Necturus maculosus (S3 to S3S4). This number of records has doubled over the last 10 years.

Pseudemys rubriventris (S2S3 to S3). More records collected in PARS/PNHP within the last 10 years; however, threats are still high, e.g., roads, subsidized predators, residential and commercial development, poaching of juveniles.

Sceloporus undulatus (S3 to S4). This increase is due to increased PARS records in the last 10 years.

Notes on decreased status change over the last 10 years

Anaxyrus fowleri (S3S4 to S2S3). This species moved down from its 2014 rank (S3S4) due to widespread collapse on the edge of its range. This collapse is likely due to residential and commercial development, habitat fragmentation, simplification of habitats that lead to hybridization with *Anaxyrus americanus americanus.*

Clemmys guttata (S3S4 to S3). The calculated rank has a broad range based on uncertainty of the range and threats, but the occurrence data is relatively robust. Unfortunately, many sites are isolated and under threat from habitat alteration, poaching.. This species is targeted for poaching due to its high value in the black market.

Coluber constrictor constrictor (S5 to S4S5). This species has a fairly large home range in PA; however, it is susceptible to fragmentation and road mortality.

Heterodon platirhinos (S3S4 to S3). This species has lost counties of occurrence in western PA (Indiana, Allegheny, Erie, Somerset Counties), potentially due to reforestation (i. edge, open habitat species).

Opheodrys aestivus (S1S2 to S1). Two questionable historical counties with occurrence records were eliminated from this analysis and resulted in a status change. .

Pseudacris brachyphona (S2 to S1S2). This species has relatively few extant occurrences and suffers high disturbance threats due to nearly all sites occurring on disturbed or altered landscapes (gameland roads, trails, etc.). Significant parts of the Chestnut and Laurel Ridges have not been adequately surveyed.

Pseudacris kalmi (S1 to SH). This species was already considered critically imperiled within PA. In 2014 there was only one known extant occurrence. After repeated surveys at this site, *P. kalmi* have not been confirmed and the site is considered extirpated.

Pseudacris triseriata (S1 to SH). Two occurrences were considered extant in 2014; after repeated visits to these sites no observations have been reported.

Pseudotriton montanus montanus (S1 to SH). This species is possibly extirpated in PA. No specimens have been observed since 1995, and the known, historical sites appear to be degraded.

Considerations for future assessments

Taxa-specific surveys should continue for Pennsylvania's rare amphibians and reptiles that are not protected via state or federal regulations, as many of these taxa suffer from a lack of information. The NatureServe calculator seems to serve its purpose well, though the process is difficult to calibrate and still, ultimately, relies on "expert" opinion. Threats weigh heavily in the analysis and an absence or overestimation of threats can significantly impact taxa rank outcomes. The occurrence of climate change is not disputed, however, the impacts on specific amphibian and reptile taxa is unknown. If future analyses include climate change results from analysis in the NatureServe Climate Change Calculator, the process should be vetted through a peer-review of climate scientists, landscape ecologists, and herpetologists. Additionally, limitations in our understanding of amphibian and reptile life history should be openly recognized.

Literature Cited

Faber-Langendoen, D., Nichols, J., Master, L.L., Snow, K., Tomaino, A., Bittman, R., Hammerson, G.A., Heidel, B., Ramsay, L., Teucher, A., and B. Young. 2012. NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe, Arlington, Virginia.

IUCN. 2001. IUCN Red List categories and criteria: Version 3.1. Prepared by IUCN Species Survival Commission. World Conservation Union, Gland, Switzerland and Cambridge, United Kingdom. Ii + 30 pp.

Master, L.L., Faber-Langendoen, D., Bittman, R., Hammerson, G.A., Heidel, B., Ramsay, L., Snow, K., Teucher, A., and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe, Arlington, Virginia.

McCoy, C. J. 1982. Amphibians and reptiles in Pennsylvania: Checklist, bibliography, and atlas of distribution. Pittsburgh, Pennsylvania: Carnegie Museum of Natural History.

NatureServe. 2020. NatureServe Conservation Status Assessments: Rank Calculator Version 3.2 . NatureServe, Arlington, VA. Online at https://www.natureserve.org/conservation-tools/data-maps-tools/conservation-rank-calculator

Ruhe, B. M., C, Urban, and K. Gipe. 2014. A Revision of the State Conservation Ranks of Pennsylvania's Herpetofauna. PA SWAP Analysis. 2015-2025 Pennsylvania State Wildlife Action Plan.

Society for the Study of Amphibians and Reptiles. 2025. Scientific and Standard English Names of Amphibians and Reptiles of North America North of Mexico, With Comments Regarding Confidence in Our Understanding. SSAR Herpetological Circular. 9th edition.

A Comprehensive Status Assessment of Pennsylvania's Crayfishes for the 2025-35 Pennsylvania Wildlife Action Plan

David A. Lieb, Ph.D.

Pennsylvania Fish and Boat Commission
Division of Environmental Services
Natural Diversity Section

9 November 2025

Table of Contents

Introduction **2**

Methods **2**

Data Sources 2

Species Selection 2

Range Extent 3

Area of Occupancy 3

Number of Occurrences 3

Population Estimate 3

Trends 3

Threats Assessment 4

Results **4**

Discussion **5**

Considerations for future assessments 7

Literature Cited 7

Introduction

The State Wildlife Grant (SWG) Program is a congressionally sponsored initiative whose objective is to provide all 50 states with funding to conserve and manage the terrestrial and aquatic species that occur within their borders. Funding is received on an annual basis and every 10 years each state is required to produce a State Wildlife Action Plan (SWAP) which is a comprehensive document that provides each state with detailed strategies (road maps) for the conservation, management, and protection of the wildlife species that occur within their respective borders. One of the major components of the SWAP is a detailed state ranking (S-rank) of each of the state's species, although some species cannot be ranked due to insufficient data. S-ranks are one of the principal ways in which Species of Greatest Conservation Need (SGCN) are identified. Species with low S-ranks (S1-S3) are considered imperiled and at risk of extinction within the state. SGCN species which typically have low S-ranks are prioritized for conservation action in the SWAP due to their extinction risk.

In Pennsylvania's first SWAP completed in 2005, SGCN species of high conservation value were determined according to experts' best professional judgment (Rawlins 2007). In the 2015 SWAP, all SGCN species from the original plan, plus selected additional species, were evaluated against explicit standard criteria in the PA Wildlife Action Plan (PA WAP) SGCN flow chart. One of the key criteria used to distinguish SGCN species in the flowchart was S-rank with species ranked S1-S3 receiving SGCN status. In the 2025 PA WAP once again a flow chart utilizing standard criteria was utilized to identify SGCN species and a key component of the flow chart was S-rank. As was done in 2015, S-ranks will be determined using the latest edition of the NatureServe Rank Calculator. In this report we provide a detailed account of this process and the resultant S-ranks for most of Pennsylvania's native crayfish species.

Methods

Data Sources

Crayfish data from a variety of sources including publications, technical reports, and unpublished data were utilized to determine S-ranks for most of Pennsylvania's native crayfishes. These sources included Fetzner (2010), Loughman et al. (2017), Glon et al. (2018), Loughman et al. (2018), Loughman et al. (2020), Williams et al. (2020), Allison et al. (2021), Horwitz et al. (2021), Allison et al. (2022), Lieb et al. (2023), and D.A. Lieb and Z.J. Loughman, unpublished data. The most recent 15 years of data (2009 - 2024) were utilized in our analysis. Older data from Ortmann (1906), Lieb et al. (2007), Bouchard et al. (2007), Lieb et al. (2008), Lieb et al. (2011a, b), and Filipová et al. (2011) were utilized to estimate trends in species occurrence and range where possible but were not otherwise utilized due to changes in occurrence and range extent since publication.

Species Selection

Nineteen species of crayfish are known from Pennsylvania. Thirteen of those species are native to the state while four others are not native to Pennsylvania. The status of the remaining two species, both of which are undescribed, is uncertain. A manuscript formally describing and naming one of these species has been submitted for publication and is under review (Lieb et al. manuscript in review). S-ranks were calculated for 12 native crayfishes and one of the species with uncertain status. The S-rank of the remaining species with uncertain status was not calculated because it was discovered in Pennsylvania in late fall 2024 (Lieb et al., manuscript accepted for publication) after S-rank calculations were completed. S-ranks were calculated for the following species: *Cambarus bartonii bartonii*, *Cambarus carinirostris*, *Cambarus* sp. C (*Cambarus* cf. *acuminatus,* undescribed member of the *Cambarus acuminatus* complex, Lieb et al. 2008), *Cambarus dubius*, *Cambarus monongalensis*, *Cambarus robustus*, *Creaserinus fodiens*, *Faxonius immunis*, *Faxonius limosus*, *Faxonius obscurus*, *Faxonius propinquus*, *Lacunicambarus diogenes*, and *Lacunicambarus thomai*, all of which are definitively native except *Cambarus* sp. C whose status is uncertain. *Procambarus acutus* was not ranked due to questions concerning native verses introduced status of many of the state's populations as well as taxonomic issues (*P. acutus* and *Procambarus zonangulus* cannot be distinguished in Pennsylvania without genetics, D.A. Lieb and B.W. Williams, unpublished data), making most currently available putative *P. acutus* data useless for species ranking purposes.

Range Extent

Range extent is the area occupied by each species in Pennsylvania and was calculated electronically using GIS. The α-hull technique as described by Master et al. (2012) was utilized. The minimum alpha value which encompassed all extant occurrences was specified (no holes allowed); occurrences identified as introductions (non-native) were excluded. Due to its disjunct range, techniques were adjusted for *Faxonius propinquus* to ensure that its range extent was not artificially increased. The specific workflow within QGIS involved applying the alpha hull tool to the xy layer of species occurrences and a CRS transformation (equal area), followed by clipping to the Pennsylvania state boundary and native drainage boundaries. The ellipsoid area was then calculated and truncated to the whole integer.

Area of Occupancy

The Area of Occupancy is the area within the range extent that a species occupies (Faber-Langendoen et al. 2012). NatureServe recommends the use of 1x1 km grids to estimate area of occupancy for linear systems, including streams (Master et al. 2012); as such crayfishes that occur in streams and rivers were calculated in that manor. Area of Occupancy for crayfishes that occur in wetland and roadside ditch habitat (burrowing crayfish) was also calculated using 1x1 km grid cells, as these habitats are generally limited in size and are often linear in nature. Area of Occupancy = number of 1km^2 grid cells occupied by species record.

Number of Occurrences

Number of Occurrences = number of unique localities and was calculated electronically using GIS.

Population Estimate

These data are not available for Pennsylvania's crayfishes.

Trends

The data necessary for determining long-term trends in species occurrence and range were available for *C. bartonii bartonii, C. robustus, F. limosus, and F. obscurus*. Long-term trends for those species were calculated by comparing data or information gleamed from Ortmann (1906), Bouchard et al. (2007), and Lieb et al. (2011a, b) to data or information from Fetzner (2010), Loughman et al. (2020), Williams et al. (2020), Horwitz et al. (2021), Lieb et al. (2023), and D.A. Lieb and Z.J. Loughman, unpublished data. Note that Bouchard et al. (2007) and Lieb et al. (2011a, b) contain historical data and information, some of which dates from the early 1900s. The data necessary for determining short-term trends in species occurrence and range were available for *Cambarus* sp. C. Short-term trends for that species were calculated by comparing D.A. Lieb and Z.J. Loughman, unpublished data from 10-20 years ago to Williams et al. (2020), Horwitz et al. (2021), Lieb et al. (2023), and D.A. Lieb and Z.J. Loughman, unpublished recent data. Data amenable to calculating trends were not available for other species.

Threats Assessment

Each threat listed in the NatureServe rank calculator was carefully assessed for each species. Criteria and guidance provided within the calculator and by the documents and manuals referenced in the calculator were carefully considered and followed. Herein we describe the highest-level threats facing each species. We do not describe medium and low-level threats due to the large number of threats evaluated for each species (as required by the rank calculator).

Results

Pennsylvania's crayfish fauna consists of 13 species which are known to be native to the state and 2 other undescribed species whose status is uncertain. Of those species, 12 native species and 1 species with uncertain status were assigned S-ranks using the latest edition of the NatureServe Rank Calculator (Table 1). One native species (*Procambarus acutus*) and one species whose status is uncertain could not be ranked (see Methods). Those efforts represent great progress relative to the 2015 PA WAP when only one Pennsylvania crayfish species (*F. limosus*) could be given a precise rank (Table 1). At that time, most species lacked the data or information necessary to take them through the ranking process (listed as Data Deficient or Not Evaluated), were given an imprecise rank (S4 or S5), or had not yet been discovered in the commonwealth (Table 1). Over the preceding decade, a number of large-scale, intensive, crayfish surveys involving the sampling of thousands of sites across Pennsylvania have been completed (Loughman et al. 2017, 2018, 2020; Glon et al. 2018, Allison et al. 2021, 2022; Lieb et al. 2023; and D.A. Lieb and Z.J. Loughman, unpublished data), ultimately allowing for most of the state's native crayfish species to be ranked.

In 2025, Ten of the thirteen crayfish species that were ranked (77%) were S1, S2, or S3 (Critically Imperiled, Imperiled, or Vulnerable) indicating that Pennsylvania's crayfish fauna is highly imperiled. The most imperiled crayfish were *C. fodiens*, *L. diogenes*, and *Cambarus* sp. C, which were classified as Critically Imperiled (S1) and *F. propinquus*, *F. limosus*, and *F. immunis*, which were classified as Imperiled (S2 or S2?). *Cambarus dubius, C. monongalensis, C. robustus*, and *L. thomai* are not as rare or threatened in Pennsylvania as the preceding species, although they were classified as Vulnerable (S3) and are of conservation concern in the state. The remaining species that were ranked (*C. bartonii, C. carinirostris*, and *F. obscurus*) are widely distributed across large parts of the state and were classified as Apparently Secure (S4). *Creaserinus fodiens* is listed as endangered in Pennsylvania, affording it protections under the Pa Code. None of the other imperiled crayfishes are state listed. Common causes of Pennsylvania crayfish imperilment include rarity and threats that were severe and widespread. Population losses resulting in declines in range extent and area of occupancy contributed to imperilment for some species. Introduced crayfishes, roads, residential and commercial development, agricultural activities, point source pollutants, and climate change/severe weather events are the most severe threats facing Pennsylvania's imperiled crayfishes.

Discussion

Based on the rankings provided herein, it is clear that Pennsylvania's crayfish fauna is imperiled and in immediate need of dedicated management and conservation efforts. For some species (e.g., *L. diogenes* and *Cambarus* sp. C) populations are disappearing from the commonwealth rapidly (in under a decade), primarily because of crayfish introductions. Residential and commercial development, agricultural activities, point source pollutants, and climate change/severe weather events may also be contributing to these declines, although additional research is needed to clarify their role.

Pennsylvania's burrowing crayfishes appear especially vulnerable with all five species of conservation concern (S1-S3 ranks). In particular, *C. fodiens* and *L. diogenes* are critically imperiled (S1) due to extreme rarity and severe threats to existing populations. *Lacunicambarus diogenes* is only known from two populations in the state and occurs within a very small part of Pennsylvania (2 km^2). Both populations are found in the highly modified, urbanized Coastal Plain in the vicinity of one of the country's largest metropolitan areas (Philadelphia; Glon et al. 2018, D.A. Lieb and Z.A. Graham, unpublished data). Recently, non-native *Procambarus clarkii* has been found intermixed with both populations and appear to have contributed to steep declines in recent years (only two *L. diogenes* individuals have been collected since 2017; D.A. Lieb, Z.J. Loughman, and Z.A. Graham, unpublished data). Residential and commercial development, point source pollutants, and climate change/severe weather events also threaten *L. diogenes* populations in Pennsylvania.

Creaserinus fodiens is slightly more common in Pennsylvania than *L. diogenes*, although *C. fodiens* is only known from two small clusters of sites in northwestern Pennsylvania within an approximately 8 km^2 area (Khan et al. 2020). Most of the known colonies of *C. fodiens* occur within or adjacent to roadside ditches (RSDs). Because *C. fodiens* is often associated with RSD habitat in Pennsylvania (Khan et al. 2020), road salts and other pollutants (e.g., hydrocarbons) that are commonly applied or spilled onto roadways pose a serious threat to the state's *C. fodiens* populations. Females with pleopodal (attached) eggs emerge from burrows in early March and are present in surface waters until pleopodal juveniles disperse and groundwater tables decline causing RSDs and ephemeral pools to begin to dry up (early to mid-May, Khan et al. 2020). During this time, females with pleopodal eggs or juveniles (ovigerous females) are often present in flooded RSDs. Snowfalls in northwestern Pennsylvania can be severe, particularly around known *C. fodiens* populations (Khan et al. 2020) and often coincide with the time period when ovigerous females (females with attached eggs) are present in flooded RSDs. As a result, the use of road salts in the vicinity of *C. fodiens* colonies may have negative impacts on pleopodal eggs (Khan et al. 2020). The application of herbicides, insecticides, biocides and other potentially toxic chemicals to roadways, RSDs, and adjacent habitats and any areas in the vicinity of *C. fodiens* colonies also pose a serious threat to the species in Pennsylvania.

The mechanical alteration of RSDs in the vicinity of *C. fodiens* colonies pose a further threat to the species in Pennsylvania. More specifically, because adults (including ovigerous females) and juveniles were commonly found in flooded RSDs in late winter, spring, early summer, and may occur there in fall and early winter (no sampling has been conducted in fall and early winter in Pennsylvania), the mechanical trenching (cutting) of RSDs that occurs outside of the driest months of the year (July/August) when individuals are restricted to their burrows (Khan et al. 2020) could result in the death or injury of large numbers of *C. fodiens* in Pennsylvania. Mechanical trenching of RSDs (likely for maintenance purposes) was observed by Khan et al. (2020) in mid-April at a *C. fodiens* site and is likely a periodic road maintenance activity in the region. In addition, because burrowing crayfishes including *C. fodiens* require fine-grained soil types (e.g., clay, loamy soils) to construct burrows (Khan et al. 2020) the lining of RSDs with rocky substrates (gravel, cobbles, boulders), as is commonly done to reduce soil erosion, could render them uninhabitable to *C. fodiens* in Pennsylvania, resulting in the extirpation of populations.

For both *L. diogenes* and *C. fodiens*, the areas that support populations in Pennsylvania are small (2-8 km^2) and disconnected from each other and populations in other states (isolated), limiting dispersal and gene flow. Species with narrow ranges and small population sizes are much more susceptible to fires, floods, droughts, diseases, and other natural disasters than species which have larger ranges and population sizes. Species with larger ranges may suffer localized extirpations because of such perturbations but typically not all populations are affected due to the large area over which such species occur. Additionally, species with narrow ranges and small population sizes often lack the genetic variability needed to adapt to changes in their environment, such as those that occur due to anthropogenic perturbations (e.g., climate change).

Cambarus dubius, C. monongalensis, and *L. thomai* are uncommon in Pennsylvania (area of occupancy=48-67 km^2) but are not as rare as *L. diogenes* and *C. fodiens* and the threats they face are not as severe as *L. diogenes*. As with *C. fodiens*, *C. dubius, C. monongalensis*, and *L. thomai* are often associated with RSD habitat in Pennsylvania and as such face the same threats faced by *C. fodiens* populations inhabiting those habitats (see above).

Of the eight surface-dwelling crayfish species that were ranked, five (63%) were S1, S2 or S3. *Cambarus* sp. C is critically imperiled (S1) due to rarity and severe threats to existing populations which have resulted in population losses and declines in range extent and area of occupancy. The species is extremely uncommon in Pennsylvania (area of occupancy=26 km^2), with reproducing populations having been documented from six small drainages in the southeastern part of the state, all occurring in a rapidly urbanizing area within approximately 30 km of Philadelphia, (Lieb et al. 2011a, b; Williams et al. 2020; D.A. Lieb, unpublished data). Additionally, in recent years, invasive crayfishes have been introduced to those drainages, resulting in substantial reductions or extirpation of *C.* species C from invaded sites (Williams et al. 2020, D.A. Lieb, unpublished data). Losses have been especially pronounced in two drainage basins where the species either no longer occurs or is now restricted to headwater sites. Residential and commercial development, point source pollutants, and climate change/severe weather events also threaten *C.* species C populations in Pennsylvania.

Faxonius immunis is also extremely uncommon, occupying a very small part of northwestern Pennsylvania (14 km^2). The threats faced by the species, which result mainly from its occurrence in RSDs (see above), are not as severe as *C.* sp. C, resulting in an imperiled ranking (S2?). *Faxonius limosus* and *F. propinquus* are more common than *C.* sp. C or *F. immunis*, occupying 55-100 km^2, although both face substantial threats from introduced crayfishes, resulting in an imperiled ranking (S2). *Faxonius limosus* has disappeared from all or most of the Potomac and Susquehanna drainages of Pennsylvania as well as parts of the Delaware drainage over the past 100+ years as a result of non-native crayfish introductions (Lieb et al. 2011a, b, 2023). *Cambarus robustus* is also threatened by non-native crayfishes but occupies a larger area than the previously mentioned species (137 km^2), resulting in a S3 rank.

Considerations for future assessments

Although much progress has been made in the preceding decade since the 2015 PA WAP, work remains for the state's crayfishes. Two punitive species remain unnamed and undescribed. One of them (*C.* sp. C herein) is well on the way to being described and named (manuscript in review at a scientific journal); however, the other is a recent discovery (fall of 2024) and much work remains before a formal description of that taxon can be completed. Another possible undescribed species occurs in northwestern Pennsylvania (Loughman et al. 2020) and warrants focused attention. All three of the punitive undescribed species in the state are extremely rare and threatened by anthropogenic disturbances adding urgency to these efforts. Genetic as well as taxonomic work will likely be needed to complete these species descriptions. Additional focused survey efforts will then be necessary to determine range extent, area of occupancy, number of occurrences, and threats for those species prior to ranking them. Determining whether *C. robustus* and *F. propinquus* populations in the northwestern portion of the Susquehanna drainage and *F. propinquus* populations in the northwestern portion of the Delaware drainage are native or introduced will allow for more precise estimates of range extent, area of occurrence, and number of populations and ultimately more accurate ranks for those species. Finally resolving issues with existing *P. acutus* records in Pennsylvania (see Methods), which will require targeted survey efforts and genetic work, is needed.

Literature Cited

Allison P.F., Jr., T.N. Khan, D.A. Davis, D.A. Lieb, and Z.J. Loughman. 2021. Review of the distribution and new occurrences of *Lacunicambarus thomai* (Jezerinac, 1993) (Decapoda, Cambaridae) in Pennsylvania and its possible introduction outside of its native range. Check List 17: 1461–1473.

Allison, P.F., Jr, D.A. Lieb, and Z.J. Loughman. 2022. Distribution, natural history, and conservation of *Cambarus dubius* in Pennsylvania. Journal of Natural History 56:829–848.

Bouchard, R.W., D.A. Lieb, R.F. Carline, T.R. Nuttall, C.B. Wengert, and J.R. Wallace. 2007. 101 Years of Change (1906 to 2007). The distribution of the crayfishes of Pennsylvania. Part I. Eastern Pennsylvania. Academy of Natural Sciences of Philadelphia, Report No. 07-11. Philadelphia, Pennsylvania. 83 pp.

Faber-Langendoen, D., J. Nichols, L.L. Master, K. Snow, A. Tomaino, R. Bittman, G.A. Hammerson, B. Heidel, L. Ramsay, A. Teucher, and B. Young. 2012. NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe, Arlington, Virginia. 44 pp.

Fetzner, J.W., Jr. 2010. Crayfish of Pennsylvania: research to assist management, law enforcement, conservation, and public awareness of Pennsylvania's unique aquatic resources. Final Report for Project Number 07-256, submitted to the Wild Resource Conservation Program, Pennsylvania Department of Conservation and Natural Resources, Harrisburg, Pennsylvania.

Filipová, L., D.A. Lieb, F. Grandjean, and A. Petrusek. 2011. Haplotype variation in the spiny-cheek crayfish *Orconectes limosus*: colonization of Europe and genetic diversity of native stocks. Journal of the North American Benthological Society 30: 871–881.

Glon, M.G., A.J. Mularo, D.A. Lieb, and Z.J. Loughman. 2018. Rediscovery of *Cambarus diogenes* (Devil Crayfish) in Pennsylvania. Northeastern Naturalist 25: 355–361.

Horwitz, R.J., D.A. Lieb, E.L. Silldorff, C.J. Blakeslee, and P. Overbeck. 2021. Delaware Watershed Conservation Fund 2018: Report on Pickering Creek Eel Reintroduction Program. Final Report to the National Fish and Wildlife Federation, 1133 15th street, NW, Suite 1100, Washington DC, 20005. 42pp.

Khan, T.N., D.A. Lieb, and Z.J. Loughman. 2020. Distribution and conservation status of the digger crayfish (*Creaserinus fodiens*, Cottle 1863) in Pennsylvania. Final Report submitted to the Wild Resource Conservation Program, Pennsylvania Department of Conservation and Natural Resources, Harrisburg, Pennsylvania. 85 pp.

Lieb, D.A., R.W. Bouchard, and R.F. Carline. 2011a. Crayfish fauna of southeastern Pennsylvania: distributions, ecology and changes over the last century. Journal of Crustacean Biology 31: 166–178.

Lieb, D.A., R.F. Carline, and H.M. Ingram. 2007. Status of Native and Invasive Crayfish in Ten National Park Service Properties in Pennsylvania. Technical Report NPS/NER/NRTR—2007/085. National Park Service, Philadelphia, Pennsylvania. 29 pp.

Lieb, D.A., R.F. Carline, J.L. Rosenberger, and V.M. Mengel. 2008. The discovery and ecology of a member of the *Cambarus acuminatus* complex (Decapoda: Cambaridae) in Valley Creek, southeastern Pennsylvania. Journal of Crustacean Biology 28: 439-450.

Lieb, D.A., R.W. Bouchard, R.F. Carline, T.R. Nuttall, J.R. Wallace, and C.L. Burkholder. 2011b. Conservation and management of crayfishes: lessons from Pennsylvania. Fisheries 36: 489–507.

Lieb, D.A., K.M. Diehl, J. Krochmal, Z.A Graham, and Z.J. Loughman. 2023. Crayfish fauna of the Susquehanna and Delaware basins of Pennsylvania with an emphasis on range extensions, new discoveries, nonnative species, and the Spinycheek Crayfish (*Faxonius limosus*). Final Report for Grant Agreement WRCP-19601. Submitted to the Pennsylvania Fish and Boat Commission, Bellefonte, Pennsylvania. 84pp.

Lieb, D.A., B.W. Williams, D.A. Foltz, II, and Z.J. Loughman. *In Review*. Description of a new stream-dwelling species of *Cambarus* (Decapoda: Cambaridae) from Virginia and Pennsylvania (USA) with notes on its distribution, ecology, and conservation status. Submitted to Zootaxa.

Lieb, D.A., N.S. Macelko, and Z.J. Loughman. *Accepted for publication*. Discovery of the *Cambarus acuminatus* species complex (Decapoda: Astacidea: Cambaridae) in New Jersey and extreme eastern Pennsylvania and addition of a new crayfish species to the fauna of both states. To be published in Northeastern Naturalist.

Loughman, Z.J, P. Woods, and D.A. Lieb. 2018. First record of *Creaserinus fodiens* (Digger Crayfish) from Pennsylvania. Northeastern Naturalist 25: N15–N18.

Loughman, Z.J., D.A. Lieb, R.K. Scott, Z.W. Dillard, and N.M. Sadecky. 2017. Historical and current distribution of Appalachian primary burrowing crayfishes (Decapoda: Astacoidea: Cambaridae) in western Pennsylvania: A century of change or stasis? Journal of Crustacean Biology 37: 533–543.

Loughman, Z.J., D.A. Lieb, A.M. Sykes, T.N. Khan, and P.F. Allison, Jr. 2020. Western Pennsylvania crayfish inventory and conservation assessment. Final Report submitted to the Pennsylvania Fish and Boat Commission, Harrisburg, Pennsylvania. 396 pp.

Master, L.L., D. Faber-Langendoen, R. Bittman, G.A. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe, Arlington, Virginia. 64 pp.

Ortmann, A.E. 1906. The crawfishes of the state of Pennsylvania. Memoirs of the Carnegie Museum 2: 343-523.

Rawlins, J. 2007. Pennsylvania Comprehensive Wildlife Conservation Strategy. Invertebrates. Version 1.1. A report submitted to the Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission (January 12, 2007). 227 pp.

Williams, B.W., Z.J. Loughman, and D.A. Lieb. 2020. Taxonomy and Conservation Status of *Cambarus* (*Puncticambarus*) sp. in Pennsylvania. Final Report for State Wildlife Grant F16AF01305, submitted to the Pennsylvania Fish and Boat Commission, Harrisburg, Pennsylvania. 50 pp.

Table 1. Previous (2015) and updated (2025) S-ranks for most of Pennsylvania's native crayfish species and one species whose status is uncertain (*Cambarus* sp. C). *Procambarus acutus*, which is native to parts of Pennsylvania could not be ranked (see Methods for explanation).

Scientific Name	Common Name	2015 PA WAP rank	2025 PA WAP rank
Cambarus bartonii bartonii	Common Crayfish	Not SGCN (S4 or S5 rank)	S4
Cambarus carinirostris	Rock Crayfish	Not evaluated	S4
Cambarus sp. C		Not evaluated	S1
Cambarus dubius	Upland Burrowing Crayfish	Data Deficient	S3
Cambarus monongalensis	Blue Crayfish	Data Deficient	S3
Cambarus robustus	Big Water Crayfish	Data Deficient	S3
Creaserinus fodiens	Digger Crayfish	Not known from PA in 2015	S1
Faxonius immunis	Calico Crayfish	Not evaluated	S2?
Faxonius limosus	Spinycheek Crayfish	S2	S2
Faxonius obscurus	Allegheny Crayfish	Not SGCN (S4 or S5 rank)	S4
Faxonius propinquus	Northern Clearwater Crayfish	Data Deficient	S2
Lacunicambarus diogenes	Devil Crayfish	Data Deficient	S1
Lacunicambarus thomai	Little Brown Mudbug	Data Deficient	S3

A Comprehensive Status Assessment of Pennsylvania's Freshwater Mussels for the 2025-35 Pennsylvania Wildlife Action Plan

Nevin T. Welte

Pennsylvania Fish and Boat Commission
Division of Environmental Services
Natural Diversity Section

17 November 2025

Table of Contents

Introduction **2**

Methods **4**

Data Sources 4

Species Selection 4

Range Extent 4

Area of Occupancy 4

Number of Occurrences 4

Population Estimate 4

Trends 5

Threats Assessment 5

Results **6**

Discussion **8**

Considerations for future assessments 9

Acknowledgements **10**

Literature Cited **10**

Introduction

Freshwater mussels are the most imperiled group of freshwater organisms in North America (Ricciardi and Rasmussen 1999). The changing scope and severity of threats faced by Pennsylvania's mussels are reflected in their regulatory status. Twelve mussel species are listed as state or federal endangered or threatened (**Table 1**). More mussels are listed as federally protected (9) than any other Pennsylvania taxonomic group. Historical, ongoing, and emerging threats (e.g., aquatic invasive species such as Round Goby, *Neogobius melanostomus*), combine with sensitive life history traits and a generally sessile nature to make Pennsylvania's mussels increasingly vulnerable and at risk for extirpation. The status of all Pennsylvania mussels is evaluated for each Pennsylvania Wildlife Action Plan (PA WAP) and mussels are assigned a rank reflective of their rarity or imperilment.

Table 1. Pennsylvania's endangered and threatened mussels.

		Regulatory Status	
Common Name	**Scientific Name**	**Federal**	**State**
Northern Riffleshell	*Epioblasma rangiana*	Endangered	Endangered
Snuffbox	*Epioblasma triquetra*	Endangered	Endangered
Longsolid	*Fusconaia subrotunda*	Threatened	Threatened
Eastern Pearlshell	*Margaritifera margaritifera*		Endangered
Round Hickorynut	*Obovaria subrotunda*	Threatened	Endangered
Rayed Bean	*Paetelunio fabalis*	Endangered	Threatened
Sheepnose	*Plethobasus cyphyus*	Endangered	Threatened
Clubshell	*Pleurobema clava*	Endangered	Threatened
Dwarf Wedgemussel	*Prolasmidonta heterodon*	Endangered	Endangered
Pistolgrip	*Quadrula verrucosa*		Endangered
Salamander Mussel	*Simpsonaias ambigua*		Endangered
Rabbitsfoot	*Theliderma cylindrica*	Threatened	Endangered

The PA WAP relies on NatureServe's methodology and data standards to develop status ranks. Broadly, NatureServe methodology uses data to assess the conservation status of vertebrates, invertebrates, plants, natural communities and animal assemblages using various factors such rarity, threats, and trends. These factors have been standardized into NatureServe's Status Assessment Methodology for Assigning Ranks (Faber-Langendoen et al. 2012). This method is meant to be applicable to all taxonomic elements run through an assessment tool (NatureServe rank calculator, version 3.2). The rank calculator is designed for determining extinction - or extirpation - risk at multiple geopolitical levels (global, national, or subnational ("state") levels) across a species or ecosystem's range (**Table 2**), similar to the International Union for the Conservation of Nature (IUCN) Red List methodology (IUCN 2001).

Table 2. Subnational ("state") ranks (S-ranks) (Master et al. 2010).

Rank	Definition
SX	**Presumed Extirpated** – Species or ecosystem is believed to be extirpated from the jurisdiction (i.e., nation, or state/province). Not located despite intensive searches of historical sites and other appropriate habitat, and virtually no likelihood that it will be rediscovered.
SH	**Possibly Extirpated** – Known from only historical records but still some hope of rediscovery. There is evidence that the species or ecosystem may no longer be present in the

	jurisdiction, but not enough to state this with certainty. Examples of such evidence include (1) that a species has not been documented in approximately 20-40 years despite some searching and/or some evidence of significant habitat loss or degradation; (2) that a species or ecosystem has been searched for unsuccessfully, but not thoroughly enough to presume that it is no longer present in the jurisdiction.
S1	**Critically Imperiled** – At very high risk of extirpation in the jurisdiction due to very restricted range, very few populations or occurrences, very steep declines, severe threats, or other factors.
S2	**Imperiled** – At high risk of extirpation in the jurisdiction due to a restricted range, few populations or occurrences, steep declines, severe threats, or other factors.
S3	**Vulnerable** – At moderate risk of extirpation in the jurisdiction due to a fairly restricted range, relatively few populations or occurrences, recent and widespread declines, threats, or other factors.
S4	**Apparently Secure** – At a fairly low risk of extirpation in the jurisdiction due to an extensive range and/or many populations or occurrences, but with possible cause for some concern as a result of local recent declines, threats, or other factors.
S5	**Secure** – At very low or no risk of extirpation in the jurisdiction due to a very extensive range, abundant populations or occurrences, with little to no concern from declines or threats.
S#S#	**Range Rank** – A numeric range rank (e.g., S2S3 or S1S3) is used to indicate any range of uncertainty about the status of the species or ecosystem. Ranges cannot skip more than two ranks (e.g., SU is used rather than S1S4).
SU	**Unrankable** – Currently unrankable due to lack of information or due to substantially conflicting information about status or trends.
SNR	**Unranked** – National or subnational conservation status not yet assessed.
SNA	**Not Applicable** – A conservation status rank is not applicable because the species or ecosystem is not a suitable target for conservation activities.
Not Provided	Species or ecosystem is known to occur in this nation or state/province. Contact the relevant NatureServe network program for assignment of conservation status.

The NatureServe ranking method used for the PA WAP differs from the Pennsylvania Biological Survey (PABS) species listing and de-listing process, although both are based upon an adaptation of the IUCN Red List methodology (Hassinger 2002). PABS, as a scientific advisory group to state resource agencies, may provide species S-ranks or species listing or de-listing recommendations. The PABS Bivalve Subcommittee listing and de-listing methodology differs from NatureServe methodology by requiring a more rigorous and detailed documentation of the scope and severity of threats facing a species proposed for listing. The decision and act of listing or delisting any mussel species is a separate PFBC regulatory process.

The goal of this effort was 1) to assess the status of Pennsylvania's native mussels using NatureServe methodology and the rank calculator; 2) present proposed S-rank updates to the PABS Bivalve Subcommittee for discussion and vote; and 3) provide PFBC with rank calculator results to be incorporated into the PA WAP 2025 update.

Methods

The status of Pennsylvania's 66 native freshwater mussels (Unionidae, n=65; Margaritiferidae, n=1) was analyzed by inputting data on at least two of three possible factor categories into the NatureServe rank calculator (Faber-Langendoen et al. 2012). The rank calculator is a Microsoft Excel-based spreadsheet which uses decision factors to determine the risk of extinction (NatureServe 2020). These three factor categories include rarity, threats, and trends.

Data Sources

The mussel data used for calculating state ranks was compiled from multiple sources including Biotics, the PNHP Mussel Database, museum data, and data from PFBC's Aquatic Resource Database and Scientific Collector's Permit database. These data were compiled into a GIS project for analysis. Species nomenclature follows the Freshwater Mollusk Conservation Society updated bivalve name list (www.molluskconservation.org; accessed October 5, 2025).

Species Selection

All 66 mussel species were evaluated using available data to determine an S-rank. All mussel survey data were assessed for quality control prior to inclusion in analyses. The life span of mussels varies, ranging from less than 10 years to more than 100 years, therefore species data collected since 1980 were utilized for all analyses (e.g., Bauer 1992; Haag and Rypel 2010).

Rarity

Range Extent

Range extent measures the area occupied by each species and is calculated using GIS. The range extent for mussels were selected as Hydrologic Unit Codes (HUC 8) clipped at the Pennsylvania boundary. The separation distance was set at 10km and a GIS snap distance to flowline was set at 400m. The snap distance was necessary to capture transect data in large, wide rivers (e.g., Ohio, Susquehanna).

Area of Occupancy

The area of occupancy is defined as the area within the range extent that a species actually occupies (Faber-Langendoen et al. 2012). NatureServe recommends the use of 1x1 km grids to estimate area of occupancy for linear systems, including rivers and streams, assuming that these systems have a fairly complete inventory (Master et al. 2012). While data gaps certainly exist for streams and rivers across Pennsylvania's >80,000 miles of streams, recent (>1980) mussel surveys provide broad survey coverage of most Pennsylvania river basins.

Number of Occurrences

The number of occurrences was calculated using GIS. The number of species occurrences were categorically assigned scores (e.g., "A" = 1-5 occurrences, "B" = 6- 20 occurrences, etc.) based upon NatureServe methodology (Master et al. 2012).

Population Estimate

Population estimates are unknown for freshwater mussels; thus, this criterion was not used. Mussel population numbers likely vary across Pennsylvania waterways. For example, the total Eastern Elliptio, *Elliptio complanata*, population in the Susquehanna River likely pales in comparison to the Delaware River although the same species occurs in both river basins.

Trends

Short- and long-term population trends are unknown for Pennsylvania's freshwater mussels; therefore, this factor was not used. Quantitative survey sites have been established in several streams, but these sites have not been systematically monitored in the same manner as other species such as recreational sportfish. Short- and long-term trend information is therefore more likely to be available for recreationally important species such as native and introduced trout (*Oncorhynchus*, *Salmo*, and *Salvelinus* spp.) and black basses (e.g., *Micropterus* spp.) versus nongame, endangered, and threatened species.

Threats

Threats Assessment

Many mussel species face similar threats although the scope and severity of each threat varies by species, depending upon a particular mussel species' distribution and its life history (Barnhart et al. 2008). Most mussels require an intermediate host, usually a fish, to complete their life cycle. Some mussels, like the Salamander Mussel, *Simpsonaias ambigua*, can utilize an amphibian host (e.g., Common Mudpuppy, *Necturus maculosus*) while others can produce juveniles directly, bypassing the parasitic phase entirely (e.g., Green Floater, *Platynaias subviridis*; Creeper, *Strophitus undulatus*). The availability of the host, and ability of the mussel to interact with their hosts, is critical to the persistence of these mussels. A few common threats to mussels are discussed below and follow NatureServe threat descriptions (Salafsky et al. 2008).

Agriculture and aquaculture

Annual and perennial non-timber crops

Non-point source pollution from agricultural activities, particularly nitrogen, phosphorus (eutrophication) and sedimentation, has the potential to alter mussel habitat or their biological functions. Sedimentation from runoff can clog mussel gills and affect their ability to breathe and filter-feed. Sedimentation can also decouple mussels from their host fish during critical life stages (see Brim Box and Mossa 1999). For example, excessive sedimentation may reduce visibility of fish lures or other displays that mimic fish prey items (e.g., worms, larval fish, darter, shiners), thereby affecting the fish host's detection of mussels and preventing the transfer of mussel larvae (glochidia) to these fish.

Energy production and mining

Mining and quarrying

Commercial and navigation sand and gravel dredging activities are currently authorized in the Ohio and Delaware rivers by the U.S. Army Corps of Engineers and the Pennsylvania Department of Environmental Protection (PADEP). Current and future dredging can have direct adverse impacts on mussels and permanently alter their habitat (see Freedman 2010 and Freedman et al. 2012).

Transportation and service corridors

Roads and railroads

Bridge replacement and repair projects over diverse and abundant populations of rare, protected, or common mussel species are currently proposed or ongoing. Current and future bridge replacement projects typically include temporary habitat alteration, mortality of mussels via direct (e.g., crushing, burial) and indirect effects (sediment deposition), and some level of mortality of salvaged and relocated mussels.

Utility and service lines

Pipeline stream crossings, including service, gathering and transmission lines, are ongoing or proposed for numerous streams occupied by mussels. Threats associated with these project types include temporary habitat alterations associated with open-cut trenching methods, bentonite frack-outs, mortality of mussels via direct (e.g., crushing, burial) and indirect effects (sediment deposition), and some level of mortality of salvaged or relocated mussels.

Natural system modifications

Dams and water management/use

The effects of impoundments on mussels are well documented (e.g., Watters 2000). Dams act as gene flow barriers and alter upstream and downstream habitats via habitat conversion and altered flow and temperature regimes. Notable Pennsylvania dams with the potential or documented impacts on mussel communities include the major Susquehanna River dams (Conowingo, Holtwood, and Safe Harbor) that block passage of migrating catadromous American Eel (*Anguilla rostrata*) and anadromous alosids, known hosts for the Eastern Elliptio (*Elliptio complanata*) and the Alewife Floater (*Utterbackiana implicata*), respectively. The Allegheny (Kinzua Dam), Shenango (Pymatuning Dam) and the upper Delaware River have all experienced historically low flows or dewatering events associated with reservoir or river management for recreational and water supply uses.

Exacerbating the water management threat to mussels is the potential for cumulative impacts associated with water withdrawals and other competing uses of water (e.g., pollution abatement). Regional climate change along with water management needs could further exacerbate impacts to freshwater mussel communities (Galbraith et al. 2010; PFBC 2022).

Pollution: Industrial and military effluents

Point source discharges are both a historical and ongoing threat to the persistence and recovery of freshwater mussels. A recent point source threat that has had a documented adverse effect on mussels is wastewater treatment plants that accepted brine wastewater from the oil and gas industry. Discharge of chlorides from brine wastes into the Allegheny River had a demonstrable impact on survival of a state and federally endangered mussel species (Patnode et al. 2015; PADEP, unpublished data).

Results

All 66 native mussel species were analyzed using the rank calculator (**Table 3**). The previous S-ranks were compared with the S-ranks generated by the rank calculator (**Table 4**).

Table 3. Previous S-rank (2015) and updated S-rank (2025) status of Pennsylvania's freshwater mussels. Data cut-off for 2025 analyses was 1980.

			S-Rank	
	Common Name	**Scientific Name**	**2015**	**2025**
1	Elktoe	*Alasmidonta marginata*	S3S4	S4

2	Triangle Floater	*Alasmidonta undulata*	S3	S2S3
3	Brook Floater	*Alasmidonta varicosa*	S1S2	S1S2
4	Threeridge	*Amblema plicata*	S2S3	S2S3
5	Cylindrical Papershell	*Anodontoides ferussacianus*	S2S3	S3S4
6	Tidewater Mucket	*Atlanticoncha ochracea*	S1	S1
7	Rainbow	*Cambarunio iris*	S3	S3
8	Purple Wartyback	*Cyclonaias tuberculata*	SH	SH
9	Fanshell	*Cyprogenia stegaria*	SH	SH
10	Butterfly	*Ellipsaria lineolata*	SH	S1
11	Eastern Elliptio	*Elliptio complanata*	S4	S4
12	Elephant Ear	*Elliptio crassidens*	SH	SU
13	Northern Lance	*Elliptio fisheriana*	S1	SX
14	Atlantic Spike	*Elliptio producta*	SNR	S1
15	Northern Riffleshell	*Epioblasma rangiana*	S2	S2
16	Snuffbox	*Epioblasma triquetra*	S2	S1
17	Spike	*Eurynia dilatata*	S4	S4
18	Wabash Pigtoe	*Fusconaia flava*	S2S3	S2
19	Longsolid	*Fusconaia subrotunda*	S2	S1
20	Cracking Pearlymussel	*Hemistena lata*	SX	SX
21	Pink Mucket	*Lampsilis abrupta*	SH	SH
22	Plain Pocketbook	*Lampsilis cardium*	S4	S4
23	Yellow Lampmussel	*Lampsilis cariosa*	S4	S4
24	Wavyrayed Lampmussel	*Lampsilis fasciola*	S3S4	S3S4
25	Pocketbook	*Lampsilis ovata*	S2S3	S4
26	Eastern Lampmussel	*Lampsilis radiata*	S1	S1S2
27	Fatmucket	*Lampsilis siliquoidea*	S4	S4
28	Flutedshell	*Lasmigona costata*	S4	S4
29	Black Sandshell	*Ligumia recta*	S4	S4
30	Eastern Pearlshell	*Margaritifera margaritifera*	S1	S1
31	Threehorn Wartyback	*Obliquaria reflexa*	S3	S3
32	Hickorynut	*Obovaria olivaria*	SH	SX
33	Ring Pink	*Obovaria retusa*	SX	SX
34	Round Hickorynut	*Obovaria subrotunda*	S1	S1
35	Mucket	*Ortmanniana ligamentina*	S4	S4
36	Rayed Bean	*Paetulunio fabalis*	S1S2	S2
37	Creek Heelsplitter	*Platynaias compressa*	S2	S3
38	Green Floater	*Platynaias subviridis*	S2S3	S3
39	Orangefoot Pimpleback	*Plethobasus cooperianus*	SH	SX
40	Sheepnose	*Plethobasus cyphyus*	S1	S1
41	Clubshell	*Pleurobema clava*	S2	S2
42	Ohio Pigtoe	*Pleurobema cordatum*	SH	SH
43	Rough Pigtoe	*Pleurobema plenum*	SH	SX
44	Round Pigtoe	*Pleurobema sintoxia*	S3S4	S3
45	Pink Heelsplitter	*Potamilus alatus*	S4	S4
46	Fragile Papershell	*Potamilus fragilis*	S2S3	S2S3
47	Pink Papershell	*Potamilus ohiensis*	S1	S2

48	Dwarf Wedgemussel	*Prolasmidonta heterodon*	S1	S1
49	White Heelsplitter	*Pterosyna complanata*	S1S2	S2
50	Kidneyshell	*Ptychobranchus fasciolaris*	S4	S4
51	Pimpleback	*Pustulosa pustulosa*	S1	SU
52	Eastern Floater	*Pyganodon cataracta*	S4	S4
53	Giant Floater	*Pyganodon grandis*	S4	S4
54	Mapleleaf	*Quadrula quadrula*	S3	S2S3
55	Pistolgrip	*Quadrula verrucosa*	S1	S1
56	Eastern Pondmussel	*Sagittunio nasutus*	S2S3	S3
57	Salamander Mussel	*Simpsonaias ambigua*	S1	S1
58	Creeper	*Strophitus undulatus*	S5	S5
59	Rabbitsfoot	*Theliderma cylindrica*	S1S2	S1
60	Rockshell	*Theliderma metanevra*	SH	SH
61	Lilliput	*Toxolasma parvum*	S1S2	S2
62	Fawnsfoot	*Truncilla donaciformis*	S1	S1S2
63	Deertoe	*Truncilla truncata*	S1	S1
64	Paper Pondshell	*Utterbackia imbecillis*	S4	S4
65	Alewife Floater	*Utterbackiana implicata*	S3	S2
66	Flat Floater	*Utterbackiana suborbiculata*	S1	SNA

Table 4. Comparison of 2015 and 2025 mussel S-ranks.

Year	S1	S1S2	S2	S2S3	S3	S3S4	S4	S5	SU	SH	SX
2015	14	5	5	7	5	3	13	1		11	2
2025	15	3	8	4	6	2	15	1	1	5	6

The PABS Bivalve Subcommittee reviewed the calculated S-ranks (February 2025). Revised S-ranks were sent to the PABS Bivalve Subcommittee chair July 23, 2025, and resent October 15. 2025. The PABS Bivalve Subcommittee reviewed and voted to approve the calculated S-ranks on November 17, 2025. PABS finalized S-ranks will be used to update the PNHP mussel S-ranks.

Discussion

Overall, the number of mussels ranked as traditional Species of Greatest Conservation Need (SGCN) – ranking between S1 and S3S4 – were comparable to 2015 (39 species in 2015; 38 species in 2025; Welte 2014).

Fewer species were described as SH in the 2025 analysis. Some 2015 SH species were transferred to SX status in the 2025 analysis. These SH and SX changes are reflective of a better understanding of host fish use (e.g., Hickorynut, *Obovaria olivaria* use of unrecoverable Ohio and Allegheny River sturgeon hosts) or taxonomic clarification (e.g., Northern Lance, *Elliptio fisheriana* and Atlantic Spike, *E. producta;* synonymizing of Pyramid Pigtoe, *Pleurobema rubrum* with Round Pigtoe, *P. sintoxia*). Other species are exceedingly rare throughout their range (Orangefoot Pimpleback, *Plethobasus cooperianus*) or on the verge of global extinction (Ring Pink, *Obovaria retusa*) and thus extremely unlikely to be encountered or recovered.

The SH status remains important. SH species are still being rediscovered in the navigational channels of the Ohio and Allegheny rivers (e.g., Butterfly, *Ellipsaria linelata* and Elephantear, *Elliptio crassidens*). Additional "big river" species may yet be detected (e.g., Ohio Pigtoe, *Pleurobema cordatum*; Pimpleback, *Pustulosa pustulosa*; Rockshell, *Theliderma metanevra*). Since the 2015 PA WAP there is additional evidence of expanding species distribution (e.g., Pink Papershell, *Potamilus ohiensis*; Threehorn Wartyback, *Obliquaria reflexa*) and continued acknowledgement that only a low percentage of the navigational pools have been surveyed (e.g., Ohio River < 1%) (Ecological Specialists 2013; PFBC, unpublished data). Continued survey efforts in the three rivers (Allegheny, Monongahela, and Ohio) are likely to make new species discoveries, connect formerly disjunct species distributions (e.g., Northern Riffleshell, *Epioblasma rangiana*; Rayed Bean, *Paetelunio fabalis*; and Clubshell, *Pleurobema clava*) or provide information about potential species and habitat restoration opportunities.

The mussel S-rank calculations provide an approximation of SGCN status. The formal designation of mussel SGCN status occurs as an output of the PA WAP SGCN flowchart, and there may be subtle differences between calculated S-ranks presented herein and published 2025 PA WAP SGCN determinations. For example, this analysis calculated the S-rank of Pocketbook, *Lampsilis ovata*, as S4 (Apparently Secure); however, the 2025 PA WAP considered Pocketbook an SGCN by virtue of the S-rank threat assessment. Several other species (e.g., Rockshell, *Theliderma metanevra*) have S-ranks calculated as SH; however, in the PA WAP flowchart these species were considered as recoverable SH, and they were thus assigned SGCN status.

Considerations for future assessments

The 2035 mussel S-rank analysis should be relatively close to automation if mussel data sharing between the Western Pennsylvania Conservancy (WPC) and PFBC continues. The 2025 mussel S-rank analysis benefited from the simultaneous development of a statewide mussel conservation plan led by WPC in partnership with PFBC. The S-rank and planning projects facilitated a coordinated effort between WPC and PFBC to share recent survey data at scale resulting in a robust dataset for S-rank analyses. Continued commitment to annual or semiannual mussel data sharing between WPC and PFBC should allow for a much more streamlined process that facilitates future rapid, at-will – automated? – evaluations of mussel S-ranks.

Standardized NatureServe guidance on how to incorporate the unique life history of mussels, including risks to known hosts, and any increased or decreased vulnerability because of that unique life history would be beneficial, acknowledging that adapting the rank calculator to meet global taxonomic needs would be challenging. Where it may be pragmatic to do so, standardizing, or calibrating threats analysis across Pennsylvania's aquatic species (e.g., fish, mussels, snails, other invertebrates) would be a worthy 2035 PA WAP goal.

Unlike other PFBC taxonomic groups (e.g., fish, reptiles and amphibians) no additional State Wildlife Grant funds, other monies, or other staff were allocated time for conducting the 2025 mussel S-rank analysis. The level of rarity and imperilment, combined with the number of SGCN taxa (50 non-S4, S5 species), suggest that assistance is appropriate. Future S-rank analyses should allocate funds to accommodate data management staff time and assistance from other mussel biologists.

Acknowledgments

Many individuals directly or indirectly contributed to the evaluation of mussel S-rank analyses. Individuals providing patience, expertise, and contributions include: PFBC – Jordan Allison, Josh Arnold, Kyle Clark, Diana Day, Greg Lech, Dakota Raab, Scott Ray, and Chris Urban; WPC – Kierstin Carlson, Eric Chapman, Charlie Eichelberger, Brad Georgic, Kathy Gipe, Susan Klugman, Ryan Miller, Trent Millum, Molly Moore, Erika Schoen, and Mary Walsh; PABS – Bob Anderson, Jeff Cole, Danielle Kreeger, Joe Snavely, Rick Spear, Mary Walsh, Chris Urban, and Greg Zimmerman.

Literature Cited

Barnhart, M.C., Haag, W.R. and W.N. Roston. 2008. Adaptations to host infection and larval parasitism in Unionoida. Journal of North American Benthological Society 27(2): 370-394.

Bauer, G. 1992. Variation in the life span and size of the freshwater pearl mussel. Journal of Animal Ecology 61(2): 425-436.

Brim Box, J. and J. Mossa. 1999. Sediment, land use, and freshwater mussels: prospects and problems. Journal of the North American Benthological Society 18(1): 99-117.

Ecological Specialists. 2013. Final report: unionid surveys at ten dams on the Monongahela, Ohio, and Allegheny Rivers. Prepared for Free Flow Power Corporation. ESI Project 13-017.

Faber-Langendoen, D., Nichols, J., Master, L.L., Snow, K., Tomaino, A., Bittman, R., Hammerson, G.A., Heidel, B., Ramsay, L., Teucher, A., and B. Young. 2012. NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe, Arlington, Virginia.

Freedman, J.A. 2010. Dams, dredging, and darters: effects of anthropogenic disturbances on benthic fish ecology. PhD dissertation. College of Agricultural Sciences, Pennsylvania State University. 177 pages.

Freedman, J.A., Carline, R.F., and J. Stauffer, Jr. 2012. Gravel dredging alters diversity and structure of riverine fish assemblages. Freshwater Biology 58: 261-274.

Galbraith, H.S., Spooner, D.E. and C.C. Vaughn. 2010. Synergistic effects of regional climate patterns and local water management on freshwater mussel communities. Biological Conservation 143: 1175-1183.

Haag, W.R. and A.L. Rypel. 2010. Growth and longevity in freshwater mussels: evolutionary and conservation implications. Biological Reviews pp. 000-000. DOI: 10.1111/j.1469-185X.2010.00146.x.

Hassinger, J. 2002. Final report – status determination and regulatory listing. Grant WRCF-28-04/40100021222. Unpublished report to the Wild Resources Conservation Fund.

International Union for the Conservation of Nature (IUCN). 2001. IUCN Red List categories and criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, United Kingdom.

Master, L.L., Faber-Langendoen, D., Bittman, R., Hammerson, G.A., Heidel, B., Ramsay, L., Snow, K., Teucher, A., and A. Tomaino. 2012. NatureServe Conservation Status Assessments: Factors for Evaluating Species and Ecosystem Risk. NatureServe, Arlington, Virginia.

NatureServe. 2020. NatureServe Conservation Status Assessments: Rank Calculator Version 3.2 . NatureServe, Arlington, VA. Online at https://www.natureserve.org/conservation-tools/data-maps-tools/conservation-rank-calculator

Patnode, K.A., Hittle, E., Anderson, R.M., Zimmerman, L., and J. W. Fulton. 2015. Effects of high salinity wastewater discharges on freshwater mussels in the Allegheny River, Pennsylvania. Journal of Fish and Wildlife Management 6(1): 55-70.

PGC-PFBC (Pennsylvania Game Commission and Pennsylvania Fish & Boat Commission). 2015. Pennsylvania Wildlife Action Plan, 2015-2025. C. Haffner and D. Day, editors. Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, Harrisburg, Pennsylvania.

PFBC. 2022. Pennsylvania Fish and Boat Commission Climate Action Plan: Strategies for enhancing climate adaptation and resilience to protect, conserve, and enhance Pennsylvania's aquatic resources and support anglers and boaters, version 2022-1.0. Harrisburg, Pennsylvania.

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H.M., Collen, B., Cox, N., Master, L.L., O'Conner, S. and D. Wilkie. 2008. A standard lexicon for biodiversity conservation: unified classifications of threats and actions. Conservation Biology 22: 897-911.

Ricciardi, A. and J.B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13(5): 1220-1222.

Watters, G.T. 2000. Freshwater mussels and water quality: a review of the effects of hydrologic and instream habitat alteration. Proceedings of the First Freshwater Mollusk Conservation Society Symposium. Pages 261-274.

Welte, N.T. 2014. A status assessment of Pennsylvania's freshwater mussels, utilizing NatureServe ranking methodology and rank calculator for application to the 2015 State Wildlife Action Plan. Pennsylvania Fish and Boat Commission, Bellefonte, Pennsylvania.

NOTE: Species of Greatest Conservation Need (SGCN) changes occurred after assessment report writing. Please reference Chapter 1 text and Appendix 1.3 for the final SGCN statistics and species list.

Invertebrate Conservation Status Assessment for the 2025-35 Pennsylvania Wildlife Action Plan

Final Report to the Pennsylvania Fish and Boat Commission
Prepared by the Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy
State Wildlife Grant Agreement PFBC 2022-0817.01 4100093356
19 November 2025

Table of Contents

Acknowledgements 3
Introduction 4
Methods 5
Species Selection 5
Data Sources 5
NatureServe Conservation Rank Calculator Assessments 6
Results 10
Discussion 17
SGCN assessment overview 17
Threats and Conservation Actions 18
Summary and considerations for future assessments 27
Literature Cited 30
Appendix 1. Data sources by taxa group 32
Lepidoptera – Butterflies and Moths 32
Odonates – Dragonflies and Damselflies 32
Ephemeroptera, Plecoptera, and Trichoptera – Mayflies, Stoneflies, and Caddisflies 32
Gastropods – Freshwater and Terrestrial Snails 33
Diptera –Flies 33
Hymenoptera – Wasps, Bees, Ants, and Sawflies 33
Other Invertebrates 34
Multi-taxon Sources 34
Appendix 2. Best Management Practices 37

Cover photos

Top left: Phacelia Miner Bee *Andrena phaceliae*

Top right: Appalachian Tiger Beetle *Cicindela ancocisconensis*

Bottom left: Beach Wolf Spider *Arctosa littoralis*

Bottom right: Hop-tree Ermine Moth *Prays atomocella*

Suggested citation: Leppo, B., M. Walsh, and P. Woods. 2025. A Comprehensive Status Assessment of Pennsylvania's Invertebrates for the 2025-35 Pennsylvania Wildlife Action Plan (exclusive of freshwater molluscs-bivalves and crayfishes), Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy *in* PGC-PFBC (Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission). Pennsylvania Wildlife Action Plan, 2025-2035. C. Haffner and D. Day editors. Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission, Harrisburg, Pennsylvania.

Acknowledgements

This project was funded by U.S. Fish and Wildlife Service, State Wildlife Grant Agreement F22AF03534; Agreement 2022-0817.01 4100093356, administered by the Pennsylvania Fish and Boat Commission.

Matching funding was provided by two Wild Resources Conservation Program grants: WRCP-22389: Invertebrate Databasing Project to Support Species Assessment and Conservation, and WRCP-21635: Conservation Ranking of Moths in Preparation for the 2025 State Wildlife Action Plan Update.

Introduction

Pennsylvania's Wildlife Action Plan (PA WAP, or "plan"), is a comprehensive strategy for managing and protecting the Commonwealth's fish and wildlife Species of Greatest Conservation Need (SGCN). As required by congress, each state and U.S. territory must comprehensively review and revise their plan at least once every 10 years to maintain eligibility for receiving federal State Wildlife Grant (SWG) funding. The first PA WAP was published in 2005 and subsequently revised in 2015. Each plan used the most current data to evaluate the conservation status, threats, actions, habitats, monitoring, and research and survey needs for Pennsylvania's wildlife, including mammals, birds, reptiles, amphibians, fish, and invertebrates.

The PA WAP is a proactive conservation framework identifying actions to avoid species listing as Endangered or Threatened under the Endangered Species Act (1973). Administered by the Pennsylvania Fish and Boat Commission (PFBC) and the Pennsylvania Game Commission (PGC), the agencies charged with regulating and protecting the Commonwealth's fish and wildlife, the PA WAP is for all Pennsylvanians to use and implement.

Through the comprehensive review and revision process, information is compiled from scientific experts across wildlife disciplines to determine SGCN and priority actions. The process to evaluate SGCN has evolved since the 2005-2015 PA WAP and it has become more standardized. The invertebrates of high conservation value were determined according to experts' best professional judgment (Rawlins 2007) and nearly 500 invertebrates were rated as priority species (akin to SGCN) in the plan. Additionally, the 2005-2015 PA WAP delineated threats, habitat management recommendations, and research needs for invertebrates.

Building on the previous plan, in the 2015-2025 PA WAP a standardized process was applied using criteria for SGCN status (based on a PA WAP Species of Greatest Conservation Need Flowchart in the 2015-2025 PA WAP, version 10.03.2014, Leppo 2015). To complete the SGCN evaluation, subnational ranks (S-rank) were determined. The total 664 SGCN in the 2015-25 PA WAP included 450 aquatic and terrestrial invertebrates based on selection criteria including global, regional, or state conservation concern, declining trends and high threats, or state responsibility for a substantial portion of a population. Invertebrate species reviewed in previous PA WAPs comprise a small portion of an estimated 11,000+ invertebrates in Pennsylvania (2013 PABS Box Score). In 2015, we noted resource constraints limited the number of species assessed and that other species and taxa groups should be included in future plans (Leppo et al. 2015). For the 2025-2035 plan, we reviewed the invertebrates considered SGCN in the previous plan to update their status and evaluated additional invertebrates. This project evaluated the conservation status, including threats, for 1,420 aquatic and terrestrial invertebrates, representing many rare and declining species, and giving much needed attention to the most diverse group of wildlife in the state.

Invertebrates constitute a large portion of Pennsylvania's biodiversity, pollinate plants including food crops, and are part of vital food webs essential to the health and functioning of our ecosystems. Invertebrates are chronically overlooked and underfunded for wildlife conservation efforts (Cardoso et al., 2011; Donaldson et al, 2016; Mammides 2019). Compared to megafauna, the lack of scientific information about many species of invertebrates and the lack of understanding by the public and policy makers about ecological services provided by invertebrates contributes to the lag in conservation. For instance, many species are undescribed; and for described species, their distribution is not well known, population characteristics, habitats, and threats are not well studied, and policy makers are not well-informed of the loss of invertebrate biodiversity and conservation needs (Cardosa et al. 2011).

Many challenges persist for invertebrates, but the PA WAP sets the stage for the future for their conservation in the Commonwealth. The PA WAP uses information about species known from Pennsylvania, classifies conservation status, assesses threats and prioritizes needs for invertebrates. Conservation assessment of invertebrates for the 2025-2035 PA WAP prioritizes the species for which conservation measures are needed and provides a blueprint for future actions.

Methods

Species Selection

With an estimated 12,000 to 32,000 species of invertebrates in Pennsylvania (2025 draft PABS Box Score), it was not feasible to evaluate all taxa for this effort, and we therefore focused our attention on a subset of species. We first prioritized reevaluation of the non-bivalve, non-crayfish invertebrates included in the 2015-25 Plan (399 SGCN, plus 61 additional data deficient species), using new data to determine if any species statuses had changed.

For the 2025-35 PA WAP, we aimed to evaluate 1,000 invertebrates not previously assessed and selected focal groups that fill important roles in various ecosystems (e.g., herbivores, pollinators, predators, parasitoids, decomposers, filter-feeders) and to represent the diversity of Pennsylvania invertebrates. Invertebrate species were from a wide variety of taxonomic groups including crustaceans, insects (terrestrial and aquatic), snails (terrestrial and aquatic), and other invertebrate groups (e.g., springtails, spiders, sponges, and flatworms). See Table 4 for a taxonomic breakdown of assessed species. The final species list was determined after we compiled and assessed species with data about range, rarity and threats.

NOTE: Freshwater mussels (bivalves) and crayfishes were assessed as part of separate projects and are not included in this report.

Data Sources

We used a multi-step selection process to evaluate species within groups, and began by compiling data to update Pennsylvania species checklists for our focal taxonomic groups. The intent was to document which species are currently in Pennsylvania (extant) and which species had records from a previous time but have since disappeared (historical or extirpated). We also identified species that entered the state in recent decades through human introduction or natural migration. Building these checklists was a painstaking process, vetting thousands of records, cross-walking old or invalid scientific names to the current ones, screening out potentially erroneous records, assigning historical or extant status, digitizing locality data for records that needed spatial representation, and flagging introduced or migratory species.

Since publishing the 2015-25 PA WAP, more specimen databases and community science records are available online. We gathered hundreds of thousands of invertebrate records from online data repositories including community science databases like iNaturalist, the Butterflies and Moths of North America (BAMONA), Odonata Central, and from aggregated databases of museum specimens like idigbio.org, Global Biodiversity Information Facility (GBIF.org), and Symbiota Collections of Arthropods Network (SCAN).

We also collated data from Pennsylvania Natural Heritage Partnership (PNHP) projects and databases, scientific journal articles, unpublished reports, and internal datasets maintained by museums and associated with the personal collections of local experts. Data were systematically compiled through collaborations with museums and researchers. For example, collections of bees, craneflies, and syrphid flies from the Academy of Natural Sciences and Drexel University's Entomology Collection were digitized using project funding in collaboration with Dr. Jon Gelhaus. Collaborators (Dr. Margarita López-Uribe, Dr. Nash Turley and others) at Penn State University's Entomology Department compiled bee specimen datasets with funding from a project subcontract. Additionally, beetle and moth specimens from Carnegie Museum's Entomology Collection were digitized by project staff. We also referenced scientific literature, unpublished reports, white papers, websites, and corresponded with species experts who provided the context essential to documenting the life history, threats, and conservation actions for potential SGCN. All data sources for taxa groups are in Appendix 1.

These many datasets were vetted and compiled into a standardized format that included coordinates formatted as decimal degrees, and an estimate of mapping precision that allowed us to analyze records spatially using a Geographic Information System (GIS) (ESRI-ArcGIS Pro, version 3.3.1).

NatureServe Conservation Rank Calculator Assessments

After updating species checklists and accumulating and standardizing species locality data, we then accumulated additional information to determine the conservation status for each species we potentially wanted to assess. Using the aforementioned data collation and consultation with taxa experts, we selected individual species important to assess based on apparent rarity or threats, and the additional information that was available to support a state conservation rank assessment.

State rank assessments were conducted using a standardized tool, the NatureServe Rank Calculator (Version 3.2, NatureServe 2020) with detailed guidance (Faber-Langendoen et al. 2012; Master et al. 2012). The NatureServe Rank Calculator collects and rates factors that characterize a species' occurrence and threats in the state. The calculator ultimately generates a state rank that estimates an element's risk of being lost from Pennsylvania. The sub-national (i.e., state) ranks range from 1-5, with S1 species most imperiled, and S5 species most secure. S-ranks spanning a range (e.g., S1S2 or S1S3) reflect uncertainty about the status, or rank factors straddle the line between categories. The numerical S-ranks and their summary definitions are:

S1 = critically imperiled

S2 = imperiled

S3 = vulnerable
S4 = apparently secure
S5 = secure

Other S-ranks include special cases such as:
SX = extirpated (virtually no likelihood of rediscovery)
SH = possibly extirpated (known only from historical occurrences, but potential rediscovery)
S#S# = range rank (used to indicate uncertainly about status, no more than 2 degrees of separation is considered valid)
SU – unrankable (lack of data or conflicting information about status or trends)
SNA = not applicable (species is not a suitable target for conservation activities, e.g., non-native or transient species)

Key factors determining state conservation rank of a species include the number, size, and distribution of populations (occurrences) that are known to occur in the state, both in the present and in the past. The criteria applied to the Rank Calculator depended on the available information. For invertebrate assessments, we typically used Number of Occurrences to represent the abundance of the populations, and Range Extent and Area of Occupancy to describe the species range and distribution. Records reported prior to 1995 were typically considered historical, however in some cases the bulk of information available for a taxonomic group was collected prior to 1995, and it was necessary to consider older records as likely extant, to assess the species. Population trends were included when sufficient data suggested a species was gaining or losing abundance in the state or remaining relatively stable over the short- or long-term. Population estimates are rarely available for invertebrate species and were not included in these assessments.

For the 2025-35 PA WAP species assessments, the Western Pennsylvania Conservancy GIS manager developed custom tools for ArcGIS Pro called the 'Rank Calculator Prep Toolbox' to automate calculating the core spatially derived statistics. This tool helped streamline and standardize spatial data aggregation and analysis. Application of the tool will be further described in the sections on number of occurrences, range extent, and area of occupancy.

Number of Occurrences

Our data sources often contained duplicate or overlapping observations of a species from a particular site, so we merged the overlapping records to avoid overestimating the number of occurrences present in the state. The 'Occurrence Grouping Tool' grouped observation and specimen-based records into occurrences, according to species separation distances. The tool groups closely occurring observations that may be part of a single interconnected population. The concept of separation distances was developed by NatureServe (2002). The separation distance varies by taxa group according to relevant life history and habitats. The separation distances can be found in the NatureServe Conservation Explorer, explorer.natureserve.org. The Occurrence Grouping Tool had an option for terrestrial and lentic species, which grouped observations using a straight-line separation distance, and an option for riverine species, which grouped occurrences using a separation distance along a stream network dataset built from a flowline feature class. After records were grouped using the appropriate tool, the number of occurrences was calculated for the Rank Calculator.

Range Extent

The Rank Calculator Prep Toolbox provides options for calculating range extent, which is a measure of area in square kilometers of a species' overall distribution within the state. The range extent at the subnational (state) level can range from statewide for broadly distributed species that are found all around the state, to a single site, watershed, or county for species with a very limited distribution in the state. The range extent for terrestrial and palustrine (wetland) habitats is calculated as the area in square kilometers of a convex hull polygon drawn around all known occurrences. For aquatic species, the Occupied Hydrologic Unit Code (HUC) Watershed is selected as the range extent type, and is calculated as the sum of area of occupied HUC watersheds in square kilometers. For subnation (state) level evaluations, we also typically clip the occupied area so that it does not exceed the subnational (state) boundary.

Area of Occupancy

The Rank Calculator Prep Toolbox also provides options for calculating area of occupancy. Animals have an overall range extent they do not fully occupy. For example, fairy shrimp are an aquatic crustacean that can only survive in suitable vernal pool wetlands. They will not be found anywhere else on the landscape, so area of occupancy is a measurement of how much suitable and occupied vernal pool habitat is found within the larger range extent. Area of occupancy is calculated by overlaying the state in 2x2 or 1x1 km^2 grid cells and summing the area of all grid cells that contain an occurrence of the evaluated species. Terrestrial and palustrine (wetland) habitat species typically use 2x2 km^2 grid cells in this calculation, while aquatic species using linear lotic habitats, like streams and rivers, typically use 1x1 km^2 grid cells.

Threats Assessment

Threats that contribute to a species' decline and potential extirpation are incorporated into the S-rank calculation. The NatureServe Rank Calculator features a detailed threats analysis that is used to assess the scope, severity, and timing of various threats, which combine to calculate an Overall Threat Impact level of low, medium, high, or very high definitions of threats, as applied in this assessment.

Additional Considerations

After state ranks were generated by the NatureServe Rank Calculator, PNHP staff reviewed the results and considered whether additional factors should be included in the rank determination. Life-history and other species information provided by taxonomic experts was particularly useful for interpreting, adjusting, and selecting various rank factors. PA Biological Survey (PABS) technical committee members were invited to provide feedback about the ranks that resulted from the assessment. For some invertebrate taxa groups (e.g., flatworms, grasshoppers, or fairy shrimp) no PABS experts were available to provide review, and our staff were responsible for determining those ranks using available data.

With general data deficiency we commonly incorporated a strategy of 'bracketing' values for range extent or number of occurrences into invertebrate assessments, depending on which criterion was applied. We often used range ranks for these factors in the NatureServe Rank Calculator, where we started with a value based on known occurrences to anchor the lower end of a split rank, and included a higher end estimate of the potential occurrences in the state based on expert opinion for determining a reasonable upper end that reflects a more likely true number of occurrences

Taxonomic experts from PABS who participate in the sub-committees of the Invertebrate Technical Committees provided data on species locations and life histories to PA Natural Heritage Program (PNHP) staff conducting assessments.

Species of Greatest Conservation Need Determination

The Pennsylvania Fish and Boat Commission and The Pennsylvania Game Commission provided criteria for SGCN determination, in the form of a flow chart. Using the flow chart, we determined which of our evaluated species were SGCN, which were Data Deficient, and which were not SGCN.

We applied the factors in the Animal Species of Greatest Conservation Need (SGCN) Determination flowchart (Pennsylvania Fish and Boat Commission and Pennsylvania Game Commission, personal communication) to the species evaluated. As of the time of this report writing the criteria in the flow chart have not been formally finalized and the chart is not included here.

Throughout this assessment process we determined that many species did not have sufficient information on one or more key factors to reasonably assess their conservation status. These species were given a state rank of SU (status undetermined) and were data deficient for SGCN status. In some cases, species were assigned a state rank but were still considered data deficient for SGCN status based because of insufficient knowledge of threats or conservation actions. This information was required for species with SGCN designation (Pennsylvania Fish and Boat Commission and Pennsylvania Game Commission, personal communication).

Information on species assessed for the 2025-35 PA WAP was standardized in the Pennsylvania Wildlife Action Plan Species Account Database. We entered the assessed S-rank into the database, and for SGCN additional information included the habitat, threats, conservation actions, monitoring, research, and survey needs. We suggested conservation actions to address threats to SGCN species and to maintain and recover populations.

Results

We completed 1,420 invertebrate conservation status assessments to support 2025-35 PA WAP development. There were 399 taxa rated as SGCN and 61 classified as Data Deficient from the 2015-25 PA WAP SGCN. An additional 960 species were assessed for the first time (Table 4).

Updated status of 2015-25 SGCN

In this section, we summarize findings and changes in S-ranks from the 2015-25 PA WAP (Figure 1). A species' rank may be adjusted because of: 1) actual changes in the species' abundance, 2) enhanced data allowing more accurate assessment of the species' abundance and range to correct previous errors, or 3) a different understanding of threats to the species.

In seven cases, we downgraded species previously ranked as S1 to S4, to SH (Historic) (Table 1). This typically happened because there were no new records for the species, and the existing records were more than 30 years old. In the case of the Rusty Patched Bumblebee *Bombus affinis*, the most recent record was from 2006, but there has been enough survey effort following the species' dramatic decline we consider the probability of its persistence in Pennsylvania to be low.

In five cases, we downgraded species previously ranked SH, to SX (Table 2). Despite adequate survey effort, these species had not been seen for many decades, and we had no realistic hope they persist in Pennsylvania.

Twelve species previously ranked as SH in 2015, and one ranked as SX, were re-ranked as extant (S1 to S4) (Table 3). In most cases, these re-rankings were based on field observation since 2015. However, for the Vernonia Borer Moth *Papaipema limpida* and the Sunflower Borer Moth *P. necopina*, specimens had been collected in the late 1990s, but we only became aware of them during this analysis.

2025 S-Ranks

2015 S-Ranks	SNA	SU	SX	SH	S1	S2	S3	S4	
S4						1			1
S3						26	62	42	130
S2		1		5	2	82	38	4	132
S1	1			4	25	44	5		79
SH		3	5	31	1	8	3		51
SX	1		2		1				4
SU		1		1					2
	2	5	7	41	29	161	108	46	

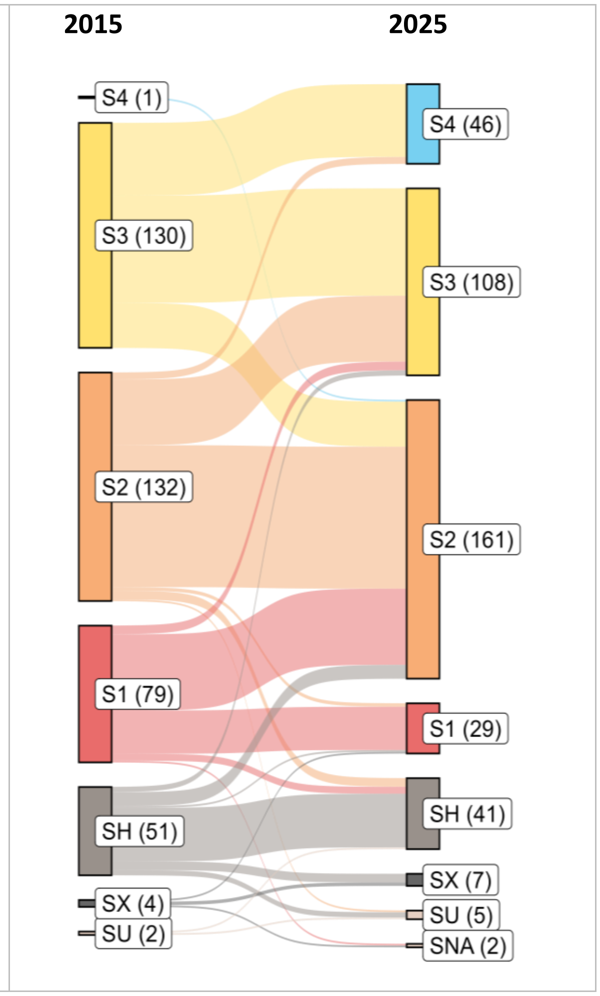


Figure 1. For Species of Greatest Conservation Need from 2015, S-ranks from 2015 and 2025 are compared. Rounded S-ranks are presented here to reduce the number of categories for simplicity. For example, S2, S2?, S2S3, and S1S3 all round to S2 (see the NatureServe website for more details on rounding: https://www.natureserve.org/nsexplorer/about-the-data/statuses/conservation-status-categories). On the left is a table showing the number of species of each rank in 2015, and the numbers of species that switched ranks in 2025. Gray squares indicate no change in rounded rank. On the right is a Sankey diagram of the same data, showing the numbers of species that moved between categories. Note that for those species that changed rounded rank, most became one rank more common.

Table 1. Species of Greatest Conservation Need considered extant in 2015, then re-evaluated and determined to be state historic (SH) in the 2025 conservation status assessment. No Pennsylvania records within the last 30 years are known for these species (except for *Bombus affinis*, last seen here in 2006, when the regional collapse of the species was happening).

Taxon Group	Common Name	Scientific Name
Bumblebees	Rusty-patched Bumble Bee	*Bombus affinis*
Butterflies and Skippers	Mottled Duskywing	*Erynnis martialis*
Caddisflies	Vannote's Cheumatopsyche Caddisfly	*Cheumatopsyche vannotei*
	A Free-living Caddisfly	*Rhyacophila otica*
Dragonflies and Damselflies	Taiga Bluet	*Coenagrion resolutum*
	Extra-striped Snaketail	*Ophiogomphus anomalus*
Stoneflies	Stonyfork Snowfly	*Allocapnia harperi*

Table 2. Species of Greatest Conservation Need considered Historic (SH) in 2015, meaning that their continued presence in the state was uncertain, then re-evaluated and determined to be Extirpated (SX) in the 2025 conservation status assessment.

Taxon Group	Common Name	Scientific Name
Butterflies and Skippers	Dusky Azure	*Celastrina nigra*
Dragonflies and Damselflies	Attenuated Bluet	*Enallagma daeckii*
Moths	Hop Vine Borer Moth	*Hydraecia immanis*
Other Beetles	Ghost Tiger Beetle	*Ellipsoptera lepida*
Tiger Beetles	Festive Tiger Beetle	*Cicindela scutellaris*

Table 3. These Species of Greatest Conservation Need were ranked Historic (SH) or Extirpated (SX) in 2015 but are considered extant in the 2024-25 conservation status assessment. Most of these cases were rediscoveries of the species in the field since 2015, but in a few cases (*Papaipema limpida* and *P. necopina*) we uncovered older records that are still within the 30-year cutoff.

Taxon Group	Common Name	Scientific Name
Dragonflies and Damselflies	Appalachian Jewelwing	*Calopteryx angustipennis*
	Atlantic Bluet	*Enallagma doubledayi*
	Stripe-winged Baskettail	*Epitheca costalis*
	Furtive Forktail	*Ischnura prognata*
	Yellow-sided Skimmer	*Libellula flavida*
	Saffron-winged Meadowhawk	*Sympetrum costiferum*
Grasshoppers, Katydids, and Crickets	Appalachian Grasshopper	*Appalachia hebardi*
Moths	Yellow Stoneroot Borer Moth	*Papaipema astuta*
	Vernonia Borer Moth	*Papaipema limpida*
	Sunflower Borer Moth	*Papaipema necopina*
	Franck's Sphinx	*Sphinx franckii*
Stoneflies	Lobed Stone	*Acroneuria internata*
Terrestrial Snails	Striped Whitelip	*Webbhelix multilineata*

Overall results: S-ranks and SGCN determinations

Of 1,420 species assessed, 806 species met SGCN selection criteria and 381 species are Data Deficient. Of the 399 non-bivalve, non-crayfish invertebrate SGCN from 2015, 303 of them are maintained as SGCN, and 96 are removed from SGCN status (Figure 2; Table 4). The largest groups of 2025-35 SGCN are Lepidoptera (moths and butterflies) and Hymenoptera (bees and wasps), together comprising just over two thirds of the invertebrate SGCN list (Figure 2). 630 SGCN are terrestrial species, while 176 are aquatic (spending at least one life stage mainly submerged in water).

Species that were not considered SGCN in 2025 included those:

- that have a state conservation rank of S4 (apparently secure) or S5 (secure);
- which are considered extirpated in Pennsylvania with no realistic hope for recovery;
- which may occasionally occur in Pennsylvania, but do not have stable breeding populations;
- whose presence in Pennsylvania was based on misidentified specimens (such as the Toothless Column Snail *Columella columella*);
- which are no longer considered valid species (such as Snetsinger's Purseweb Spider *Atypus snetsingeri*, which had been considered an endemic species, until it was found to be an introduced population of an Asian species);
- whose threats are not well-understood and therefore conservation actions could not be specified;
- whose threats are known but for which we have been unable to identify substantive actions.

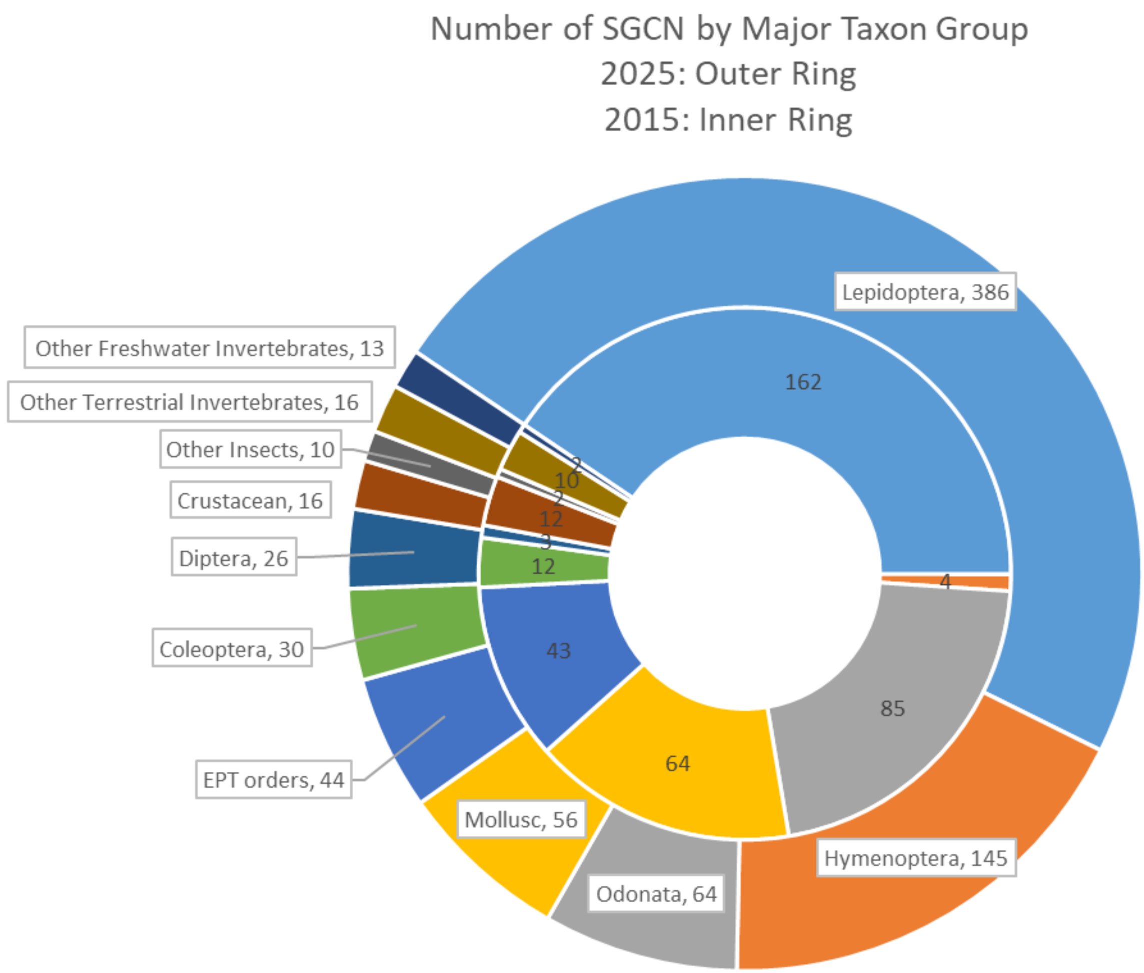


Figure 2. Number of Species of Greatest Conservation Need (SGCN) in each major taxonomic group in the 2025-35 PA WAP (outer ring) and in the 2015-25 PA WAP (inner ring). Note that Lepidoptera (moths and butterflies) and Hymenoptera (bees and wasps) make up over two thirds of the SGCN in 2025. (EPT = Ephemeroptera, Plecoptera, and Trichoptera).

Table 4. Summary statistics for each taxonomic group are presented, including number of Species of Greatest Conservation Need (SGCN) recognized in 2015, number of species evaluated in 2025, number of SGCN recognized in 2025, number of data deficient species recognized in 2025, number of SGCN from 2015 maintained as SGCN in 2025 (Maintain), number of SGCN newly added in 2025 (Add), and number of SGCN from 2015 that are no longer recognized as SGCN (Remove).

Taxon	SubTaxon	SCGN 2015	S ranks evaluated 2025	SCGN 2025	Data Deficient 2025	Maintain	Add	Remove
Crustacean	Amphipods, Copepods, and Isopods	12	14	13	1	12	1	0
	Fairy, Clam, and Tadpole Shrimps	0	3	3	0	0	3	0
	Other Crustaceans	0	1	0	1	0	0	0
Freshwater Invertebrate	Flatworms	1	1	1	0	1	0	0
	Sponges	1	14	12	0	1	11	0
Insect:Coleoptera	Fireflies	0	9	1	7	0	1	0
	Tiger Beetles	9	11	10	1	9	1	0
	Other Beetles	3	52	19	23	1	18	2
Insect:Diptera	Hover Flies	0	9	3	6	0	3	0
	Other Flies	3	153	23	92	1	22	2
Insect:EPT	Caddisflies	7	43	14	22	2	12	5
	Mayflies	15	46	5	29	2	3	13
	Stoneflies	21	43	25	13	14	11	7
Insect:Hymenoptera	Ants	0	1	1	0	0	1	0
	Bumble Bees	3	9	6	2	1	5	2
	Sawflies, Horntails, and Allies	1	2	2	0	1	1	0
	Solitary Bees	0	194	124	50	0	124	0
	Other Hymenoptera	0	22	12	8	0	12	0
Insect:Lepidoptera	Butterflies and Skippers	51	59	42	1	42	0	9
	Moths	111	438	344	38	97	247	14
Insect:Odonata	Dragonflies and Damselflies	85	94	64	1	61	3	24
Insect:Other	Grasshoppers, Katydids, and Crickets	1	38	5	30	1	4	0
	Other Insects	1	9	5	2	1	4	0
Marine Invertebrate	Marine Crustaceans	0	1	0	1	0	0	0
Mollusc	Freshwater Snails	16	39	21	5	14	7	2
	Terrestrial Snails	48	86	35	40	35	0	13
Other Terrestrial Invertebrate	Diplurans, Springtails, and Proturans	1	1	1	0	1	0	0
	Spiders and Harvestmen	9	28	15	8	6	9	3
Total	**total**	**399**	**1420**	**806**	**381**	**303**	**503**	**96**

**In this report, assessments for crayfishes and freshwater mussels are not included. They were completed by David Lieb and Nevin Welte (PNHP-PFBC), respectively, as part of separate State Wildlife Grants.*

Selected Taxa Groups

For six of the taxa groups we have well-vetted species lists and ranked or attempted to rank all of the species (Figures 3 and 4). The new S-ranks assessed in this project give us a revised comprehensive view of these groups.

Thirty-five percent (35%) of butterflies and skippers are S3 (vulnerable) or rarer. Twenty-six percent (26) of the species are ranked SNA (conservation rank not applicable), in most cases because they are migrants or vagrants that don't have permanent populations in the state (Figure 3a). Among the odonate (damselflies and dragonfly) species, 79% were assessed as S5 (secure) or S4 (apparently secure), a higher rate than for the other groups presented here (Figure 3b). For terrestrial snails, 40 species are ranked SNA because they are introduced species, and 36 other species are ranked SU (unrankable) or SNR (not ranked) because there is uncertainty about the taxonomy or specimen identification that prevent them from being ranked (Figure 3c).

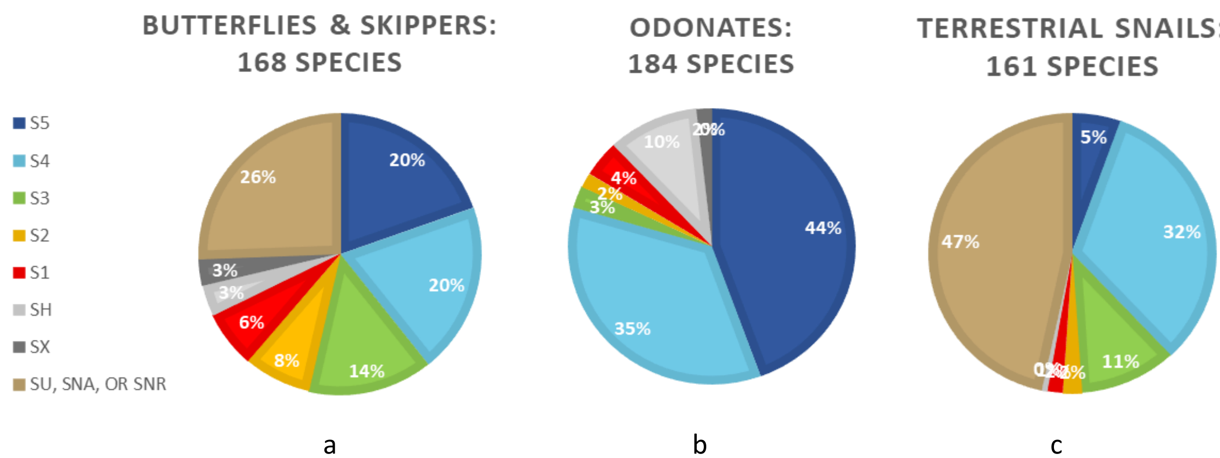


Figure 3a-c. Proportions of (a) butterflies and skippers, (b) dragonflies and damselflies, (c) terrestrial snails by rounded S-rank as assessed for the 2025-35 PA WAP. Note that the butterflies have a high proportion of vagrant species not permanently established (SNA, in brown), the odonates have a higher proportion of secure species (S4 and S5) than other groups, and the terrestrial snails have a high proportion of introduced species (SNA) and species with questionable taxonomy or uncertain identifications (SU and SNR).

Fourteen freshwater sponge species are known from Pennsylvania, but only six of them have been found in recent decades. Two species are considered apparently secure (S4), and four are considered vulnerable (Figure 4a). For the 2025-35 PA WAP, eleven species were newly added as SGCN. Recent survey efforts in the Ohio River watershed have contributed valuable records, but missing species may yet be found with more effort across the state. Recent survey efforts have been directed to tiger beetles, allowing us to refine the conservation status of three of the species. Five of nineteen species (37%) are considered secure (S5) or apparently secure (S4), and ten species (53%) are rated as SGCN (Figure 4b). Data from studies directed to stoneflies provided a comprehensive species list, with sufficient threats information allowing 23% to be ranked S1-S3 and 18% to be considered SGCN (Figure 4c).

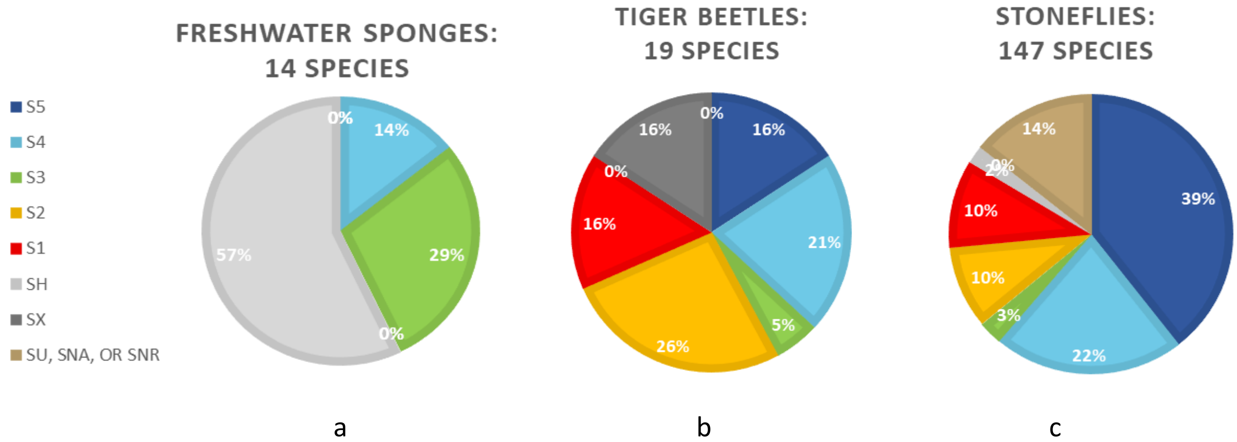


Figure 4a-c. Proportions of (a) sponges, (b) tiger beetles, (c) stoneflies by rounded S-rank as assessed for the 2025-35 PA WAP. Note that sponges and tiger beetles have low proportions (14% and 37%, respectively) of secure (S5) or apparently secure (S4) species. Stoneflies are relatively more secure, with 18% of the species recognized as SGCN.

Discussion

SGCN assessment overview

Through this data compilation and assessment we have greatly expanded the understanding of foundational taxonomic groups which had not been previously evaluated for the PA WAP. From this work we developed conservation rankings and SGCN assessments for over 1,400 species, of which 303 species will be maintained from the 2015-25 PA WAP and 504 *new* SGCN to be added to the 2025-35 PA WAP, including many taxa groups not in the 2015-25 PA WAP. This increase in SGCN from the previous PA WAP is directly related to additional effort and the resources committed through this project. Comprehensive datasets developed over the past 10 years enabled approximately three times the number of species assessments since the prior effort (i.e., 2014-15). Nevertheless, this assessment represents a small portion of work required to understand the status and needs of Pennsylvania's invertebrates.

For the 2025-35 PA WAP we specifically sought information for underrepresented taxa groups in the 2015-25 PA WAP, such as sponges, fireflies, beetles, craneflies, solitary bees, moths, and terrestrial snails. This invertebrate data compilation and assessment for Pennsylvania was the most comprehensive effort to-date accounting for approximately 14% of the estimated 11,000 Pennsylvania invertebrates species.

Ninety-five (95) SGCN were removed from the list, typically due to:

– additional data showing the species to be more common than previously assessed.

- the species having an increasing trend in the state, often linked to climate and/or a shift in a species biology allowing it to use more habitats.
- a change in how we treat species with uncertain threats and conservation actions causing some species to be moved from 2015 SGCN to data deficient in 2025.

Threats and Conservation Actions

Threats are a key component of the 2025-35 PA WAP, which documents the actions needed to decrease imperilment for SGCN. Threats to invertebrates by taxa group were previously described in Leppo et al. (2015) and many of the same threats remain today. In this section we discuss the commonly observed threats to invertebrates assessed for the 2025-35 PA WAP and key recommended conservation actions.

Threat types and levels (low to very high), identified during the process of determining state ranks of invertebrates with the NatureServe Rank Calculator, were documented for the 2025-35 PA WAP. All high- and very high-level threats were entered in the Pennsylvania Wildlife Action Plan Species Account Database. For species without known high or very high-level threats, one to three low- or medium-level threats were entered into the database. Conservation actions to ameliorate threats were recommended for SGCN and documented in the database.

Recommending actions based on known threats focuses attention on key threats with actionable conservation measures, given limited resources to address species' needs. However, readers should consider that not all threats to invertebrates assessed are well-documented and those identified may not be complete list of issues; conservation actions to genuinely improve SGCN imperilment may be very complex or prohibitively costly.

SGCN invertebrates were found to be most impacted (i.e., having medium- or high-level threat levels) by the following threats:

- **residential and commercial development** related to housing and industrial areas;
- **pollution** from domestic, municipal, industrial sources including sewage, wastewater, agricultural run-off, or air pollution;
- **natural system modifications** such as loss of habitat from succession, prescribed fire and wildfire suppression, dams and water management;
- **agriculture and aquaculture**, including the conversion of natural lands to cropland, ranchland, and plantations and related habitat degradation;
- **invasive and other problematic species, genes and diseases**, such as introduced plants, animals, pathogens and other microbes that cause harm to native species and the environment (e.g., beech disease, emerald ash borer, rusty crayfish, spongy moth). Additionally, native organisms that outcompete SGCNs may be problematic;
- **transportation and service corridors** such as dirt and paved roads, railroads, shipping lanes, and powerline and pipeline rights-of-way;
- **energy production and mining** including mining and quarrying and dredging;
- **climate change and severe weather** – climatic instability causing droughts, temperature extremes, storms and flooding, and shifts in habitats and species' ranges;
- **biological resource use** including hunting, fishing, collecting animals, gathering plants, logging, and firewood cutting and salvage;

- **human intrusions and disturbance** such as recreational activities and military training.

We next provide an assessment of these threats and, where feasible, potential actions to address the threats.

Pollution and habitat loss related to land use changes

Threat(s): Large scale changes in Pennsylvania's natural landscapes continue to threaten invertebrate conservation, and converting natural landcover types to agriculture and development (residential and commercial) remains a widespread threat. In 2016, nearly one-quarter (22%) of lands had been converted to agriculture and 12% developed (2020 State Land Use and Growth Management Report). The rate of change from natural to developed land cover was rapid in the five preceding years, developed areas (measured by acres of landcover) had increased by 4.5%, likely due to increasing human populations in northeastern and southeastern Pennsylvania.

For SGCN invertebrates, agriculture or residential and commercial development was associated with habitat loss and degradation. There are few remaining examples of high-quality habitats of limestone streams and related habitats as they often coincide with intensive agricultural land use areas. For aquatic invertebrates requiring specialized limestone streams habitats, there is little habitat in Pennsylvania without the influence of agriculture including water pollution from farm runoff and habitat degradation from siltation. Species occurring where urban development dominates the landscape, (e.g., Coastal Plain habitats in southeastern Pennsylvania), are also subject to stormwater runoff that degrades water quality and scours aquatic habitats. The cranefly *Tipula dejecta* is primarily documented from the suburban Philadelphia region and the central Pennsylvania Ridge and Valley agricultural region; in both locations aquatic habitats are degraded from water pollution related to land use.

Pennsylvania's extensive history of resource extraction, including coal mining, also greatly altered wildlife habitats. Species in areas with historic or current coal mining in the bituminous and anthracite coal regions, habitats and water quality are also greatly degraded with more than 5,500 miles of acidified waters and/ or polluted by iron or aluminum from mine drainage. Threats to aquatic organisms include poor water quality and metal precipitates that coat aquatic substrates. Watersheds inhabited by the stonefly, Appalachian Forestfly *Amphinemura appalachia*, have mine drainage and stream impairment.

Recommended action(s): Implement best management practices to ameliorate conditions related to water quality and habitat degradation from agriculture, development, or mining.

Aquatic invasive species

Threat(s): Problematic exotic species introduced to waterways are threats to SGCN because of resource competition, habitat degradation, ecosystem alteration, or other detrimental effects. Invasive snails, like the small New Zealand Mudsnail *Potamopyrgus antipodarum*, have spread across several basins in Pennsylvania, likely transported on fishing gear. Round Goby *Neogobius melanostomus*, a recent transplant to Lake Erie and Allegheny River basin, may compete with native benthic fish and consume native freshwater mussels and snails, including rare species.

Recommended action(s): Outreach and education actions to reduce future aquatic invasive species introductions are recommended. For example, it is expected that recreationists informed about ecological harm posed by Round Goby, would be less likely to dump a bait bucket into a waterbody and enabling the spread of infestation.

Invasive Bees

Threat(s): Exotic bee species introductions have negatively affected native bees due to interspecific competition and pathogens brought by introduced bees.

The European Honey Bee *Apis mellifera* has been in North America for centuries, but it has only recently been understood that competition with honey bees for floral resources can be detrimental to native bee populations. Additionally, pathogens carried by honeybees can be transferred to native bees, with deleterious effects.

The movement of bumble bees between Europe and North America is suspected to have introduced a new strain of the microsporidian fungus, *Vairimorpha bombi,* to North America. This fungus has played a major role in the severe decline of many North American bumblebees, including the Rusty Patched Bumblebee *Bombus affinis* and Ashton Cuckoo Bumblebee *B. ashtoni*, both of which may now be extirpated in Pennsylvania, and the Pennsylvania Bumblebee *Bombus pensylvanicus*, which has declined less severely.

Mason bees *Osmia* spp. have long been appreciated for pollinating orchards, but this has led to the introduction of exotic bees and the pathogens they carry. The Hornfaced Mason Bee *O. cornifrons* was intentionally introduced from Japan in 1978 for pollinating orchards. The Taurus Mason Bee *Osmia taurus* was an accidental introduction first detected here in 2002. These bees are believed to have brought with them a parasitic wasp *Monodontomerus osmiae* and two species of chalkbrood fungus *Ascosphaera* spp. The fungi have spread to native mason bees and are suspected to be a primary cause of the catastrophic declines now observed in native mason bees. Declines of 10 to 16 percent per year have been observed in six native mason bees in the mid-Atlantic region. These six species also live in Pennsylvania, along with five other native mason bees that may be experiencing similar declines.

Recommended action(s): How to directly address spread of these fungi affecting bees is unknown, but actions addressing general pollinator needs would reduce stressors that may contribute to the observed declines.

Asian Lady Beetle

Threat(s): Asian Lady Beetle *Harmonia axyridis* introduction to North America for pest-control purposes has devastated populations of some native lady beetles. Notably, the Two-spotted Lady Beetle *Adalia bipunctata* and the Nine-spotted Lady Beetle *Coccinella novemnotata* were previously ubiquitous across Pennsylvania, and they have now been extirpated or nearly extirpated from the state. Asian Lady Beetles directly compete with native lady beetles for food, and prey on them, but the main factor contributing to the loss of these two lady beetles is probably the microsporidian fungal parasites that are carried by Asian Lady Beetles. The Asian Lady Beetles do not suffer from the fungus, but they pass it to other lady beetles, some species of which are highly vulnerable to it.

Recommended action(s): For the two native lady beetles mentioned above we are currently unaware of restorative conservation actions. Consequently, with no identifiable action, we categorize them as Data Deficient.

Emerald ash borer

Threat(s): Emerald Ash Borer EAB, *Agrillus planipennis*, introduced from Asia to North America around 1990, has devastated populations of ash trees *Fraxinus* spp. (Family Oleaceae), and this tree loss threatens at least 33 invertebrates throughout Pennsylvania with extirpation, or even extinction. EAB was first detected in Pennsylvania in 2007 and subsequently spread to every county by 2019. EAB caused mortality in ash trees larger than a few inches in diameter, except for a small number of mature trees receiving insecticide treatment.

The threat is especially high to the approximately 100 North American invertebrates highly dependent on ash trees, and at least 33 of those occur (or occurred) in Pennsylvania. Of the ash-dependent invertebrates, those requiring mature trees for habitat or food resources are now believed to extirpated from Pennsylvania. Likely extirpated are invertebrates that consume ash seeds, that live in the inflorescences, or which inhabit the bark and wood of mature trees. Other invertebrates can survive on ash saplings, which are still abundant in Pennsylvania forests. Several of these invertebrates are still common as of 2025, but ash saplings are a dwindling resource which will eventually disappear as the seed bank is depleted. In the 2015-25 PA WAP, 12 ash-dependent invertebrates were recognized as SGCN and, in the interim, focused surveys and community science have brought the total to 33 species in 2025. Extinction of many of these ash-dependent invertebrates appears likely in the coming decades as EAB persists and remaining ash trees are decimated.

Recommended action(s): Four parasitoid wasps from Asia are now deployed as biological control agents for EAB, and three of them have become locally established. However, early data suggest these wasps have a limited effect on EAB and are not, by themselves, a magic bullet that will restore ash trees to their former abundance. Some of the ash-dependent invertebrates have been documented on other trees and shrubs of the Oleaceae family, including the Fringetree *Chionanthus virginicus*, native but rare in Pennsylvania, and introduced privets *Ligustrum* spp. and lilacs S*yringa* spp. It remains unclear if any of these hosts can sustain populations of these invertebrates.

Beech Leaf Disease

Threat(s): As the EAB swept through Pennsylvania's forests, another ecosystem threat was also spreading quickly. Beech Leaf Disease (BLD), first seen in Lake County, Ohio in 2012, is caused by an invasive nematode *Litylenchus crenatae mccannii.* It attacks leaves of American beech *Fagus grandifolia* and all other species of beech *Fagus* spp. BLD is easy to diagnose when infected leaves develop a distinctive banded pattern that forms as long linear cells in the leaves turn dark. BLD has spread very rapidly over the past thirteen years and is now found in the eastern United States, parts of Canada, and all 67 counties of Pennsylvania.

Research in Ohio has captured the trajectory of this outbreak in the decade since it was first observed. Nearly 30% of the beech trees within the initial impact zone have died, with mortality increasing as the disease progresses. The highest rates of mortality to-date have been in medium and small trees less than 25 cm diameter at breast height, and in denser stands of beech (Shepherd et al., 2025). Loss of beech at this rate will cause stand-level changes in forest composition, with far reaching effects into the connected terrestrial and aquatic ecosystems. American beech is a keystone species that has an oversized impact on forests where it is prevalent, such as our vast northern hardwoods, and the tuliptree-beech-maple forests of the western Allegheny Plateaus.

Recommended action(s): No effective controls that can be applied to large tracts of forest are currently available to curtail this disease. Many vertebrate and invertebrate wildlife species will be impacted by decline and loss of beech trees. Beech trees produce highly nutritious nuts for wildlife, but they don't produce them in substantial amounts until they are 40 to 60 years old. Monitoring and research is needed into these impacts, as well as into potential conservation actions that can help mitigate those impacts. For the 2025-35 PA WAP, we identified several SGCN that we expect will be highly impacted, including the Early Hairstreak Butterfly *Erora laeta* whose caterpillars feed on the beech leaves and fruits. The Eastern Ironclad Beetle *Phellopsis obcordata* and the Six-banded Longhorn Beetle *Dryobius sexnotatus* are associated with old growth hemlock-beech forests, where beech trees provide key resources to support their life cycles.

Spongy moth

Threat(s): Spongy Moth *Lymantria dispar* is an introduced forest pest, and in 2022 its common name was updated according to guidelines provided by the Better Common Names Project of the Entomological Society of America (ESA 2022). Spongy moth refers to the sponge-like egg masses produced by the females. Their populations tend to go through boom-and-bust cycles. High densities of spongy moths can lead to severe defoliation of oaks and other trees and shrubs. Healthy trees can usually survive one year of defoliation, though in severe outbreaks lasting multiple years, repeated defoliations can weaken and kill trees, especially ones coping with other stressors.

Recommended action(s): Management by Pennsylvania Department of Conservation and Natural Resources (DCNR) on state and federal forest lands suppresses infestations. We recommend that effort be supplemented by other organizations that manage forests on other lands.

A variety of mechanical and chemical control options can be applied to manage spongy moths. However, these control options can also harm native and beneficial insects (Schweitzer 2004). It is important to apply control measures that are appropriate given the specifics of the location and severity of the outbreak. DCNR's spongy moth webpage provides information and control options for the spongy moth (DCNR 2025). For serious infestations, where pesticides are justified to prevent tree mortality, individuals may consult with the DCNR Bureau of Forestry to determine the best approach. Use the PA Conservation Explorer tool to check for local rare insects prior to applying pesticides and apply best practices to minimize impacts to non-target species.

Broad spectrum insecticides like carbaryl (active ingredient in Sevin) and diflubenzuron (active ingredient in Dimilin) should not be used to control spongy moth, as options targeting Lepidoptera (i.e., moths and butterflies) are available such as Btk *Bacillius thuringiensis kurstaki* and tebufenozide (active ingredient in Mimic).

Climate Change

Threat(s): A changing climate due to increased carbon emissions and an elevated global temperature impacts a variety of habitats and SGCN in Pennsylvania. Climate change threats to aquatic SGCN are related to altered hydrology, including more intense flooding, reduced ice cover, frequent droughts and saltwater intrusion to coastal habitat (PA DEP 2025). Scour of river habitats from severe flooding may remove habitats and displace rare species. Species may experience ambient temperatures warmer than typical for Pennsylvania and, coupled with droughts, aquatic habitats may become unsuitable. Pond water levels may decrease and water temperatures increase. With warmer temperatures and altered conditions, some invasive species and pathogens may expand their range or be harder to control. For example, the warmer and dryer forest conditions occurring due to climate change impede biocontrols for the invasive spongy moth (Liu et al 2025). Habitats for warm water habitats fishes are predicted to increase in the United States by 31%, which could enable the expansion of fish like Smallmouth Bass *Micropterus dolomieu* (non-native in the Atlantic basins in Pennsylvania) or other species into waters that are currently thermally limiting (Rahel and Olden 2008). Non-native smallmouth bass can decimate the native fish community.

Climate change impacts many terrestrial invertebrates, including their life cycles which are tied to the plant phenology. Additionally, invertebrates have specific habitat requirements related to temperatures and seasonal conditions. Moths and butterflies have a tightly coupled synchrony between larval stages and host plants. With patterns of shorter winters and warmer springs, plants are shifting the timing of leaf out and blooming. Sixty percent of herbivorous insects in Europe are out of sync with the plants they require due to changing phenologies (British Ecological Society 2023). Another example of invertebrate life cycles tied to climate are fireflies, which require moist habitats in soil, leaf litter or rotting wood for larval and pupal stages (Paul 2025) and that dry soil conditions results in lower firefly abundance (Evans et al. 2018). Alteration of typical precipitation cycles linked to intensified storms or droughts from climate change, may result in altered moisture in firefly habitat and decrease larval survival.

Recommended action(s): From the examples above, complex direct and indirect climate change effects, support focused invertebrate conservation planning to identify needs and suggest mechanisms to mitigate climate change related threats.

Pesticides

Threat(s): Pesticides, especially neonicotinoids and pyrethroids, are a general growing threat to pollinators and to invertebrates (Ara and Haque 2021; Singla et al. 2020). Pesticides can travel through plants, the air, the soil, the water, and the food web, reaching far beyond the place and time they were applied. There is a widespread increasing use of these two classes of pesticides, despite the threats they present.

Recommended action(s): Integrated Pest Management methodologies minimize pesticide use. Reconsidering regulations based on simplistic models of bee biology would provide policy based on sound science. Informing gardeners and farmers about harms posed by these pesticides, and broader purchasing options, would allow them to make safer choices.

Loss of Early Successional Habitats

Threat(s): Many invertebrates in Pennsylvania are found in open habitats like grasslands, old fields, wet meadows, pine-oak barrens, and woodland glades. Pollinating insects need sunlit habitats because they provide abundance and variety of flowering plants for pollen and nectar. Predators, like dragonflies and robberflies, hunt in old fields and riparian meadows. Open habitats also provide the specific nesting and overwintering conditions that many species such as certain ground nesting bees. Grassland and meadow habitats have been destroyed by development and agriculture, degraded by invasive species, and lost to the natural process of succession.

Recommended action(s): Conservation actions for open habitat species should protect remaining habitat patches, restore degraded habitats or create new ones, and connect isolated habitats with green corridors. Mowing and prescribed fire are effective for creating and maintaining early successional habitats.

Wildlife Habitat management plans should consider invertebrate SGCN life histories alongside vertebrate SGCN. This will help identify where management activities may be adjusted to benefit more species and avoid unintentional negative impacts. Before starting habitat restoration projects, baseline inventories for invertebrates should be conducted across a minimum of one growing season. Broad inventory across a variety of invertebrate taxonomic groups is ideal, but studies that focus on a few better known groups are helpful as well. Large and diverse insect groups, like butterflies and moths, beetles, and bees contain many specialists whose presence would indicate important microhabitats. Baseline inventories should include an assessment of floral resources and food plants that support specialist feeders.

Baseline inventories on invertebrates, their unique microhabitats, and important food plants will allow managers to give these species and resources special consideration during management. In this way, better known taxa groups, such as butterflies, can serve as an umbrella for lesser-known invertebrates sharing similar habitat needs. Post-management monitoring is also important to ensure sensitive species and key resources are maintained. Partnerships across agencies and with museums and other taxonomic experts is an excellent way to add capacity to studies that wish to be more inclusive of invertebrate biodiversity. Resources are available to provide in-depth information on habitat management for pollinators, including the PNHP online guide to habitat management for pollinators that links to other useful resources (PNHP, 2023, see Appendix 2: Best Management Practices).

Habitat Specialists: Old Growth

Old growth forests are recognized as special habitats in Pennsylvania, with high ecological value due to the large trees and largely undisturbed understory and forest floor. PA DCNR supports research on old growth forests to better understand their distribution across Pennsylvania, document current conditions, and prioritize sites for protection and restoration. The role of old growth forests in carbon sequestration is also an important consideration for climate change mitigation strategies.

Invertebrates form unique assemblages and reach higher diversities in old growth forests in comparison to younger forests because of the stable environment old forests provide, with moderated temperatures and moisture conditions (Schowalter 2017). The old trees and accumulation of large woody material on the ground provides diverse microhabitats for invertebrates including herbivores, fungivores, detritivores, bark and wood borers, and the many predators and parasitoids that feed upon them. Invertebrates are an important component of old growth ecosystem through their effects on primary production and contributions to decomposition and nutrient cycling. Several species reviewed for the PA WAP are associated with old trees and forests include the Eastern Ironclad Beetle *Phellopsis obcordata*, Six-banded Longhorn Beetle *Dryobius sexnotatus*, Black Lordithon Rove Beetle *Lordithon niger*, and the American Golden Longhorn Fly *Callicera erratica*. More research is needed about the life history requirements of these and other invertebrates of old growth forests.

Threat(s): Remnant old growth forest is exceedingly rare in Pennsylvania; nearly all forests have been cut at some point in their history. Remaining fragments are often small and disconnected from each other. As our second- and third-growth forests mature and become potential future old growth forest, their timber value increases, creating an incentive to log these forests.

Eastern Hemlock *Tsuga canadensis* and American Beech *Fagus grandifolia* are the most common trees of old growth forest in this region, but both of these trees are experiencing severe declines because of invasive diseases. Beech trees in this region have been affected by Beech Bark Disease *Neonectria* spp. for decades, and are now also threatened by the emerging Beach Leaf Disease *Litylenchus crenatae mccannii* (see the entry above), while hemlocks are threatened by Hemlock Woolly Adelgid *Adelges tsugae*.

Recommended action(s): There are ongoing efforts to map old growth and mature forest in the State Forests. Similar efforts could be applied to other forests in Pennsylvania. Old growth remnants should be identified, mapped, and protected. Stands of mature forest with potential to be future old growth can be identified and put into old growth management. Buffers around older growth forests can be established to expand and connect remaining fragments.

Individual hemlock trees can be protected from Hemlock Woolly Adelgid with insecticides, but this is generally not practical for large stands. There are ongoing efforts to use biocontrol agents to control the adelgids, which have had mixed results.

Habitat Specialists: Vernal pools

Threat(s): Over half of all wetland habitats that historically occurred in Pennsylvania have been filled or otherwise destroyed (Myers et al. 2000). Vernal pools are small wetland habitats that can easily be disturbed or destroyed by human activities and are often not identified as wetlands due to their seasonal nature. Because of their small size, vernal pools are very susceptible to degradation and loss due to filling, deepening into permanent ponds, agriculture, building and road construction, quarries, and logging operations. Vernal pools that are not identified cannot be protected during development activities that would alter or destroy them.

Climate change is an intensifying threat impacting vernal pools and other small and shallow wetland habitats. Wildlife like fairy shrimp (Anostraca) and clam shrimp (Spinicaudata) have evolved synchronized responses to the environmental cues and conditions of vernal pools as they cycle through seasonal wet-dry periods. Climate change is bringing more erratic and extreme temperatures, rainfall events and droughts that disrupt those responses. Temporal shifts and quantity of precipitation accumulating also manifests in the hydroperiod of shallow wetlands like vernal pools.

Recommended action(s): Conservation actions for vernal pools include wetland mapping and protection, implementing best management practices for vernal pools and the adjacent supporting uplands, creating/restoring vernal pools to replace lost habitats, and creating green corridors to increase connectivity between vernal pools and other wetland habitats. Research and monitoring into the impacts of climate change will help us develop additional mitigation strategies. The PNHP has an online guide available on habitat management for vernal pools with links to other useful resources (PNHP, 2022, see Appendix 2: Best Management Practices).

Habitat Specialists: Sandy habitats

Habitats with loose, deep sand are rare in Pennsylvania, and support specialized species that do not occur in other habitats. For this analysis, we identified potential SGCN by searching records for species found at sandy sites, and identified a set of species found in few other sites in Pennsylvania. Overall, we identified 36 species of sand specialist SGCN and Data Deficient species, and 9 additional species with at least moderate affinity for sand.

A relevant example of a sandy habitat in Pennsylvania is Presque Isle State Park (Erie Co.), which is also a biodiversity hotspot, and which has been the focus of species inventories. 30 of the sand specialist SGCN and Data Deficient species are known from Presque Isle State Park, with 20 of those species not known to occur elsewhere in Pennsylvania.

Threat(s): Suppression of disturbances such as fire and floods cause open sand habitats to become overgrown with vegetation and lose their distinctive fauna. See the section on Loss of Early Successional Habitats above.

Recommended action(s): Disturbance regimes that keep sand open can include wave action, periodic flooding that allows deposition of fresh sand, and fire. In some cases, disturbances from timbering or other earthmoving activities can create habitat. Proper reclamation and revegetation following such activities is very important for limiting erosion and protecting waterways, but it can also remove habitat for species such as the Northern Barrens Tiger Beetle *Cicindela patruela*. There may be cases where limiting the degree of reclamation may be warranted.

Host plant specialists

Many invertebrate SGCN are host specialists, relying on a small set of host species (or a single host species) to complete part of their lifecycle. At least 331 of our SGCN specialize on a single host family, while at least 226 specialize on a single host genus, and at least 78 use only a single host species. Our knowledge of the hosts used by each species is often imperfect, and older literature is often rife with erroneous host records. As researchers elucidate these relationships, it gives us insights into how to manage these species and how to survey for them.

The Pollen Specialist Bees of the Eastern United States website (Fowler and Droege 2020) and the Host Plants for Pollen Specialist Bees of the Eastern United States (Fowler 2020) are compilations of pollen specialist bees and their associated host plants, along with general conservation recommendations.

Notably, not all host specialists are herbivores. Four of the spider wasp SGCN are specialist predators on certain spiders. An example is the spider wasp *Anoplius apiculatus*, which provisions its nests exclusively with the Beach Wolf Spider *Arctosa littoralis*. 27 of the SGCN bees are cuckoo bees, kleptoparasites that lay their eggs in the nests of other bees, and these are all specialists to varying degrees. One example is the Macropis Cuckoo Bee *Epeoloides pilosula*, which parasitizes three species of host bee in the genus *Macropis*, which are themselves SGCN and specialists on the floral oils from several species of loosestrife *Lysimachia* spp. An additional 32 species of cuckoo bee are data deficient, and our limited knowledge of which host bees they use is one of the main factors contributing to their data deficiency.

Threat(s): The threats faced by host specialists vary greatly, and they include all the threats faced by the host species, as well as potential additional threats that do not affect the host. For example, 19 species of borer moths in the genus *Papaipema* are SGCN, and each one is a specialist on one to several host plants. Because these moths overwinter as exposed eggs at the base of host plants, they are highly vulnerable to fire. None of the host plants are particularly threatened by fire, but accidental or prescribed burns can destroy populations of the moths.

Recommended action(s): Actions will vary according to the threats faced by each species. Actions to maintain or grow the population of the host species are usually an important part of managing for a species, although availability of the host is not always a limiting factor. When determining where to apply an action, the presence of host plants can be used as a proxy for the presence of the SGCN that is known or suspected to be in an area.

Microhabitats (craneflies)

Threats to invertebrates may not be well-known because the required habitats are not yet understood. In such cases, an invertebrate habitat type may be inferred based on collection information. However, this approach may not always be appropriate when species have very specialized habitat requirements. For example, Craneflies have wide ranging habitat requirements and are tied to specific conditions: some are associated with hygropetric environments (i.e., vernal rock seeps), wet mosses, soils at the edge of streams or wetlands, forest soils, or rotting wood. Where applicable, actions recommended for these environments include land protection strategies or outreach to landowners to encourage habitat conservation.

Habitats with sensitive hydrology - Seeps, springs, and caves

Threat(s): Relatively understudied habitats in Pennsylvania are groundwater (i.e., seeps and springs) and subterranean systems which harbor specialized invertebrates. Particularly in karst regions, ground water emerges in small seeps or springs which may be connected to underground caves and share some of the same aquatic fauna – amphipods, isopods, snails and flatworms. Groundwater in karst regions is easily polluted from surface waters and runoff from surrounding areas. Caves are often filled in or subject to degradation from development activities.

Recommended action(s): For these habitats, recommended actions include remediating local water pollution sources and protecting cave entrances through land conservation measures and outreach to landowners.

Summary and considerations for future assessments

This project builds on the 2007 and 2015 invertebrate assessments and, compared to the prior efforts, determined conservation ranks and SGCN status for many more species. For groups that had previously been comprehensively assessed (butterflies and skippers, dragonflies and damselflies, terrestrial snails, tiger beetles, and stoneflies), we reviewed the ranks of only the species that are known to be rare or are associated with rare habitats. For other groups, we evaluated species likely to be SGCN. In total we evaluated over 1,400 species including terrestrial and aquatic invertebrates, with over 500 new SGCN for the 2025-35 PA WAP.

The SGCN review process relied on species lists and widely available datasets, for groups like dragonflies and damselflies, where species are known to occur in Pennsylvania. PNHP experts and collaborators assessed the veracity of records, and determined species’ ranges, habitats, and threats. For less studied groups, the species evaluation process for SGCN status was less straightforward, especially where records were sparse and life history or threats were undocumented.

For the 2025-35 PA WAP, there was a concerted effort to obtain information for taxa groups underrepresented in previous versions of the plan. Partnering with outside experts and museums to digitize already collected specimen information was an efficient and cost-effective approach to enhance understanding of invertebrate biodiversity for the Commonwealth. We acquired much new information about species' distributions, yet there are many additional species for which a similar effort would likely yield previously unrevealed data and potential SGCN status. Additional resources to collate information and assess conservation status are needed for a comprehensive understanding of invertebrates.

Invertebrate expertise was vital to the SGCN assessments. Our staff's training and long-term invertebrate work, along with expertise from partners, facilitated conservation status assessments, but more experts are needed to continue to extend our taxonomic coverage. For many taxa groups the lack of taxonomic experts and inadequate information inhibited conservation assessments. For many species we encountered no new information collected since the previous PA WAP, and available data may be decades old, precluding inferences (with confidence) about the current status of species. Updating records is critical for understanding distribution, status, and conservation needs. Lastly, basic research and monitoring is needed to understand ecology, habitats, life history, and trends for most invertebrates. Monitoring priorities should include species likely to be declining, have high threat levels, are intrinsically vulnerable, occupy specialized or threatened habitats, are rare at the state or global level, or are endemic to the state.

The taxa listed below remain greatly in need of further study. Among insects, which are better studied than most other groups of invertebrates, the orders for which more than 75% of the species are unranked include the following: bristletails (Archaeognatha), cockroaches (Order Blattaria), beetles (Coleoptera), springtails (Collembola), earwigs (Dermaptera), two-pronged bristletails (Diplura), flies (Diptera), mayflies, Ephemeroptera), true bugs (Hemiptera), wasps, bees, ants, and sawflies (Hymenoptera), termites (Isoptera), mantids (Mantodea), scorpionflies and hangingflies (Mecoptera), dobsonflies, fishflies, and alderflies (Megaloptera), lacewings and ant-lions (Neuroptera), grasshoppers, crickets, and katydids, Orthoptera), chewing lice and suckling lice (Phthiraptera), coneheads (Protrua), booklice and barklice (Psocoptera), fleas (Siphonaptera), twisted-wing insects (Strepsiptera), thrips (Thysanoptera), silverfish and firebrats (Thysanura), caddisflies, Trichoptera), and angel insects (Zoraptera) (draft PABS Box Score 2025).

Among non-insect invertebrates, the following groups have more than 75% of species unranked: mites and ticks (Acari), leeches (Annelida: Hirudinida), earthworms (Annelida: Oligochaeta), polychaetes (Annelida: Polychaeta), spiders (Araneae), fishlice (Branchyura), bryozoans (Bryozoa), centipedes (Chilopoda), hydras and freshwater jellyfish (Cnidaria), millipedes (Diplopoda), entroprocts (Entoprocta), hairy-backs (Gastrotricha), sporozoans (Myxozoa), roundworms (Nematoda), horsehair worms (Nematomorpha), proboscis worms (Nemertea), daddy-longlegs (Opiliones), mussel shrimps (Ostracoda), pauropods (Pauropoda), tongue worms (Pentastomida), tapeworms (Platyhelminthes: Cestoda), flukes (Platyhelminthes: Trematoda), flatworms (Platyhelminthes: Turbellaria), pseudoscorpions (Pseudoscorpiones), rotifers and spiny-headed worms (Rotifera), symphylans (Symphyla), and water-bears (Tardigrada) (draft PABS Box Score 2025).

Current funding for invertebrate monitoring, inventory, and ecological studies in Pennsylvania is inadequate to address the needs identified. While SWG funding has previously supported invertebrate projects, including the analysis for 2025-35 PA WAP assessment, the number of species classified as

SGCN and amount of funds needed for conservation programs far exceed the available resources. Very limited federal programs and other state programs are available for invertebrate projects. Inventory or research projects are supported by DCNR's Wildlife Resource Conservation Program (WRCP), but the project budgets tend to be small. Other grants from federal sources, e.g. the Recovery Implementation grants from the USFWS Endangered Species Conservation funds, for listed species or select federal priorities (e.g. pollinator programs) provide monies for targeted research or conservation. However, the need for basic research to reverse data deficiency status greatly exceeds the available funding for the Commonwealth for researchers, museums, and conservation partners. Sustained funding programs for invertebrate studies and monitoring between now and the next PA WAP would benefit additional species.

Invertebrates are a key component of all ecosystems; they are a large fraction of the animal biomass, a critical part of food chains, and contribute broadly to ecosystem services. They have great potential to contribute medicinal and scientific advances. And yet we still know so little about them: we still have much to learn about which species occur in Pennsylvania, where they occur, how they interact with other species, which ones are of conservation concern. This iteration of the Pennsylvania Wildlife Action Plan moves us closer to those goals, and provides concrete actions that can be accomplished with SWG funding.

Literature Cited

British Ecological Society Press Office. 12 December 2023. Climate change causing 60% of plants and insects to fall out of synch, https://www.britishecologicalsociety.org/climate-change-causing-60-of-plants-and-insects-to-fall-out-of-synch/.

Cardoso, P., T.L. Erwin, and P.A.V. Borges. 2011. The seven impediments in invertebrate conservation and how to overcome them. Biological Conservation. 144. 2647-2655.

Department of Conservation and Natural Resources. 2025. Lymantria dispar dispar (Spongy Moth). Available from https://www.pa.gov/agencies/dcnr/conservation/forests-and-tree/insects-and-diseases/spongy-moth.html (accessed June 2025).

Donaldson, M.R., N.J. Burnett, D.C. Braun, C.D. Suski, S.G. Hinch, S.J. Cooke, and J.T. Kerr. 2016. Taxonomic bias and international biodiversity conservation research. Facets 1 (105-113)Entomological Society of America. 2022. 'Spongy Moth' Adopted as New Common Name for Lymantria dispar. Press release, Annapolis, MD. Available at https://entsoc.org/publications/common-names/spongy-moth (accessed June 2025).

Fowler, J. 2020. Host Plants for Specialist Bees of the Eastern United States. Available at https://jarrodfowler.com/host_plants.html (accessed June 2025).

Fowler, J. and S. Droege. 2020. Pollen Specialist Bees of the Eastern United States. Available at https://jarrodfowler.com/specialist_bees.html (accessed June 2025).

Leppo, B., D. Lieb, M. Walsh, N. Welte, and P. Woods. 2015. Invertebrate Assessment for the 2015 Pennsylvania Wildlife Action Plan Revision. Final report for State Wildlife Grant F14AF00255 to the Pennsylvania Fish and Boat Commission. Pennsylvania Natural Heritage Program, Harrisburg, PA.

Mammides, C. 2019. European Union's conservation efforts are taxonomically biased. Biodiversity Conservation. 28: 1291-1296.

Myers, W., J. Bishop, R. Brooks, T. O'Connell, D. Argent, G. Storm, J. Stauffer, and R. Carline. 2000. The Pennsylvania Gap Analysis Project. Final Report, School of Forest Resources, Pennsylvania State University, University Park, PA. 142. pp. Available at https://courseware.e-education.psu.edu/courses/geog487/data/readings/Meyers_et_al_2000.pdf (accessed June 2025).

NatureServe 2002 February 6. Element occurrence data standard. Available at https://www.natureserve.org/sites/default/files/2025-01/element_occurence_data_standard.pdf

Pennsylvania Biological Survey. 2013. Box Score http://pabiologicalsurvey.org/box-scores/pabs-2013-box-score.pdf

Pennsylvania Natural Heritage Program. 2022. Vernal Pool Conservation and Management. Harrisburg, PA. Available at https://www.naturalheritage.state.pa.us/docs/VernalPool/Vernal%20Pools%20-%20PNHP%20Best%20Management%20Practices.pdf (accessed June 2025).

Pennsylvania Natural Heritage Program. 2023. Habitat Management for Pollinators. Harrisburg, PA. Available at: https://www.naturalheritage.state.pa.us/docs/VernalPool/Habitat%20Management%20for%20Pollinators%20PNHP.pdf (accessed June 2025).

Schweitzer, Dale F. 2004. Gypsy Moth (*Lymantria dispar*): Impacts and Options for Biodiversity-Oriented Land Managers. 59 pages. NatureServe: Arlington, Virginia.

Schowalter, T. 2017. Arthropod Diversity and Functional Importance in Old-Growth Forests of North America. Forests 8(4):97.

Shepherd, B.L., D.J. Burke, and K.L. Stuble. 2025. *Fagus grandifolia* growth and mortality a decade after the emergence of Beech leaf disease. Trees, Forests and People 20(4):100836.

State land use and growth management report 2020 Prepared by Governor's Center for Local Government Services, Department of Community and Economic Development. https://dced.pa.gov/download/2020-state-land-use-and-growth-management-report/?wpdmdl=105569&refresh=684ae052dbb041749737554

Appendix 1. Data sources by taxa group

Lepidoptera – Butterflies and Moths

Lotts, Kelly and Thomas Naberhaus, coordinators. 2024. Butterflies and Moths of North America (BAMONA). Data set accessed 2024-02-09 at http://www.butterfliesandmoths.org/. Curt Lehman, Pennsylvania's state coordinator on BAMONA, has curated and vetted the Pennsylvania records.

Guilfoyle, M., K. Philley, E. Britzke, A. Harrison, W. Slack, and N. Schoppmann. 2019. Shale Barren Mapping and Threatened and Endangered Species Surveys for Raystown Lake, PA: U.S. Army Corps of Engineers, Baltimore District. USACE-ERDC, Environmental Laboratory, Vicksburg, Mississippi.

Steve Johnson, Paul Dennehy, and Sam Smith provided records from their personal moth collections.

Rawlins, J.E., C.W. Bier, C.W. Young, R.L. Davidson, S.A. Thompson, and R.A. Androw. 1997. Study of Nocturnal Macrolepidoptera in Forest Ecosystems Associated with Population Outbreaks of the Elm Spanworm on the Allegheny National Forest, Pennsylvania. Unpublished report submitted to Allegheny National Forest by the Carnegie Museum of Natural History Sections of Invertebrate Zoology and Botany, and the Western Pennsylvania Conservancy.

Rawlins, J.E., C.W. Bier, S.A. Thompson, R.A. Androw, R.L. Davidson, and C.W. Young. 1999. Temporal and Spatial Relationships of Non-target Insects in Wetlands Associated with Outbreaks of the Forest Tent Caterpillar on the Allegheny National Forest, Pennsylvania. Unpublished report submitted to Allegheny National Forest by the Carnegie Museum of Natural History Sections of Invertebrate Zoology and Botany, and the Western Pennsylvania Conservancy.

Rawlins, J.E., C.W. Bier, S.A. Thompson, R.L. Davidson, C.W. Young, and R.A. Androw. 1998. Study of Nocturnal Macrolepidoptera, Sarcophagid Flies, and Carabid Beetles in Oak Habitats Historically Exposed to Pesticide Applications Targeted on the Gypsy Moth on the Allegheny National Forest, Pennsylvania. Unpublished report submitted to Allegheny National Forest by the Carnegie Museum of Natural History Sections of Invertebrate Zoology and Botany, and the Western Pennsylvania Conservancy.

Carnegie Museum of Natural History and Pennsylvania Natural Heritage Program. Undated. Invertebrate Inventory of Barrens Habitats of Pennsylvania. Unpublished.

Carnegie Museum of Natural History and Pennsylvania Natural Heritage Program. 2015. Invertebrate Inventory of Slaughtering Ground Barrens, Clinton County, Pennsylvania. Unpublished.

Odonates – Dragonflies and Damselflies

Abbott, J.C. 2006-2025. OdonataCentral: An online resource for the distribution and identification of Odonata. Available at https://www.odonatacentral.org/. Accessed: 17 January 2024.

Pennsylvania Natural Heritage Program. 2013. Pennsylvania Odonate Database. Pennsylvania Natural Heritage Program, PA Department of Conservation and Natural Resources, Harrisburg, PA.

Ephemeroptera, Plecoptera, and Trichoptera – Mayflies, Stoneflies, and Caddisflies

Earle, J., Pennsylvania Department of Environmental Protection (retired) – stonefly data

Funk, D., Stroud Water Research Center – mayfly data

Global Biodiversity Information Facility (www.gbif.org) – mayfly, stonefly, & caddisfly data

Grubbs, S., Western Kentucky University – stonefly data

Hoover, Gregory A. 2000. Biodiversity of Mayflies (Ephemeroptera) of Pennsylvania. Department of Entomology, Pennsylvania State University. Report submitted to the Wild Resource Conservation Fund (Harrisburg, PA) and PA Fish & Boat Commission (Bellefonte, PA). 350 pp.

Integrated Digitized Biocollections (idigbio), idigbio.com – mayfly, stonefly, caddisfly data

Masteller, E., Pennsylvania Aquatic Flies database, Tom Ridge Natural History Museum – mayfly, stonefly, & caddisfly data

Masteller, E.C., and O.S. Flint. 1992. The Trichoptera (Caddisflies) of Pennsylvania: An Annotated Checklist. Journal of the Pennsylvania Academy of Science 66(2): 68-78.

Symbiota Collections of Arthropods Network (SCAN), scan-bugs.org – mayfly, stonefly, & caddisfly data

Gastropods – Freshwater and Terrestrial Snails

Dillon, R. Freshwater gastropods of North America, www.fwgna.org – Freshwater Snails

Evans, R. and S. Ray. 2010. Distribution and environmental Influences on freshwater gastropods from lotic systems and springs in Pennsylvania, USA, with conservation recommendations. American Malacological Bulletin (28): 135-150 – Freshwater Snails

Integrated Digitized Biocollections (idigbio), idigbio.com – Freshwater Snails

Pearce, T., Section of Mollusks, Carnegie Museum of Natural History – terrestrial snails

Diptera –Flies

Gelhaus, J., The Academy of Natural Sciences (ANS) of Drexel University – cranefly data from ANS and Carnegie Museum of Natural History collections and studies

Skevington, J., M. Locke, A. Young, K. Moran, W. Crins, and S. A. Marshall. 2019. Field guide to the flower flies of northeastern North America. Princeton, New Jersey: Princeton University Press. 511 pp.

Young, C.W. & Gelhaus, J.K. 2000. Crane flies of Pennsylvania: Preliminary Checklist and Database Development with emphasis on Aquatic Species. Report submitted to The Wild Resource Conservation Fund (Harrisburg, PA) and PA Fish & Boat Commission (Bellefonte, PA).

Hymenoptera – Wasps, Bees, Ants, and Sawflies

The Pennsylvania Bee Monitoring Project, run by the López-Uribe Lab at Pennsylvania State University, provided data from their Pennsylvania bee surveys. They also compiled bee data from a variety of other sources, and made it available on GBIF.

The USGS Bee Inventory and Monitoring Lab provided bee identifications for the Xeric Habitat for Pollinators project. Those bee data are available at: https://northeastwildlifediversity.org/project/xeric-habitat-pollinators

Kurczewski, F.E. 1999. Comparison of spider wasp faunas from two ecologically distinct sites in Erie County, Pennsylvania (Hymenoptera: Pompilidae). Journal of the Kansas Entomological Society 72:339–360.

Kurczewski, F. and E. Kurczewski. 1963. An annotated list of digger wasps from Presque Isle State Park, Pennsylvania (Hymenoptera: Aculeata). Proceedings of the Entomological Society of Washington. 65(2): 141-149.

Kurczewski, F.E., and J.P. Pitts . 2011. Additions to the spider wasp fauna of Erie County, Pennsylvania (Hymenoptera: Pompilidae). Journal of the Kansas Entomological Society 84:320–322.

Other Invertebrates

Marc Yergin provided freshwater sponge records from his ongoing surveys of Pennsylvania creeks and rivers.

Spiders and Harvestmen

Bug Guide, bugguide.net

Bier, C., Western Pennsylvania Conservancy (retired)

Coyle, F. A. 197). Systematics and natural history of the mygalomorph spider genus Antrodiaetus and related genera (Araneae: Antrodiaetidae). Bulletin of the Museum of Comparative Zoology 141(6): 269-402.

Dondale, C. D. & Redner, J. H. 1983. Revision of the wolf spiders of the genus Arctosa C. L. Koch in North and Central America (Araneae: Lycosidae). Journal of Arachnology 11: 1-30.

Edwards, R. J. 1958. The spider subfamily Clubioninae of the United States, Canada and Alaska (Araneae: Clubionidae). Bulletin of the Museum of Comparative Zoology 118: 365-436.

Gertsch, W. J. 1984. The spider family Nesticidae (Araneae) in North America, Central America, and the West Indies. Bulletin of the Texas Memorial Museum 31: 1-91.

Millidge, A. F. 1993). Blestia, a new genus of erigonine spider with clypeal sulci (Araneae: Linyphiidae). Bulletin of the British Arachnological Society 9: 126-128.

Natural History Museum collection, Tom Ridge Environmental Center

Ryndock, J., Natural Heritage Section, Pennsylvania Department of Conservation & Natural Resources Bureau of Forestry

Multi-taxon Sources

Pennsylvania Natural Heritage Program. 2024. Biotics 5 database. Pennsylvania Natural Heritage Program, Harrisburg, Pennsylvania. Accessed on various dates in 2024.

Pennsylvania Natural Heritage Program provided data from its decades of biological inventory surveys throughout Pennsylvania.

Mark Lethaby, Natural History Museum Curator at the Tom Ridge Environmental Center, provided records from museum collection.

INaturalist – Research-grade observations were downloaded via GBIF, but casual grade observations were also downloaded from iNaturalist.org at various times between 9 February 2024 and 20 November 2024, and were available for inclusion in analyses, at the discretion of the biologist.

GBIF: The Global Biodiversity Information Facility. 2024. Available from https://www.gbif.org. We downloaded data from GBIF numerous times between 9 February 2024 and 20 November 2024. These downloads included Pennsylvania records from the following sources:

- Academy of Natural Sciences Entomology Collection
- Arizona State University Hasbrouck Insect Collection
- Australian Museum provider for OZCAM
- Brigham Young University Arthropod Museum
- C.P. Gillette Museum of Arthropod Diversity
- Carnegie Museum of Natural History - Mollusks
- CHAS Entomology Collection (Arctos)
- Clemson University Arthropod Collection
- Cleveland Museum of Natural History
- Digitization PEN: Digital Data from the Terrestrial Polyneoptera at American Museum of Natural History
- Diptera Collection of Richard Frey (MZH/Luomus, Helsinki, Finland)
- Earth Guardians Weekly Feed
- Entomology Collection at the Natural History Museum of Utah
- Entomology Division, Yale Peabody Museum
- Essig Museum of Entomology
- Fairbanks Museum and Planetarium Lady Beetle (Coccinellidae) Specimens
- Field Museum of Natural History (Zoology) Insect, Arachnid and Myriapod Collection
- Frost Entomological Museum
- Illinois Natural History Survey Insect Collection
- iNaturalist Research-grade Observations
- INSDC Sequences
- Insect Species Occurrence Data from Multiple Projects Worldwide with Focus on Bees and Wasps in North America
- International Barcode of Life project (iBOL)
- IZIKO South Africa Museum Collection (1800-2013)
- López-Uribe Lab Collection
- Middlebury College Insect Collection Coccinellidae
- Mississippi Entomological Museum
- Museum of Comparative Zoology, Harvard University
- Museum of Texas Tech University Invertebrate Zoology Collection

- Natural History Museum (London) Collection Specimens
- New Brunswick Museum - Insects
- New Syrphidae (Diptera) of North-eastern North America
- NMNH Extant Specimen Records (USNM, US)
- Snow Entomological Museum Collection
- Triplehorn Insect Collection, The Ohio State University
- UCM Entomology Collection
- University of Alberta E. H. Strickland Entomological Museum (UASM)
- University of British Columbia - Spencer Entomological Collection (UBCZ)
- University of Delaware Insect Research Collection
- University of Guelph Insect Collection (DEBU)
- University of Michigan Museum of Zoology, Division of Insects

Appendix 2. Best Management Practices (BMPs) Recommended for Invertebrate SGCN, from the Wildlife Action Plan Species Account Database

Best Practices	Best Practice Source	Best Practice Links
A Conservation Catalog: Practices (BMPs) for Conserving Pennsylvania's Natural Resources	Agricultural Research Service, ARS–163, July 2006, USDA, NRCS	https://www.clintoncountypa.gov/home/showpublisheddocument/2984/637387022626500000
A global synthesis of fire effects on pollinators	Carbone, L.M., J. Tavella, J.G. Pausas and R. Aguilar. 2019. A global synthesis of fire effects on pollinators. Global Ecology and Biogeography 28: 1487–98.	
A Landowner's Guide to Conservation Buffer Incentive Programs in Pennsylvania	PSU-Extension, Natural Resources Conservation Service, USDA	https://extension.psu.edu/programs/nutrient-management/educational/best-management-practices/stream-bank-fencing-green-banks-clean-streams,
A Landowner's Guide to Conservation Buffer Incentive Programs in Pennsylvania	PSU-Extension	https://pacd.org/wp-content/uploads/2009/09/LandownerGuide-1.pdf
A literature review of insect responses to fire, compared to other conservation managements of open habitat	Swengel, Ann. (2001). A literature review of insect responses to fire, compared to other conservation managements of open habitat. Biodiversity and Conservation - BIODIVERS CONSERV. 10. 1141-1169. 10.1023/A:1016683807033.	https://www.researchgate.net/publication/251336801
Abandoned Mine Site Characterization and Cleanup Handbook	US Environmental Protection Agency	https://www.epa.gov/sites/default/files/2015-09/documents/2000_08_pdfs_amscch.pdf
Agricultural Conservation Easement Program	USDA-Natural Resources Conservation Service	https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/acep/
Benefit of permanent non-fire refugia for Lepidoptera conservation in fire-managed sites	Swengel, Ann & Swengel, Scott. (2007). Benefit of permanent non-fire refugia for Lepidoptera conservation in fire-managed sites. Journal of Insect Conservation. 11. 263-279. 10.1007/s10841-006-9042-9.	https://www.researchgate.net/publication/225403609_Benefit_of_permanent_non-fire_refugia_for_Lepidoptera_conservation_in_fire-managed_sites
Best Management Practices for Silvicultural Activities in Forest Wetlands	PSU-Extension	https://extension.psu.edu/best-management-practices-for-silvicultural-activities-in-forest-wetlands
Best Management Practices To Minimize Agricultural Phosphorus Impacts on Water Quality	Agricultural Research Service, United States Department of Agriculture	https://www.ars.usda.gov/is/np/bestmgmtpractices/best%20management%20practices.pdf
Best Practices for Forage and Habitat	Penn State, College of Agricultural Sciences, The Center for Pollinator Research	https://pollinators.psu.edu/bee-health/pennsylvania-pollinator-protection-plan-p4/best-practices-for-forage-and-habitat
Best Practices for Roadside and Utility Rights of Way	Pennsylvania Pollinator Protection Plan	-
Biological Dos and Don'ts for Cave Restoration and Conservation	Elliott, W.R. 2006. Biological Dos and Don'ts for Cave Restoration and Conservation. pp. 33-46 IN Hildreth-Werker, V., and J. Werker (eds.), Cave Conservation and Restoration, NSS. 600 pp Part 2—Conservation, Management, Ethics: Elliott—Biological Dos and Don'ts	https://cavelife.info/pdf/2006%20cavebio%20dos.pdf
CLEAN, DRAIN AND DRY— Aquatic Invasive Species Composting Stations	Pennsylvania Fish and Boat Commission	https://www.pa.gov/content/dam/copapwp-pagov/en/fishandboat/documents/about-us/angler-and-boater/angler-and-boater-2024/mayjune2024_cleandraindry.pdf
Climate Change Connectivity, Prioritization, and Mapping for Pennsylvania	Yeany, D., A. Johnson, C. Tracey, and J. Wagner. 2020. Pennsylvania Natural Heritage Program. Western Pennsylvania Conservancy. Priorities for climate change connectivity in Pennsylvania. GIS data product for Pennsylvania Department of Conservation and Natural Resources, WPC-TA-038, WPC-TA-049.	https://storymaps.arcgis.com/stories/1afdb4e7fba64c178bff31620cb6808c

Climate Change Mitigation and Adaptation Plan for Pennsylvania	Yeany, D., A. Johnson, C. Tracey, and J. Wagner. 2020. Pennsylvania Natural Heritage Program. Western Pennsylvania Conservancy. Priorities for climate change connectivity in Pennsylvania. GIS data product for Pennsylvania Department of Conservation and Natural Resources, WPC-TA-038, WPC-TA-049.	https://www.pa.gov/agencies/dcnr/conservation/climate-change.html
Climate Change Resilient Land Mapping Tool	Department of Conservation and Natural Resources. 2018. Climate Change Adaptation and Mitigation Plan. Harrisburg, PA. , Resilient Land Mapping Tool [Web application, version 2.0.36]. 2025. Content by Anderson, M.G., Clark, M., Olivero, A.P., Barnett, A.R., Hall, K.R., Cornett, M.W., Ahlering, M., Schinel, M., Unasch, B., Schoss, C., and D.R. Cameron.	https://www.maps.tnc.org/resilientland
Climate Solutions for Pennsylvania	Web application by E. H. Martin. The Nature Conservancy, Center for Resilient Conservation Science. https://www.maps.tnc.org/resilientland, The Nature Conservancy. 2023. Stories in Pennsylvania: Climate Solutions. Harrisburg, PA (accessed May 2025)	https://www.nature.org/en-us/about-us/where-we-work/united-states/pennsylvania/stories-in-pennsylvania/pennsylvania-climate-solutions/
Conducting Prescribed Burns in Species at Risk Habitats Best Management Practices for Tallgrass Prairie, Oak Savanna, and Oak Woodland (see section 5.6 for insect-specific concerns)	prepared by Natural Resource Solutions, Inc. for Canada's Ministry of Environment, Conservation, and Parks Species at Risk Stewardship Program	https://priorityplace.ca/wp-content/uploads/2024/04/NRSI_2746_BMP-for-Prescribed-Burns-in-Tallgrass-SAR-Habitat_2023_04_12_FINAL.pdf
Conseration measures for landscaping and urban design.	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation measures for landscaping and urban design. Internal report, unpublished. Harrisburg, PA.	-
Conservation Cover (327) for Pollinators: Pennsylvania Installation Guide and Job Sheet	Xerces Society for Invertebrate Conservation	https://www.xerces.org/sites/default/files/2018-05/15-025_02_XercesSoc_HabitatInstallGuide_Pennsylvania_ConservationCover327_web.pdf
Conservation Measures for Agriculture (DCNR)	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation Measures for Agriculture and Invertebrates. Internal report, unpublished. Harrisburg, PA.	https://pollinators.psu.edu/bee-health/pennsylvania-pollinator-protection-plan-p4#:~:text=The%20Pennsylvania%20Pollinator%20Protection%20Plan,the%20varied%20landscapes%20in%20Pennsylvania,
Conservation measures for artificial lighting (DCNR)	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation measures for artificial lighting. Internal report, unpublished. Harrisburg, PA.	
Conservation Measures for Interior Forests (DCNR)	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation Measures for Interior Forests and Invertebrates. Internal report, unpublished. Harrisburg, PA.	
Conservation measures for invasive species (DCNR)	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation measures and best practices to control invasive plants and encourage native species. Internal report, unpublished. Harrisburg, PA.	-
Conservation measures for landscaping and urban design for native pollinators and other insects (DCNR)	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation measures for landscaping and urban design. Internal report, unpublished. Harrisburg, PA.	
Conservation measures for spongy moth control to minimize harm to native lepidoptera and other insects (DCNR)	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation measures for spongy moth control. Internal report, unpublished. Harrisburg, PA.	https://www.pa.gov/agencies/dcnr/conservation/forests-and-tree/insects-and-diseases/spongy-moth.html

Conservation Practice Standard Streambank and Shoreline Protection Code 580	Natural Resources Conservation Service, USDA	https://www.nrcs.usda.gov/sites/default/files/2022-10/Streambank_Shoreline_Protection_580_CPS_10_2020.pdf
Conservation Reserve Enhancement Program	USDA-Farm Service Agency	https://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-enhancement/index
Conservation, management and stewardship of barrens communities in Pennsylvania (DCNR, includes Lepidoptera)	Pennsylvania Department of Conservation and Natural Resources. 2022. Conservation Measures for Woodlands, Shrublands and Glades (Barrens): Internal report, unpublished. Harrisburg, PA.	
Conservation, management and stewardship of barrens communities in Pennsylvania (TNC, includes Lepidoptera)	Orndorff, S., M. Batcher, J. Case, R. Cook, A. Davis, G. Gress, R. Harnishfeger, N. Johnson, S. Klugman, R. Latham, B. Leppo, P. McElhenny, T. Coleman, G. Podniesinski, R. Ramsey, and D. Schweitzer. 2008. Management Guidelines for Barrens Communities in Pennsylvania. The Nature Conservancy, Harrisburg, Pennsylvania.	
Conservation, management and stewardship of prairies and barrens for butterflies	Swengel A.B. and S.R. Swengel. 2001. Effects of prairie and barrens management on butterfly faunal composition. Biodiversity and Conservation 10(10):1757-1785.	https://www.researchgate.net/publication/251141103_Effects_of_prairie_and_barrens_management_on_butterfly_faunal_composition
Conservation, management and stewardship of rare wetland butterflies (with climate change vulnerability assessment)	Selfridge, J., B. Leppo, S. Olcott, R. Somes, C. Tracey, and P. Woods. 2018. Conservation and Management of Rare Wetland Butterflies: Strategies for Monitoring, Modeling and Wetland Enhancement in the Mid-Atlantic Region. Final report for Regional Conservation Needs Grant 2015-02 to the Wildlife Management Institute.	https://rcngrants.org/content/conservation-and-management-rare-wetland-butterflies-strategies-monitoring-modeling-and
Conservation, management and stewardship of ridgetop barrens (PGC)	Pennsylvania Game Commission. No Date. Improving Habitat for Wildlife: Barrens Habitat Management. Harrisburg, PA. Available from https://www.pa.gov/agencies/pgc/habitat-management/landowner-resources/improving-habitat-for-wildlife.html (accessed May 2025).	https://www.pa.gov/agencies/pgc/habitat-management/landowner-resources/improving-habitat-for-wildlife.html
Conservation, management and stewardship of ridgetop barrens at Big Pine Flats in southcentral PA (TNC, includes Lepidoptera)	Seymour, S., B. Eichelberger, B. Leppo, J. Kunsman, M. Kowalski, C. Eichelberger, D. Watts, T. Davis and J. Hart. 2012. Natural Resources Inventory and Management Recommendations for the Big Pine Flats Biological Diversity Area. Unpublished report. Pennsylvania Natural Heritage Program, Harrisburg, PA. 166 pp.	
Conservation, management and stewardship strategies for mesic till barrens at Long Pond in Monroe County, PA (TNC, includes Lepidoptera)	Orndorff, S., M. Batcher, J. Case, R. Cook, A. Davis, G. Gress, N. Johnson, S. Klugman, R. Latham, B. Leppo, P. McElhenny, T. Patten, G. Podniesinski, R. Ramsey, and D. Schweitzer. 2008. Conservation Plan for the Long Pond Barrens. The Nature Conservancy, Harrisburg, Pennsylvania.	
Conservation, management, and stewardship of serpentine barrens communities (plants)	Latham, R.E. 1993. The serpentine barrens of temperate eastern North America: Critical issues in the management of rare species and communities. Bartonia (supplement) 57:61-74.	
Conservation, management, and stewardship of serpentine barrens communities (Unionville 2012, includes Lepidoptera)	R.E. Latham and M. McGeehin. 2012. Unionville Serpentine Barrens Restoration and Management Plan. Continental Conservation, Rose Valley, Pennsylvania and Natural Lands Trust, Media Pennsylvania. 157 pp. + 10 maps.	
Conservation, management, and stewardship of serpentine barrens communities (Unionville 2016 update, includes Lepidoptera)	Latham, R.E. 2016. Unionville Serpentine Barrens Restoration and Management Plan: 2016–2020 Update. 59 pp. Supplement to R.E. Latham and M. McGeehin. 2012. Unionville Serpentine Barrens Restoration and Management Plan. Continental Conservation, Rose Valley, Pennsylvania and Natural Lands Trust, Media Pennsylvania. 157 pp. + 10 maps.	https://www.lakeroland.org/wp-content/uploads/2022/01/Unionville-Barrens-restoration-plan-2016-2020-update.pdf
Conservation, management, and stewardship of serpentine barrens communities at Pink Hill in southeastern PA (Lepidoptera included)	Latham, R.E. 2008. Pink Hill Serpentine Barrens Restoration and Management Plan. John J. Tyler Arboretum, Media, PA. 87 pp.	https://tylerarboretum.org/wp-content/uploads/2013/04/Latham-PinkHillReport-2008.pdf

Construction of temporary storage areas to contain runoff	WIREs WATER focus article	
Controlling Insects, Disease, Invasives and Fire (SFI)	Sustainable Forestry initiative. Controlling Insects, Disease, Invasives, and Fire. Available at https://sfiofpa.org/sustainable-forestry/controlling-insects-disease-invasives-and-fire/ (accessed June 2025).	https://sfiofpa.org/sustainable-forestry/controlling-insects-disease-invasives-and-fire/
Deer Management, Community-Based (PGC)	Pennsylvania Game Commission. 2014. A Guide to Community Deer Management in Pennsylvania. Pennsylvania Game Commission's Deer & Elk Section, Harrisburg, PA.	https://www.pa.gov/content/dam/copapwp-pagov/en/pgc/documents/wildlife/mammals/white-taileddeer/documents/guide%20to%20community%20deer%20management.pdf
Deer Management, Resident Resources	Allegheny County Council. Deer Management. Pittsburgh, PA.	https://www.alleghenycounty.us/Government/Departments-and-Offices/County-Council/Deer-Management, https://hdl.handle.net/1813/65
Deer Management, Suburban Environments	DeNicola, A.J., K.C. VerCauteren, P.D. Curtis, and S.E. Hygnstrom. 2000. Managing White-tailed Deer in Suburban Environments: A Technical Guide. Cornell Cooperative Extension, Ithaca, New York.	
Deer Management,Community-Based (NE Wildlife Damage Coop)	Decker, D.J., Raik, D.B. and Siemer, W.F. 2004. Community-based deer management: A practitioner's guide. Northeast Wildlife Damage Management Research and Outreach Cooperative.	https://deeradvisor.dnr.cornell.edu/resource/community-based-deer-management-practitioners-guide
Effects of prairie and barrens management on butterfly faunal composition	Swengel, Ann & Swengel, Scott. (2001). Effects of prairie and barrens management on butterfly faunal composition. Biodiversity and Conservation. 10. 1757-1785. 10.1023/A:1012051510584.	https://www.researchgate.net/publication/251141103
Effects of prairie and barrens management on butterfly faunal composition	Harper, M.G., C.H. Dietrich, R.L. Larimore and P.A. Tessene. 2000. Effects of Prescribed Fire on Prairie Arthropods: An Enclosure Study. Natural Areas Journal 20(4)325-335.	https://www.researchgate.net/publication/251141103_Effects_of_prairie_and_barrens_management_on_butterfly_faunal_composition
Effects of Prescribed Fire on Prairie Arthropods: An Enclosure Study	Harper, M.G., C.H. Dietrich, R.L. Larimore and P.A. Tessene. 2000. Effects of Prescribed Fire on Prairie Arthropods: An Enclosure Study. Natural Areas Journal 20(4)325-335.	
Environmental Risks to Arthropods from Imidacloprid Applications for Hemlock	McCarty, E. 2020. Environmental Risks to Arthropods from Imidacloprid Applications for Hemlock Conservation. University of Georgia, Warnell School of Forestry & Natural Resources. Publication WSFNR-20-88A. 11 Pages. Available at (accessed June 20205)	https://savehemlocksnc.org/wp-content/uploads/2020/11/McCarty-2020_Enviro-Risks-to-Arthropods-from-Imid_WSFNR-20-88A.pdf
Environmentally Sensitive Road Maintenance Practices for Dirt and Gravel Roads	USDA-Forest Service	https://www.epa.gov/sites/default/files/2015-10/documents/environmentallysensitivemaintenance_dirtgravelroads.pdf
Erosion, Sediment and Runoff Control for Roads and Highways	US EPA	https://wires.onlinelibrary.wiley.com/doi/10.1002/wat2.1634, https://archive.epa.gov/water/archive/web/html/road_runoff.html
Erosion, Sediment and Runoff Control for Roads and Highways	US EPA	https://archive.epa.gov/water/archive/web/html/road_runoff.html
Example of research investigating direct and indirect effects of wetland restoration on wetland butterflies (Aschehoug et al. 2015)	Aschehoug E.T., Sivakoff F.S., Cayton H.L., Morris W.F., Haddad N.M. 2015. Habitat restoration affects immature stages of a wetland butterfly through indirect effects on predation. Ecology 96(7):1761-1767.	
Example of research investigating wetland butterfly life history requirements and habitat preferences (Severns et al. 2006)	Severns, P.M., L. Boldt and S. Villegas. 2006. Conserving a wetland butterfly: quantifying early lifestage survival through seasonal flooding, adult nectar, and habitat preference. Journal of Insect Conservation 10:361-370.	
Farmland Preservation	PA Department of Agriculture	https://www.pa.gov/agencies/pda/plants-land-water/farmland-preservation.html
Forest Buffers Along Waterways	PA Department of Conservation and Natural Resources	https://www.pa.gov/agencies/dcnr/conservation/water/riparian-buffers.html
Forest Stewardship: Best Management Practices for Pennsylvania Forests	Penn State Extension	https://extension.psu.edu/forest-stewardship-best-management-practices-for-pennsylvania-forests

Forested buffers along waterways	PA Department of Conservation and Natural Resources	https://www.pa.gov/agencies/dcnr/conservation/water/riparian-buffers.html, https://ecosystems.psu.edu/research/centers/private-forests/outreach/forested-riparian-buffers
Habitat Management for Pollinators	Leppo, B. 2023. Habitat Management for Pollinators. Pennsylvania Natural Heritage Program, Harrisburg, Pennsylvania.,	https://www.naturalheritage.state.pa.us/docs/VernalPool/Habitat%20Management%20for%20Pollinators%20PNHP.pdf
Healthy Forests Guides	Audubon Pennsylvania	https://pa.audubon.org/conservation/healthy-forests-guides
Healthy Forests Reserve Program (HFRP)	USDA-Natural Resources Conservation Service	https://www.nrcs.usda.gov/programs-initiatives/hfrp-healthy-forests-reserve-program
Historical and current perspectives on wetland values, policies, losses and protections	Vileisis, A. 1997. Discovering the Unknown Landscape: A History of America's Wetlands. Island Press, Washington, D.C.	
Historical and current perspectives on wetland values, policies, losses and protections	Vileisis, A. 1997. Discovering the Unknown Landscape: A History of America's Wetlands. Island Press, Washington, D.C.	https://rcngrants.org/content/conservation-and-management-rare-wetland-butterflies-strategies-monitoring-modeling-and, , , , ,
iMapInvasives (Resources)	iMapInvasives, Fact sheets with information on how to identify and remove a variety of invasive plants found in Pennsylvania.	https://www.imapinvasives.org/
Implement use of green infrastructure and control runoff.	PSU-Center for Private Forests, US EPA	https://www.epa.gov/green-infrastructure/mitigate-flooding
Integrated Approach to Hemlock Woolly Adelgid Mitigation (PSU)	Penn State University. Integrated Approach to Hemlock Woolly Adelgid Mitigation - A publication discussing hemlock woolly adelgid management techniques to help conserve the eastern hemlock in the long run. Available at https://extension.psu.edu/integrated-approach-to-hemlock-woolly-adelgid-mitigation (accessed June 2025).	https://extension.psu.edu/integrated-approach-to-hemlock-woolly-adelgid-mitigation
Integrated Pest Management Principles for Agricultural Areas	Pennsylvania Pollinator Protection Plan	https://pollinators.psu.edu/bee-health/pennsylvania-pollinator-protection-plan-p4/best-practices-for-pesticide-use
Invasive Plant Fact Sheets (DCNR)	Pennsylvania Department of Conservation and Natural Resources. Invasive Plant Fact Sheets. Available at https://www.pa.gov/agencies/dcnr/conservation/wild-plants/invasive-plants/invasive-plant-fact-sheets.html (accessed June 2025).	https://www.pa.gov/agencies/dcnr/conservation/wild-plants/invasive-plants/invasive-plant-fact-sheets.html
Invasive Plant Fact Sheets (PSU)	Penn State University Invasive Plant Fact Sheet Series. Sustainable Forestry Initiative. Available at https://sfiofpa.org/sustainable-forestry/psu-invasive-fact-sheets/ (accessed June 2025).	https://sfiofpa.org/sustainable-forestry/psu-invasive-fact-sheets/
Invasive Plants of Riparian Areas - Identification, Habitat and Control (DEP)	Pennsylvania Department of Environmental Protection. Pennsylvania Field Guide to Common Invasive Plants in Riparian Areas. Available at https://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/streamreleaf/Docs/Invasive%20Plants.pdf (accessed June, 2025).	https://www.dep.state.pa.us/dep/deputate/watermgt/wc/subjects/streamreleaf/Docs/Invasive%20Plants.pdf
Invasive Species	USDA-Natural Resources Conservation Service	https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/plantsanimals/invasive/
Invasive Species Mapping, Identification, Management, Best Practices, and Other Resources	Pennsylvania iMapInvasives Program. Available at https://www.paimapinvasives.org/ (accessed June 2025).	https://www.paimapinvasives.org/, https://digitalcommons.usu.edu/govdocs/533
Keystone Grasslands: Restoration and Reclamation of Native Grasslands, Meadows, and Savannas in Pennsylvania State Parks and State Game Lands	Latham, R. and J.F. Thorne. 2007. Keystone Grasslands: Restoration and Reclamation of Native Grasslands, Meadows, and Savannas in Pennsylvania State Parks and State Game Lands. For the Wild Resource Conservation Program, Pennsylvania Department of Conservation and Natural Resources, Harrisburg. 100 pp.	

Landscaping with Native Plants (DCNR)	Pennsylvania Department of Conservation and Natural Resources. Landscaping with Native Plants. Harrisburg, PA. Available at: https://www.pa.gov/agencies/dcnr/conservation/wild-plants/landscaping-with-native-plants (accessed June 2025).	https://www.pa.gov/agencies/dcnr/conservation/wild-plants/landscaping-with-native-plants
Management and Removal of invasive or undesirable plant species	Grassland Bird Trust, USDA-Natural Resources Conservation Service	https://www.grasslandbirdtrust.org/conservation/land-management-practices/, https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/plantsanimals/invasive/
Management Guidelines for Barrens Communities in Pennsylvania	Orndorff, S., M. Batcher, J. Case, R. Cook, A. Davis, G. Gress, R. Harnishfeger, N. Johnson, S. Klugman, R. Latham, B. Leppo, P. McElhenny, T. Coleman, G. Podniesinski, R. Ramsey, and D. Schweitzer. 2008. Management Guidelines for Barrens Communities in Pennsylvania. The Nature Conservancy, Harrisburg, Pennsylvania.	
Managing Your On-Lot Septic System	Penn State Extension	https://extension.psu.edu/managing-your-on-lot-septic-system
Manureshed' management in Susquehanna River basin key to Chesapeake Bay cleanup	Penn State University	https://www.psu.edu/news/research/story/manureshed-management-susquehanna-river-basin-key-chesapeake-bay-cleanup
National Menu of Best Management Practices (BMPs) for Stormwater-Pollution Prevention and Good Housekeeping	US Environmental Protection Agency	https://www.epa.gov/npdes/national-menu-best-management-practices-bmps-stormwater-pollution-prevention-and-good
National Menu of Best Management Practices (BMPs) for Stormwater-Pollution Prevention and Good Housekeeping	US EPA	https://www.epa.gov/npdes/national-menu-best-management-practices-bmps-stormwater-pollution-prevention-and-good
Pennsylvania Pollinator Protection Plan (P4), 2017	Pennsylvania Pollinator Task Force. 2017. Pennsylvania Pollinator Protection Plan (P4). Original 2017 report is available as a pdf online at the Penn State University's Center for Pollinator Research. Note: The three main best practices sections of the this report (Beekeepers, Pesticide Use, Forage and Habitat) are also maintained online and underwent one cycle of revisions in 2022-2023.	
Pennsylvania Pollinator Protection Plan (P4), 2023 revision	Pennsylvania Pollinator Task Force. 2023. Pennsylvania Pollinator Protection Plan (P4), revised. Note: The P4 was first created as a report and published in 2017, available as a pdf online at the Penn State University's Center for Pollinator Research. The three main best practices sections of the original report (Beekeepers, Pesticide Use, Forage and Habitat) are maintained online at the Penn State University's Center for Pollinator Research. and underwent one cycle of revisions in 2022-2023.	
Pennsylvania Sustainable Forestry Initiative. Forest operations: Controlling insects, disease, invasives, and wildfire. PA-SFI Implementation Committee, Bellefonte, PA. Available from: .	Pennsylvania Sustainable Forestry Initiative. Forest operations: Controlling insects, disease, invasives, and wildfire. PA-SFI Implementation Committee, Bellefonte, PA.	https://sfiofpa.org/sustainable-forestry/controlling-insects-disease-invasives-and-fire/#PLANTS (accessed May 2025)
Pollinators and Roadsides: Managing Roadsides for Bees and Butterflies	Xerces Society for Invertebrate Conservation	https://www.xerces.org/sites/default/files/2018-05/12-037_05_XercesSoc_Pollinators%2BRoadsides_web.pdf
Prescribed fire best practices for arthropods - unburned refugia and burn interval	Harper, M.G., C.H. Dietrich, R.L. Larimore and P.A. Tessene. 2000. Effects of Prescribed Fire on Prairie Arthropods: An Enclosure Study. Natural Areas Journal 20(4)325-335	
Prescribed fire best practices for Lepidoptera - permanent non-fire refugia, Conservation, management, and stewardship of serpentine barrens communities (Goat Hill Lepidoptera)	Leppo, B. 2010. Management Plan for the Lepidoptera of the Goat Hill Serpentine Barrens. Unpublished Report. Pennsylvania Natural Heritage Program, Harrisburg, PA. 16 pp.	

Prescribed fire versus other habitat management practices for Lepidoptera	Swengel, A.B. 2000. A literature review of insect responses to fire, compared to other conservation managements of open habitat. Biodiversity and Conservation 10:1141-1169.	
Preserve headwater stream/river forested buffers	PA Department of Conservation and Natural Resources	https://www.pa.gov/agencies/dcnr/conservation/water/riparian-buffers.html
Preserve headwater stream/river forested buffers, implement use of green infrastructure and control runoff.	US EPA	https://www.epa.gov/green-infrastructure/mitigate-flooding
Recommendations for building climate resiliency	PFBC (Pennsylvania Fish and Boat Commission). 2022. Pennsylvania Fish and Boat Commission Climate Action Plan: Strategies for Enhancing Climate Adaptation and Resilience to Protect, Conserve, and Enhance Pennsylvania's Aquatic Resources and Support Anglers and Boaters, Version 2022-1.0. Harrisburg, Pennsylvania.	https://www.pa.gov/content/dam/copapwp-pagov/en/fishandboat/documents/conservation/plans/cap_final.pdf
Reduction of general river pollution, especially nutrient pollution from agriculture.	Penn State University, Chesapeake Bay Foundation	https://www.nrcs.usda.gov/sites/default/files/2022-10/Streambank_Shoreline_Protection_580_CPS_10_2020.pdf
Resources for Spongy Moth Identification and Control	Department of Conservation and Natural Resources. 2025. Lymantria dispar dispar (Spongy Moth). Available from https://www.pa.gov/agencies/dcnr/conservation/forests-and-tree/insects-and-diseases/spongy-moth.html (accessed May 2025).	https://www.pa.gov/agencies/dcnr/conservation/forests-and-tree/insects-and-diseases/spongy-moth.html
Responses from bees, butterflies, and ground beetles to different fire and site characteristics: A global meta-analysis	Mason, S.C., V. Shirey, L.C. Ponisio, and J.K. Gelhaus. 2021. Responses from bees, butterflies, and ground beetles to different fire and site characteristics: A global meta-analysis. Biological Conservation 261(5):109265.	
Rights-of-way Ecological Research at Penn State	The Pennsylvania State University. 2025. Rights-of-way Ecological Research at Penn State. Available at https://sites.psu.edu/transmissionlineecology/documents-reports/ (accessed June 2025).	https://sites.psu.edu/transmissionlineecology/documents-reports
Riparian Buffers for Private Lands	Penn State College of Agricultural Sciences, Department of Ecosystem Science and Management	https://ecosystems.psu.edu/research/centers/private-forests/outreach/forested-riparian-buffers
Riparian Buffers for Private Lands	PSU-Center for Private Forests	https://ecosystems.psu.edu/research/centers/private-forests/outreach/forested-riparian-buffers
Roadside Best Management Practices that Benefit Pollinators	US Department of Transportation Federal Highway Administration	https://www.environment.fhwa.dot.gov/env_topics/ecosystems/Pollinators_Roadsides/BMPs_pollinators_landscapes.aspx
Spongy moth biocontrol by the parasitic fly Compsilura concinnata - benefits and harm	Elkinton, J.S. and G.H. Boettner. 2012. Benefits and harm caused by the introduced generalist tachinid, Compsilura concinnata, in North America. Biocontrol 57:277-288.	
Spongy Moth Control and Biodiversity Protection	Schweitzer, Dale F. 2004. Gypsy Moth (Lymantria dispar): Impacts and Options for Biodiversity-Oriented Land Managers. 59 pages. NatureServe: Arlington, Virginia.	https://www.natureserve.org/sites/default/files/schweiter_2004.pdf
Stop Aquatic Hitchhikers	ANS Taskforce	https://stopaquatichitchhikers.org/
Stream Bank Fencing: Green Banks, Clean Streams	Penn State Extension	https://extension.psu.edu/programs/nutrient-management/educational/best-management-practices/stream-bank-fencing-green-banks-clean-streams
Stream Crossing	PA Association of Conservation Districts, A.N. Sharpley, T. Daniel, G. Gibson, L. Bundy, M. Cabrera, T. Sims, R. Stevens, J. Lemunyon, P. Kleinman, and R. Parry, United States Department of Agriculture, Agricultural Research Service, ARS–163, July 2006	https://www.nrcs.usda.gov/wps/PA_NRCSConsumption/download?cid=nrcseprd340865&ext=pdf,
Streambank Fencing and Stream Crossings	PA Association of Conservation Districts	https://pacd.org/wp-content/uploads/2009/09/StreambankFencing1.pdf

Sustain Pollinators with Native Plants (Holm, 2014)	Holm, H. 2014. Pollinators of Native Plants: Attract, Observe and Identify Pollinators and Beneficial Insects with Native Plants. Pollination Press LLC, Minnetonka, MN	
Sustain Pollinators with Native Plants (Tallamy, 2009)	Tallamy, D. 2009. Bringing Nature Home: How You Can Sustain Wildlife with Native Plants. Timber Press, Portland, Oregon.	
The Southern Pine Beetle Prevention Initiative: Working for Healthier Forests	USFS	https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd561165.pdf
Using Smart Growth Techniques as Stormwater Best Management Practices	US EPA	https://www.epa.gov/sites/default/files/2014-04/documents/stormwater-best-management-practices.pdf
Vegetation management (mechanical and herbicide) to encourage native flowering plants and reduce trees	Mahan, C.G., B.D. Ross, and R.T. Yahner. The Effects of Integrated Vegetation Management on Richness of Native Compatible Flowering Plants and Abundance of Non-Compatible Tree Species on a Right-of-Way in Central Pennsylvania, USA. Arboriculture & Urban Forestry (AUF) November 2020, 46 (6) 395-401; DOI: https://doi.org/10.48044/jauf.2020.029	https://auf.isa-arbor.com/content/46/6/395
Vegetation management (mechanical and herbicide) to increase pollinator diversity	Russo L., Stout H., Roberts D., Ross B.D., Mahan C.G. 2021. Powerline right-of-way management and flower-visiting insects: How vegetation management can promote pollinator diversity. PLoS ONE 16(1):1-17.	https://sites.psu.edu/transmissionlineecology/files/2016/02/PLoS-One-Pollinators-2021.pdf
Weed control methods handbook (TNC)	Tu, M., Hurd, C., Randall, J.M.. 2001. Weed Control Methods Handbook: Tools & Techniques for Use in Natural Areas. The Nature Conservancy. Available at https://digitalcommons.usu.edu/govdocs/533 (accessed June 2025).	https://digitalcommons.usu.edu/govdocs/533
Wetland corridors based on hydrological connectivity for biodiversity	Qu, Y., Zeng X., Luo, C., Zhang, H., Liu, Y., Wang, J. 2024. Constructing wetland ecological corridor system based on hydrological connectivity with the goal of improving regional biodiversity. Journal of Environmental Management, 368:122074.	
Wetland drainage, restoration and repair (Biebighauser 2007)	Biebighauser, T.R. 2007. Wetland Drainage, Restoration and Repair. The University Press of Kentucky, Lexington, Kentucky.	
Wetland drainage, restoration and repair (Biebighauser 2011)	Biebighauser, T.R. 2011. Wetland Restoration and Construction: A Technical Guide. Upper Susquehanna Coalition, Owego, New York.	
Wetland ecology, delineation and regulation and assessment	National Research Council. 1995. Wetlands: Characteristics and Boundaries. National Academy Press, Washington, D.C.	
ldlife habitat connectivity	Howard, T. G., and M. D. Schlesinger. 2013. Wildlife habitat connectivity in the changing climate of New York's Hudson Valley. Annals of the New York Academy of Sciences 1298:103–109.	