OFFICE OF RESOURCE CONSERVATION

State of Illinois

Final Report: September 1, 2013 – December 29, 2016

PROJECT NUMBER: T-82-R-1

PROJECT TITLE: Defining expectations for mussel communities in Illinois wadeable streams

SUMMARY

This project updated knowledge of mussel Species in Greatest Need of Conservation (SGNC). We reevaluated mussel species for listing as SGNC and provided an update of the statuses, distributions, and stresses to mussel SGNC appropriate for a revision of the Illinois Wildlife Action Plan (IWAP) and provided action items to include in the Streams Campaign.

We completed distribution maps for each mussel species, and modeled potential species presence and historical (pre-settlement) distributions. Distribution maps and modeled expectations can assist with revisions or updates to conservation or recovery plans (T&E species).

We were able to make progress in transforming the existing mussel resource database from a user-specific application to a web-based application. The new database is housed on the INHS web server space and has options for multiple user inputs. The application significantly simplified the viewable data and the web-developer provided a more transparent format for storage and organization of data.

The original staff composition on this project changed significantly during the funding period. First, a primary staff member left the project due to an agency transfer during the 1st quarter of 2014 (March 2014), and the remaining two staff members became part-time on T-82 during the middle of 2015. Hence, we were unable to adhere to the original timeline as proposed. The project timeline was modified to account loss of staff and to reasonably meet deadlines. We requested no-cost time extensions to compensate for the loss of project personnel and also revised the budget to accommodate changes to on-campus and off-campus staff. All objectives were met under the revised timeline.

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**Objective 1.** Update knowledge of Illinois' 29 mussel Species in Greatest Need of Conservation (SGNC) in areas where locality or recruitment information are incomplete.

**1.1 Define expected levels of recruitment for mussels SGNC in at least 10 sites by October 2013.**

Mussel data collection (46 sites total) and recruitment sampling (10 targeted sites, 14 total) were conducted throughout the state during the 3rd quarter of 2013 (Table 1). We completed a recruitment analysis examining occupancy and detection of juvenile mussels using tactile searches versus excavation surveys. This analysis was presented at the annual chapter of the American Fisheries Society meeting during the 1st quarter of 2014 (Appendix 1; Stodola et al. 2014).

Objective 1.1 was completed by the 2nd quarter of 2014.

**1.2 Assess geographic range of at least three SGNC mussels that are new species to Illinois or have newly discovered populations outside of their known historic range in the state by December 2013.**

We completed geographic range assessments for all mussel SGNC in Illinois, and uncovered three species that warranted further investigation into their current status in Illinois – Little Spectaclecase (*Villosa lienosa*), Louisiana Fatmucket (*Lampsilis hydiana*), and Rayed Creekshell (*Anodontoides radiatus*; or a species morphologically similar and closely related to Cylindrical Papershell- *Anodontoides ferussacianus*). Sampling was conducted in the 3rd quarter of 2013 to assess the geographic ranges of Little Spectaclecase, Louisiana Fatmucket, and Cylindrical Papershell and/or Rayed Creekshell at 39 sites across 6 basins (Table 1; Big Muddy, Cache, Kaskaskia, Little Wabash, Ohio Tributaries and Vermilion-Wabash)

- Little Spectaclecase – *Villosa lienosa*: Sampling conducted during the 3rd quarter of 2013 helped assess the range connectivity of Little Spectaclecase, across the southern basins in Illinois from the Ohio to the Mississippi Rivers. During the 1st quarter of 2014, a report on the occurrence of Little Spectaclecase entitled "Occurrence of the Little Spectaclecase *Villosa lienosa* (Conrad, 1834) (Mollusca: Unionidae) downstream of the Wabash and Ohio River confluence in Illinois" was completed and was published in Transactions of the Illinois State Academy of Science in the 1st quarter of 2015 (Appendix 2; Shasteen et al. 2015).

- Louisiana Fatmucket – *Lampsilis hydiana*: New species – Previously collected Fatmucket specimens in portions of southern Illinois resembled the Louisiana Fatmucket, which was previously unknown as Illinois fauna. We investigated the potential presence of Louisiana Fatmucket throughout Illinois. We sampled eighteen sites in the Cache River, Little Wabash, Ohio River tributaries and Big Muddy River basin using visual and hand-grab methods (Table 1).

We reviewed genetic results completed by Dr. Chuck Lydeard (Western Illinois University) that compared Fatmucket (*Lampsilis siliquoidea*) samples to similar but morphologically distinct *Lampsilis cf. siliquoidea* (those that resembled Louisiana Fatmucket). Based on morphological characteristics and genetic analysis by Dr. Lydeard, it appears that southern *Lampsilis cf. siliquoidea* individuals are a separate species from Fatmucket and closely related to Louisiana Fatmucket, and are present in the Big Muddy, Cache, Kaskaskia, Ohio and Wabash basins.

Genetic work on this species is on-going in multiple states, as specimens from the type locality (Louisiana) and neighboring watersheds in Illinois (i.e., Missouri, and Kentucky) are being procured by cooperative agencies to ascertain the fullest geographic range of Louisiana Fatmucket. Results from this project have provided a very significant advancement to our knowledge of this species in Illinois.

Results from this job were presented at the 2015 Illinois American Fisheries Society meeting and the 2015 International Symposium for the Freshwater Mollusk Conservation Society in the form of a poster entitled "Genetic confirmation of putative *Lampsilis hydiana* in Illinois" (Appendix 3; Stodola et al. 2015), and as an oral platform by Dr. Chuck Lydeard (co-author and collaborator) at the 2015 American Malacological Society annual meeting.

- Rayed Creekshell (*Anodontoides radiatus*)– Specimens that resemble Rayed Creekshell (currently not known from Illinois) have been collected in some Ohio River tributaries in southern Illinois, and several specimens are cataloged in the INHS Mollusk Collection. Sampling was conducted in the 3rd quarter of 2013 (Table 1) to collect additional specimens that are morphologically similar to either *Anodontoides ferussacianus*, Cylindrical Papershell, or *Strophitus undulatus*, Creeper, which also resembles Rayed Creekshell. Specimens were collected in Big Grande Pierre Creek (Ohio River) and Rose Creek (Big Grande Pierre Creek – Ohio River), and both tissues and shell material were preserved and cataloged in the INHS Mollusk Collection (lots INHS 45469, 45472, 45473, and 45476) for further genetic work if future funding is available.

Objective 1.2 was completed in the 3rd quarter of 2014.

**1.3 Assess status of at least two mussel SGNC that have not been recently observed from some portion of their historic ranges by October 2014.**

Four mussel SGNC, Snuffbox (*Epioblasma triquetra*), Black Sandshell (*Ligumia recta*), Kidneyshell (*Ptychobranchus fasciolaris*), and Purple Lilliput (*Toxolasma lividum*), were selected for further study within the Vermilion River (Wabash drainage) and Embarras River basins (Figures 1-4)**.** Snuffbox, Kidneyshell and Purple Lilliput were the primary sampling targets for Job 1.3 because live Snuffbox were not collected at all during T-53 and live Purple Lilliput and Kidneyshell were only collected in one drainage in the state during T-53. The range of Black Sandshell overlapped our established target areas for the other species, thus we assessed the status of Black Sandshell simultaneously. Job 1.3 fieldwork was conducted during the 3$^{rd}$ quarter of 2014 (Table 2).

Historical records indicate Snuffbox occurred in 17 drainages statewide but have dramatically decreased by 94%. Since the 1977-1999 time period, Snuffbox has persisted at limited sites within the Embarras River above Lake Charleston reservoir. We focused survey efforts in the Embarras River during T-82 because this is the only drainage where they are believed to persist. We did not encounter live Snuffbox within the Embarras River during T-82 but did collect recently dead shell [INHS 49122] in a section of river not previously sampled (3.2 mi NNE Hindsboro, between CR 1900E and 2075E)(Figure 1). This section of river would be an ideal candidate for protection given the mussel community present. Snuffbox distribution continues to decline and become increasingly isolated and effort (e.g., augmentation) to salvage their dwindling population is recommended.

Kidneyshell has declined 71% from its historical range, and the most recent extant records occur only in the Vermilion River (Wabash River) and Embarras River basins. During T-53 survey efforts, no live Kidneyshell were observed in the Vermilion River (Wabash River) basin, but live populations were recorded in the Embarras River basin. In this survey effort, we did not encounter any live Kidneyshell in either basin (Figure 2), although we believe they persist within the Embarras basin based on survey results during T-53. Survey efforts during T-53 and T-82 revealed Kidneyshell may be too far below the population threshold in the Vermilion River (Wabash River) drainage to successfully recolonize its former range within this basin. Conservation of remaining stocks is critical, and this species may be a candidate for future restoration efforts within the Vermilion River (Wabash River) basin.

Purple Lilliput have declined 57% from their historical range and have remained stable in 3 drainages since 1977-1999. Purple Lilliput apparently persist in Big Grande Pierre Creek, Pope County, but few live individuals have been recorded in the last decade and no extant occurrences were recorded during T-53 surveys (although dead shell were collected by other INHS researchers in 2010). In T-82, we focused on Purple Lilliput occurrences in the Vermilion River (Wabash River) and Embarras River basins. A targeted sampling approach (primarily, silty edges and banks in or near current) for Purple Lilliput revealed several healthy populations in both watersheds and it may be more common than previously believed (Figure 3). However, Lilliput (*T. parvum*) are found throughout the entire range of Purple Lilliput in similar habitats and are often locally abundant. This suggests that Purple Lilliput may have a specific habitat or life history requirement that makes it vulnerable to population decline.

While Black Sandshell was found historically statewide, today it occurs primarily in central and north central Illinois. Since 1977-1999, Black Sandshell distribution has remained stable and slightly increased in range (36%). Live Black Sandshell was discovered during T-53 surveys in the Vermilion River (Wabash River), where previously thought to be locally extirpated. With this exciting discovery during T-53, we decided to assess Black Sandshell occurrences in the Vermilion River downstream of the Danville Dam (the furthest upstream extant record). We conducted surveys in the lower Vermilion River but found only fresh dead shell of 1 Black

Sandshell (Figure 4). Previous survey efforts during T-53 on the Salt Fork and Middle Fork Vermilion Rivers and current survey efforts during T-82 on the North Fork Vermilion River did not reveal any live or extant Black Sandshell. While Black Sandshell appear to be slowly colonizing this system, populations are not widespread. The lower Vermilion River could be a good candidate for restoration efforts, and efforts should be made to conserve existing populations.

Objective 1.3 was completed in the 3rd quarter of 2014.

**1.4 Assess habitat suitability and host availability at a minimum of five sites for selected mussel SGNC by October 2014.**

Host relationship and habitat requirement evaluation of SGNC species were gathered from available literature sources. Fish survey data were collected from the most recent sampling events by IDNR and the INHS fish collection database. Based on distribution gaps from recent mussel surveys, sites were selected and fieldwork to assess habitat suitability was completed during 3rd quarter of 2014 (Table 2, Figures 1-4). Specific habitat requirements for each species were compiled and were presented in the report titled "Status revision and update for Illinois' freshwater mussel Species in Greatest Need of Conservation" (Appendix 4; Douglass and Stodola 2014).

Objective 1.4 was completed in the 3rd quarter of 2014.

**Objective 2.** Status revision and update for the 29 Illinois' mussel SGNC
**2.1 Review at least 40 mussel species using established criteria for listing as SGNC by April 2014. Timeframe: September 2013-April 2014 (revised completion by July 2014)**

A review was completed for 77 mussel species using established criteria for listing and all 29 SGNC species have been evaluated. In addition, distribution maps for 77 mussel species, including all 29 SGNC species, was completed (Appendix 4). This objective was completed during the 3rd quarter of 2014.

**2.2 Update and revise the status, objectives, and stresses listed for at least the current 29 mussel SGNC by August 2014. Timeframe: February-October 2014**

This objective was initiated in the 1st quarter of 2014 and status, objectives, and stresses were completed for the current 29 mussel SGNC species by August 2014. During our review of non-listed mussel species, an additional 11 species were included in this review for proposed listing as SGNC in 2015. Due to the relationship between host fish and freshwater mussels, we evaluated the current state of the literature regarding host fish for Illinois mussels (including extirpated and stable species). For each species, we compiled references associated with the host fish research and the infestation or transformation type. This information was used to update and revise stresses (i.e., hosts) to mussel SGNC as well as provide additional data for Objective 4. Results from this objective will guide listing status changes by the Illinois Endangered Species Protection Board (estimated to meet in spring 2017). A manuscript entitled "Freshwater mussel-host relationships of the Upper Mississippi and Ohio River systems" was submitted for peer review to Freshwater Mollusk Conservation and Biology in the 2nd quarter of 2016, but was deemed in need of major revision and will be revised and submitted at a future date.

This objective was completed in the 2nd quarter of 2014.

**2.3 Prepare a report that summarizes changes to Status, Objectives, and Stresses of Illinois' mussel SGNC by August 2014. Timeframe: May 2014-August 2014 (revised completion by November 30, 2014)**

Results from Objectives 2.1 and 2.2, host fish literature review, and current distribution maps are completed and included in the report titled "Status revision and update for Illinois' freshwater mussel Species in Greatest Need of Conservation" (Appendix 4).

This objective was completed in the 4th quarter of 2014.

**Objective 3.** Develop a list of at least five suggested Actions for the Streams Campaign in the IWAP that focus on mussel conservation by August 2014. Timeframe: August-October 2014 (revised completion by November 30, 2014)

Suggested Actions for the Streams Campaign were included in the report "Status revision and update for Illinois' freshwater mussel Species in Greatest Need of Conservation" (Appendix 4).

This objective was completed in the 4th quarter of 2014.

**Objective 4**. Develop species distribution model for at least 30 Illinois mussel species by April 2014. Timeframe: September 2013-April 2014 (revised completion February 2015)

We used Random Forests (RF) modeling to predict the relative abundance of individual mussel species and Maximum Entropy (Maxent) modeling to predict the historic ranges of individual species. Both modeling approaches rank the relative importance of environmental variables (including stressors) for the predictions.

The RF dataset was compiled for 915 sites across the state and included mussel species, habitat, water quality, and landscape variables. Landscape variables were GIS-based and included parameters such as surficial geology, elevation, slope, aspect, land cover, various soil parameters, and climatic data. RF models using only GIS-based landscape variables were completed for 39 mussel species, which were species that were collected in at least 15 reaches (a minimum number established during the modeling procedures). Fish-host relationship was investigated for the 39 mussel species in this analysis and related to the statewide fish collection data, which was previously compiled for distribution maps for Illinois fish species (Cao et al. unpublished data). We reran the mussel distribution models for 645 sites (fish data were available for only 645 of 915 sites) using fish abundance and richness. We ran multiple iterations of models using various datasets (fish host relationship, habitat data, landscape data, etc.) with an ultimate goal of identifying the data parameters that best approximate mussel abundance.

Preliminary results of the RF analysis were presented at the annual chapter of the American Fisheries Society meeting, the Prairie Lightning Symposium during the 1st quarter of 2014, and the annual meeting of the Society for Freshwater Science during the 2nd quarter of 2014. Results of the first RF analysis were published by Dr. Cao in *Freshwater Biology*, entitled "Modeling and mapping the distributions of mussel species, species diversity, and relative abundance in wadeable streams of Illinois, USA", in the 1st quarter of 2015 (Appendix 5; Cao et al. 2015).

Maximum Entropy modeling (Maxent) data analysis occurred from the 4th quarter of 2015 until the 2nd quarter of 2016. We compiled species records for 82 mussel species in Illinois and related their locations to specific stream reaches. The final created dataset consisted of unique localities (with similarly unique PUGAP codes) with freshwater mussel data associated with each unique locality and with the most recent streamline dataset. Data were linked with an environmental dataset (e.g., landcover data at a HUC12 level, glaciation data, historical landcover from 1800, and natural division data), and these datasets were used to model a perceived natural distribution for mussel species in Illinois. We identified and isolated records collected from wadeable streams and built Maxent models for 45 native species that were recorded at ten-1,212 unique stream reaches based on a range of natural environmental variables (e.g., climate, geology, soil, topography, and 1800s land covers). These models were used to predict the historic distributions of those species across wadeable streams in the state and to estimate reach species richness.

A technical report for INHS/IDNR that showcases a historical distribution map for 45 species was completed in the 2nd quarter of 2016 (Appendix 6, Stodola and Douglass 2016) and a manuscript entitled "Reconstructing the natural distribution of individual mussel species and species diversity in wadeable streams of Illinois, USA with reference to stream bioassessment" was prepared and will be submitted by Dr. Cao to *Freshwater Science* (Appendix 7; Cao et al. in review).

**Objective 5.** Enhance the data entry and export functionality of IDNR's master mussel database by April 2014 (revised completion by February 2015).

**5.1 Build a web-based data entry application that will allow multiple biologists to enter data into the mussel database by April 2014. Timeframe: September 2013-April 2014 (revised completion by December 2014)**

The Illinois Mussel Database (created under State Wildlife Grant T-12-P-1) was installed on the computers of the Mussel Coordinator and Mussel Biologists. Field sampling data from all years were added to each crew leader's database; subsequently the three individual databases were combined into a statewide "master" database. The inability of the database to accept multiple samples from a single locality, limited querying ability (e.g., sites are only accessible by temporary site id generated by database not by ILEPA code or individual field number), and several other query problems including the return of incorrect data were investigated.

INHS biological informatician Phil Anders assisted in building a web-based data entry application. The database was inventoried, reorganized, exported to new comma-separated files, and was imported into a basic online interface for data entry or export (Figure 5). Currently, users must login to a password-protected weblink to enter data, but all data are accessible for download; security levels will be assessed in the future as users provide feedback.

**5.2 Develop a data extraction tool and at least two summary reports that pull data directly from the master database by April 2014. Timeframe: September 2013-April 2014 (revised completion by February 2015)**

Automatic reports are generated that summarize sampling data collected at a given site in time that can be used for both Element of Occurrence Reporting and a summary of the Mussel Classification Index (Figure 6). Because the data summarized for these specific reporting needs are very similar and nearly redundant, a reporting tool was created that condenses all the information into one report. Users will be required to file an Element of Occurrence Record if their data meet certain criteria, which are outlined within the database.

**Literature Cited**

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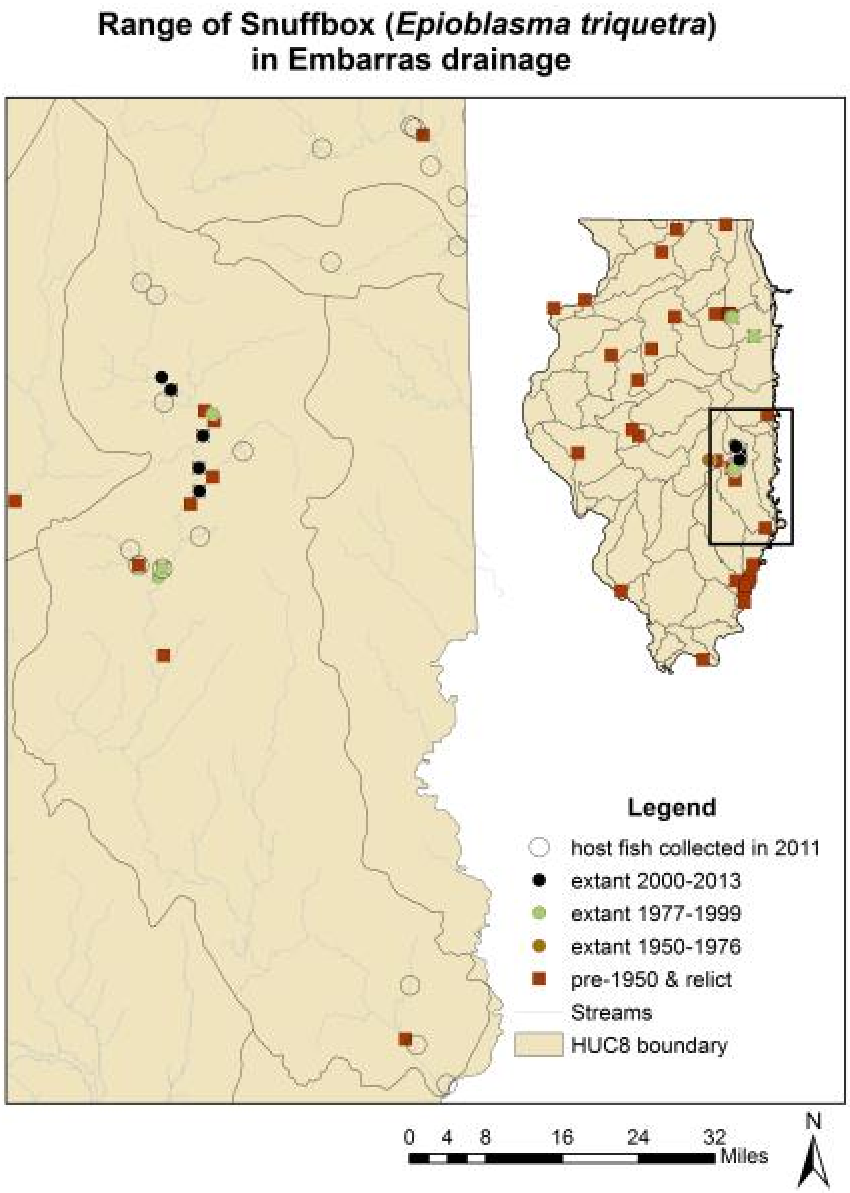
**Table 1**. 2013 field sites for evaluating levels of recruitment and assessing geographic range of mussel SGNC for completion of Objectives 1.1 and 1.2.

| Basin | Field Number | Code | Day | Month | Year | Purpose | Recruitment sampling | Stream | Location | County | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sangamon | Stodola-2013-018 | EZU-02 | 6 | August | 2013 | excavation | Yes | Big Ditch | 3.5 mi SE Fisher, 700E | Champaign | 40.2674 | -88.3276 |
| Mackinaw | Stodola-2013-019 | n/a | 7 | August | 2013 | excavation | Yes | Mackinaw River | 4.8 mi ESE Anchor, 4100E | McLean | 40.5648 | -88.4785 |
| Embarras | Stodola-2013-020 | BET-01 | 8 | August | 2013 | excavation | Yes | East Branch Embarras | 2 mi NNW Villa Grove, 100N | Champaign | 39.894 | -88.1795 |
| Vermilion-Wabash | Stodola-2013-021 | BPGE-01 | 20 | August | 2013 | recruitment resampling | Yes | Middle Branch North Fork Vermilion River | 0.5 mi W Alvin, Barlow Park | Vermilion | 40.3108 | -87.6227 |
| Vermilion-Wabash | Stodola-2013-022 | BPG-13 | 20 | August | 2013 | recruitment resampling | Yes | North Fork Vermilion River | 1 mi W Alvin, 3045N | Vermilion | 40.3086 | -87.6336 |
| Iroquois | Stodola-2013-023 | n/a | 21 | August | 2013 | excavation/timed search | Yes | Beaver Creek | 3.5 mi W Papineau, 1800E | Iroquois | 40.9699 | -87.7901 |
| Embarras | Stodola-2013-024 | BE-38 | 22 | August | 2013 | excavation | Yes | Embarras River | 2.25 mi ENE Rardin, Boyd Ford | Coles | 39.61 | -88.0716 |
| Vermilion-Wabash | Stodola-2013-001 | n/a | 8 | July | 2013 | SGNC sampling | | Salt Fork Vermilion River | 3.6 mi NNW Catlin; accessed via 1600N | Vermilion | 40.1097 | -87.7387 |
| Vermilion-Wabash | Stodola-2013-002 | n/a | 8 | July | 2013 | SGNC sampling | | Salt Fork Vermilion River | 3.4 mi NW Catlin; accessed via 1600N (450 m downstream site 17) | Vermilion | 40.1040 | -87.7408 |
| Vermilion-Wabash | Stodola-2013-003 | n/a | 8 | July | 2013 | SGNC sampling | | Salt Fork Vermilion River | 3.2 mi NW Catlin; accessed via 1600N | Vermilion | 40.1023 | -87.7396 |
| Vermilion-Wabash | Stodola-2013-004 | n/a | 9 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 1.8 mi ENE Collison; between 2600N and 900E | Vermilion | 40.2384 | -87.7743 |
| Vermilion-Wabash | Stodola-2013-005 | n/a | 15 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 2.4 mi S Potomac; uppermost section of MFFWA | Vermilion | 40.2701 | -87.7951 |
| Vermilion-Wabash | Stodola-2013-006 | n/a | 15 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 1.8 mi NE Collison; RR bridge, 0.25 mi upstream 2600N | Vermilion | 40.2435 | -87.7774 |
| Vermilion-Wabash | Stodola-2013-007 | n/a | 16 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 6 mi SE Collison; accessed via Sportsman Lake area | Vermilion | 40.1547 | -87.7373 |
| Vermilion-Wabash | Stodola-2013-008 | n/a | 16 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 6.2 mi SE Collison; accessed via Sportsman Lake area | Vermilion | 40.1505 | -87.7364 |
| Vermilion-Wabash | Stodola-2013-009 | n/a | 16 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 3.8 mi ESE Collison; upstream of Bunker Hill canoe launch | Vermilion | 40.2044 | -87.7378 |
| Vermilion-Wabash | Stodola-2013-010 | n/a | 17 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 2.0 mi ENE Collison; accessed via hunter parking #7 | Vermilion | 40.2386 | -87.7679 |
| Vermilion-Wabash | Stodola-2013-011 | n/a | 17 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 2.1 mi ENE Collison; accessed via hunter parking #7 | Vermilion | 40.2350 | -87.7664 |
| Vermilion-Wabash | Stodola-2013-012 | n/a | 17 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 2.1 mi ENE Collison; accessed via hunter parking #7 | Vermilion | 40.2328 | -87.7655 |
| Vermilion-Wabash | Stodola-2013-013 | n/a | 18 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 4 mi ESE Collison; downstream of Kennekuk CP canoe launch | Vermilion | 40.2014 | -87.7348 |
| Vermilion-Wabash | Stodola-2013-014 | n/a | 18 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 3.9 mi ESE Collison; upstream of Kennekuk CP canoe launch | Vermilion | 40.2033 | -87.7354 |
| Vermilion-Wabash | Stodola-2013-015 | n/a | 22 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 4.4 mi NW Catlin; accessed via Skyline Drive | Vermilion | 40.1237 | -87.7344 |
| Vermilion-Wabash | Stodola-2013-016 | n/a | 23 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 3.3 mi SE Collison; accessed via 2400N and horse trail-south | Vermilion | 40.2064 | -87.7465 |
| Vermilion-Wabash | Stodola-2013-017 | n/a | 23 | July | 2013 | SGNC sampling | | Middle Fork Vermilion River | 4 mi ESE Collison; accessed via 2250N and horse trail | Vermilion | 40.1938 | -87.7392 |
| Cache | Shasteen-2013-013 | n/a | 3 | September | 2013 | V. lienosa sampling | Yes | Cache River | 1200 N Rd; SW of Buncombe | Johnson | 37.4652 | -89.0189 |
| Cache | Shasteen-2013-014 | ADP-01 | 3 | September | 2013 | L. hydiana/V. lienosa | | Bradshaw Creek | Mt Pleasant Rd; N of Cache River | Union | 37.4726 | -89.0798 |
| Little Wabash | Shasteen-2013-015 | CA-07 | 4 | September | 2013 | L. hydiana/V. lienosa | Yes | Skillet Fork | 1250 N Rd; Ford W of Crisp | Wayne | 38.4393 | -88.6263 |
| Little Wabash | Shasteen-2013-016 | n/a | 4 | September | 2013 | L. hydiana sampling | Yes | Horse Creek | 300 E Rd; NNW of Keensville | Wayne | 38.3719 | -88.6459 |
| Little Wabash | Shasteen-2013-017 | CAR-01 | 4 | September | 2013 | L. hydiana sampling | | Brush Creek | 1500 N Rd; NW of Crisp | Wayne | 38.4758 | -88.6346 |
| Ohio Tribs | Shasteen-2013-018 | ALF-11 | 5 | September | 2013 | L. hydiana/A. radiata | Yes | Rose Creek | Rt 34 bridge; SE of Herod | Hardin | 37.5667 | -88.4121 |
| Ohio Tribs | Shasteen-2013-019 | AL-13 | 5 | September | 2013 | L. hydiana/A. radiata | Yes | Big Grande Pierre | Blackman Cemetary Rd; SE of Herod | Pope | 37.5574 | -88.4233 |
| Ohio Tribs | Shasteen-2013-020 | AJG-17 | 5 | September | 2013 | A. radiata/V. lienosa | | Hayes Creek | Rt 145; S of Eddyville | Pope | 37.464 | -88.6307 |
| Cache | Shasteen-2013-021 | n/a | 10 | September | 2013 | V. lienosa sampling | | Lick Creek | Allen Rd; WNW of Buncombe | Johnson | 37.4787 | -89.0159 |
| Cache | Shasteen-2013-022 | IXM-02 | 10 | September | 2013 | L. hydiana/V. lienosa | | Cypress Creek | Mt Pleasant Rd; W of Moscow | Union | 37.4085 | -89.0776 |
| Little Wabash | Shasteen-2013-023 | CD-09 | 10 | September | 2013 | L. hydiana sampling | | Elm River | 2200 N Rd; near Enterprise | Wayne | 38.5735 | -88.3682 |
| Kaskaskia | Shasteen-2013-024 | OK-01 | 11 | September | 2013 | L. hydiana sampling | | East Fork Kaskaskia | Rt 51; N of Sandoval | Marion | 38.6903 | -89.0996 |
| Kaskaskia | Shasteen-2013-025 | OL-98 | 11 | September | 2013 | L. hydiana sampling | | Hurricane Creek | 1550 N; W of Vandalia | Fayette | 38.9648 | -89.2131 |
| Kaskaskia | Shasteen-2013-026 | ON-02 | 11 | September | 2013 | L. hydiana sampling | | Hickory Creek | 1300 N; S of Bluff City | Fayette | 38.9247 | -89.0461 |
| Cache | Shasteen-2013-027 | n/a | 11 | September | 2013 | V. lienosa sampling | | Lick Creek | Lick Creek Rd; N of Lick Creek | Union | 37.5301 | -89.0666 |
| Big Muddy | Shasteen-2013-028 | N-08 | 12 | September | 2013 | L. hydiana sampling | Yes | Big Muddy | Rt 15; W of Mt. Vernon | Jefferson | 38.3098 | -88.9886 |
| Cache | Shasteen-2013-029 | n/a | 12 | September | 2013 | L. hydiana/V. lienosa | Yes | Cache River | Lick Creek Rd; NE of Anna | Union | 37.4852 | -89.1513 |
| Big Muddy | Shasteen-2013-030 | n/a | 12 | September | 2013 | L. hydiana sampling | | Beaucoup Creek | Wisely Rd @ old bridge crossing | Jackson | 37.8917 | -89.3585 |
| Kaskaskia | Stodola-2013-025 | OT-03 | 18 | September | 2013 | L. hydiana | | West Okaw River | 3 mi SW Lovington, 1850N | Moultrie | 39.6737 | -88.6651 |
| Kaskaskia | Stodola-2013-026 | OW-03 | 18 | September | 2013 | L. hydiana | | Lake Fork Kaskaskia River | 4 mi SE Bement, 1200E | Piatt | 39.8761 | -88.5185 |
| Kaskaskia | Stodola-2013-027 | OZZX | 18 | September | 2013 | L. hydiana | | Twomile Slough | .5 mi SW Parkville, 500E | Champaign | 39.8842 | -88.3682 |
| Kaskaskia | Stodola-2013-028 | OT | 18 | September | 2013 | L. hydiana | | West Okaw River | 4 mi SW Lovington, 1750N | Moultrie | 39.6588 | -88.6841 |

**Table 2.** Sampling locations and suitable habitat recommendations for completion of Objectives 1.3 and 1.4.

| Basin | River | Location and access type | County | Latitude | Longitude | Sample date | Target species found live? | Suitable mussel habitat? | Host fish present | Fish collection source and date |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sites sampled for Snuffbox (*Epioblasma triquetra*)** | | | | | | | | | | |
| Embarras | Embarras River | access off of 300N; walk-in | Coles | 39.4203 | -88.1775 | 21-Aug-14 | No (R) | Yes | Yes | INHS - 1999, 2007 |
| Embarras | Embarras River | access off of trail in Fox Ridge SP; walk-in | Coles | 39.4088 | -88.1706 | 21-Aug-14 | No | Yes | Yes | INHS - 1999, 2007 |
| Embarras | Embarras River | 1760E to 1900N; canoe | Douglas | 39.7519 | -88.1427 | 18-Aug-14 | No | No | no samples | |
| Embarras | Embarras River | 1760E to 1900N; canoe | Douglas | 39.7473 | -88.1399 | 18-Aug-14 | No | Yes | no samples | |
| Embarras | Embarras River | 1900E to 2075E; canoe | Douglas | 39.7256 | -88.105 | 19-Aug-14 | No | Yes | no samples | |
| Embarras | Embarras River | 1900E to 2075E; canoe | Douglas | 39.7191 | -88.0906 | 19-Aug-14 | No (D) | Yes | no samples | |
| **Sites sampled for Black Sandshell (*Ligumia recta*)** | | | | | | | | | | |
| Vermilion-Wabash | North Fork Vermilion River | d/s of Hungry Hollow Road; walk-in | Vermilion | 40.1329 | -87.6548 | 15-Aug-14 | No | Yes | no samples | |
| Vermilion-Wabash | North Fork Vermilion River | d/s of Hungry Hollow Road; walk-in | Vermilion | 40.1294 | -87.6506 | 15-Aug-14 | No | Yes | no samples | |
| Vermilion-Wabash | Vermilion River | Grape Creek Rd to Forest Glen; canoe | Vermilion | 40.0358 | -87.5575 | 13-Aug-14 | No (D) | Yes | Yes | IDNR - 2011 |
| **Sites sampled for Kidneyshell (*Ptychobranchus fasciolaris*)** | | | | | | | | | | |
| Vermilion-Wabash | Middle Branch North Fork Vermilion River | 3200N to 3060N; walk-in | Vermilion | 40.3151 | -87.6204 | 12-Aug-14 | No | Yes | Yes | INHS - 2001 |
| Vermilion-Wabash | Middle Branch North Fork Vermilion River | 3200N to 3060N; walk-in | Vermilion | 40.3165 | -87.6184 | 12-Aug-14 | No | Yes | no samples | |
| Vermilion-Wabash | Middle Branch North Fork Vermilion River | 3200N to 3060N; walk-in | Vermilion | 40.3228 | -87.6173 | 12-Aug-14 | No | Yes | no samples | |
| Vermilion-Wabash | North Fork Vermilion River | d/s of Hungry Hollow Road; walk-in | Vermilion | 40.1329 | -87.6548 | 15-Aug-14 | No | Yes | no samples | |
| Vermilion-Wabash | North Fork Vermilion River | d/s of Hungry Hollow Road; walk-in | Vermilion | 40.1294 | -87.6506 | 15-Aug-14 | No (R) | Yes | no samples | |
| Vermilion-Wabash | Vermilion River | Grape Creek Rd to Forest Glen; canoe | Vermilion | 40.0358 | -87.5575 | 13-Aug-14 | No (R) | Yes | Yes | |
| Embarras | Embarras River | 1760E to 1900N; canoe | Douglas | 39.7519 | -88.1427 | 18-Aug-14 | No | No | no samples | |
| Embarras | Embarras River | 1760E to 1900N; canoe | Douglas | 39.7473 | -88.1399 | 18-Aug-14 | No | Yes | no samples | |
| Embarras | Embarras River | 1900E to 2075E; canoe | Douglas | 39.7256 | -88.105 | 19-Aug-14 | No | Yes | no samples | |
| Embarras | Embarras River | 1900E to 2075E; canoe | Douglas | 39.7191 | -88.0906 | 19-Aug-14 | No | Yes | no samples | |
| Embarras | Embarras River | access off of 300N; walk-in | Coles | 39.4203 | -88.1775 | 21-Aug-14 | No | Yes | Yes | INHS - 1999, 2007 |
| Embarras | Embarras River | access off of trail in Fox Ridge SP; walk-in | Coles | 39.4088 | -88.1706 | 21-Aug-14 | No | Yes | Yes | INHS - 1999, 2007 |
| **Sites sampled for Purple Lilliput (*Toxolasma lividum*)** | | | | | | | | | | |
| Embarras | Brushy Fork | 2510E bridge | Douglas | 39.7852 | -87.9974 | 11-Aug-14 | No | Yes | Yes | INHS - 2001 |
| Embarras | Brushy Fork | off 800N | Douglas | 39.7737 | -88.0172 | 11-Aug-14 | Yes (3) | Yes | Yes | INHS - 2001 |
| Embarras | Embarras River | 1760E to 1900N; canoe | Douglas | 39.7519 | -88.1427 | 18-Aug-14 | No | No | no samples | |
| Embarras | Embarras River | 1760E to 1900N; canoe | Douglas | 39.7473 | -88.1399 | 18-Aug-14 | No | Yes | no samples | |
| Embarras | Embarras River | 1900E to 2075E; canoe | Douglas | 39.7256 | -88.1050 | 19-Aug-14 | No | Yes | no samples | |
| Embarras | Embarras River | 1900E to 2075E; canoe | Douglas | 39.7191 | -88.0906 | 19-Aug-14 | No (D) | Yes | no samples | |
| Embarras | Scattering Fork | d/s 130 | Douglas | 39.7433 | -88.1732 | 11-Aug-14 | No | Yes | Yes | IDNR - 2011 |
| Vermilion-Wabash | Middle Fork Vermilion River | 2700E to 3100 E; canoe | Champaign | 40.358 | -87.9458 | 20-Aug-14 | No | Yes | Yes | IDNR - 2011 |
| Vermilion-Wabash | Middle Fork Vermilion River | 2700E to 3100 E; canoe | Champaign | 40.3383 | -87.9433 | 20-Aug-14 | No | Yes | Yes | IDNR - 2011 |
| Vermilion-Wabash | Jordan Creek | 2020E; bridge | Vermilion | 40.3563 | -87.5647 | 7-Aug-14 | Yes (8) | Yes | Yes | IDNR - 2011 |
| Vermilion-Wabash | Jordan Creek | state line road | Vermilion | 40.3562 | -87.5291 | 7-Aug-14 | Yes (16) | Yes | Yes | IDNR - 2011 |
| Vermilion-Wabash | Middle Branch North Fork Vermilion River | 3200N to 3060N; walk-in | Vermilion | 40.3151 | -87.6204 | 12-Aug-14 | No | Yes | Yes | INHS - 2001 |
| Vermilion-Wabash | Middle Branch North Fork Vermilion River | 3200N to 3060N; walk-in | Vermilion | 40.3165 | 87.6184 | 12-Aug-14 | Yes (8) | Yes | no samples | |
| Vermilion-Wabash | Middle Branch North Fork Vermilion River | 3200N to 3060N; walk-in | Vermilion | 40.3228 | -87.6173 | 12-Aug-14 | Yes (1) | Yes | no samples | |
| Vermilion-Wabash | North Fork Vermilion River | d/s of Hungry Hollow Road; walk-in | Vermilion | 40.1329 | -87.6548 | 15-Aug-14 | No | Yes | no samples | |
| Vermilion-Wabash | North Fork Vermilion River | d/s of Hungry Hollow Road; walk-in | Vermilion | 40.1294 | -87.6506 | 15-Aug-14 | No | Yes | no samples | |
| Vermilion-Wabash | North Fork Vermilion River | 3200E (Illinois-Indiana state line); bridge | Vermilion | 40.501 | -87.5264 | 6-Aug-14 | No | Yes | Yes | |
| Vermilion-Wabash | North Fork Vermilion River | 1950E; bridge | Vermilion | 40.4757 | -87.5847 | 6-Aug-14 | No (R) | Yes | Yes | |
| Vermilion-Wabash | North Fork Vermilion River | 1700E; bridge | Vermilion | 40.4642 | -87.6299 | 6-Aug-14 | Yes (5) | Yes | Yes | |



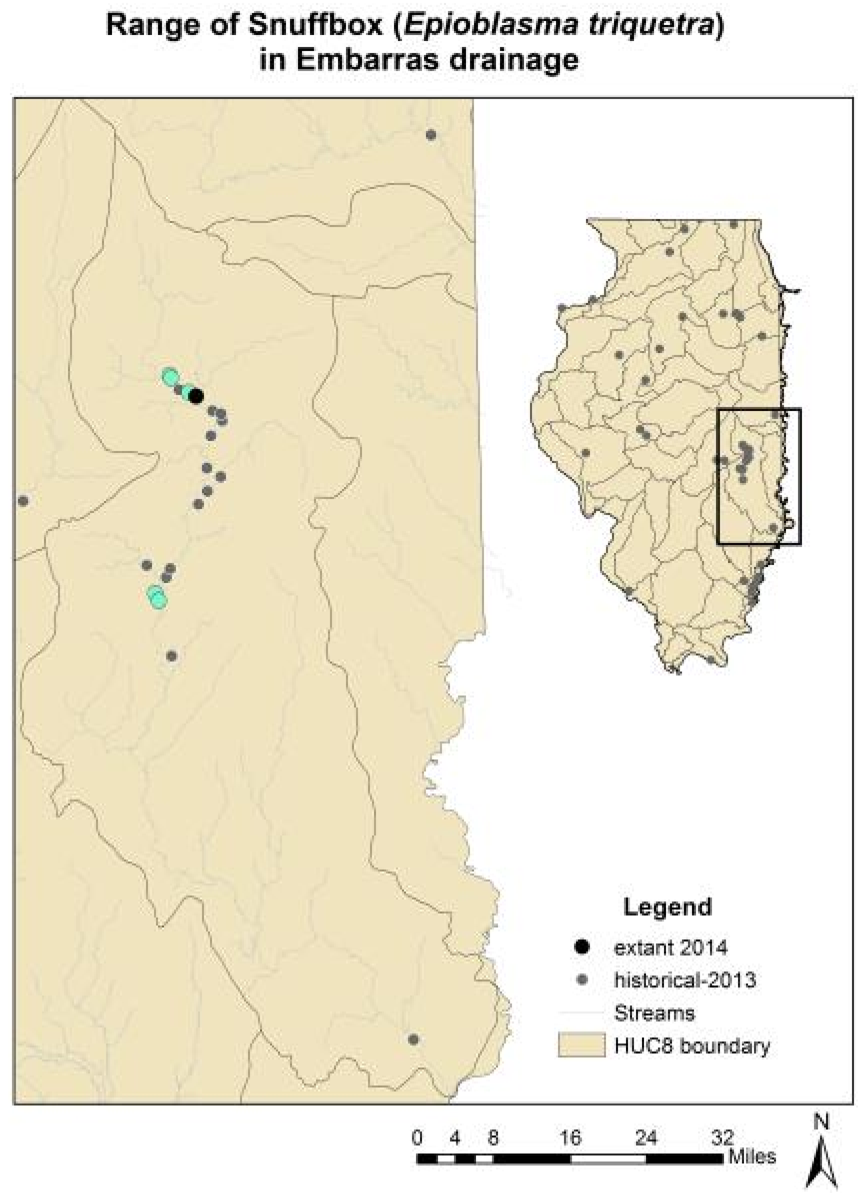
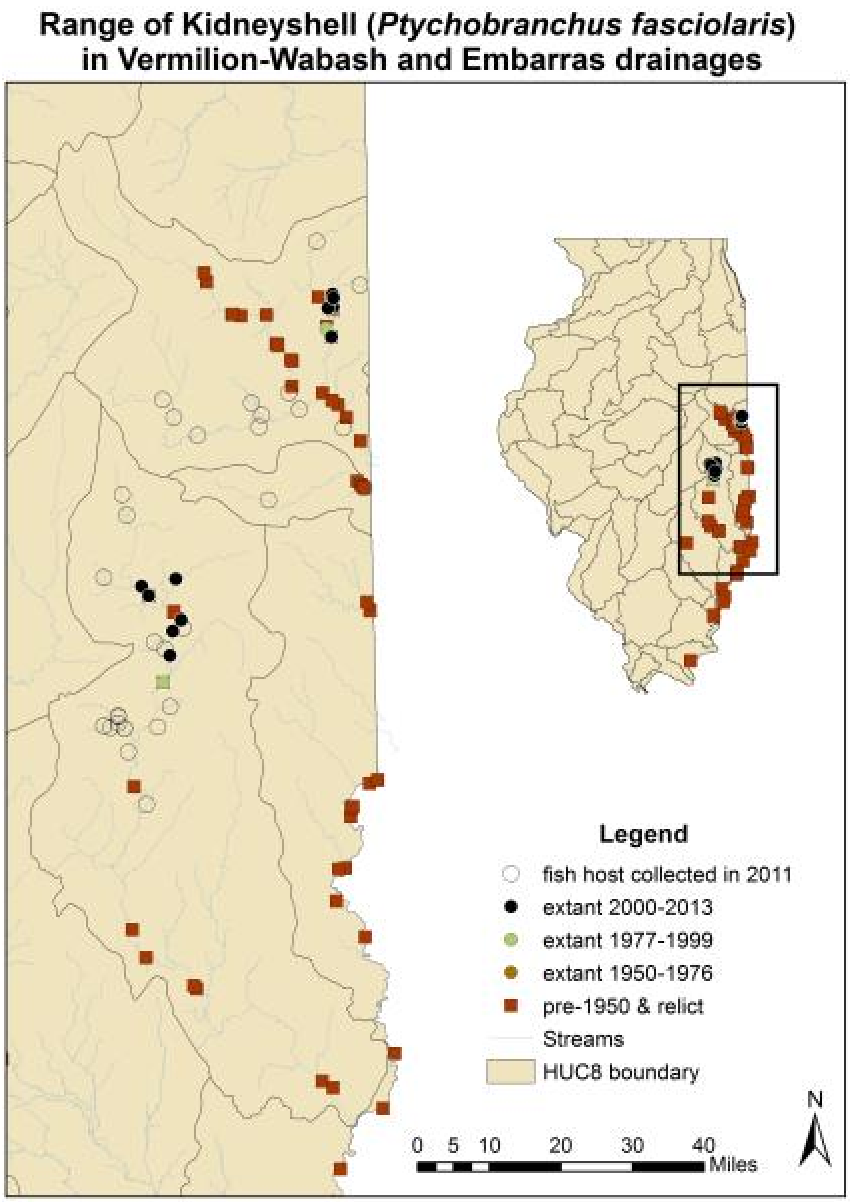




**Figure 1.** Current and historic range for Snuffbox *Epioblasma triquetra* and host fish range map for Vermilion River (Wabash drainage) and Embarras River basins.



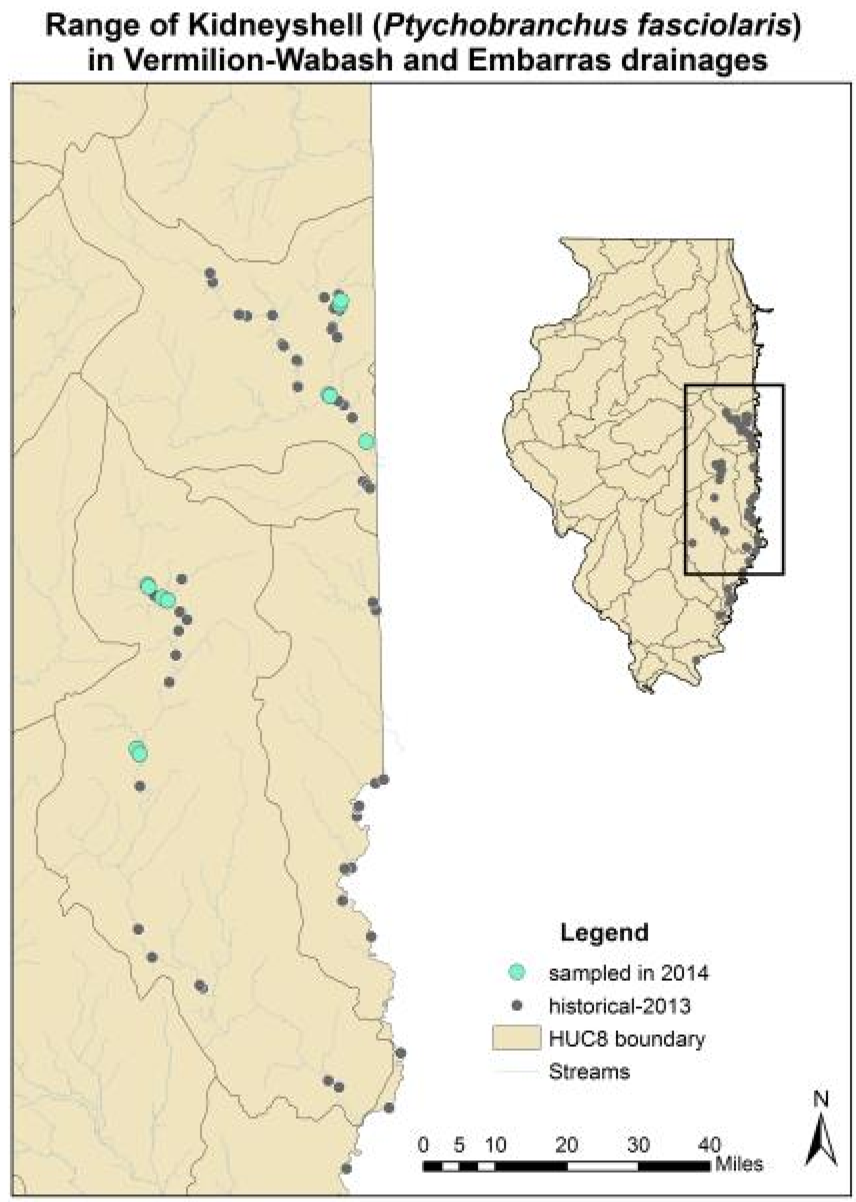
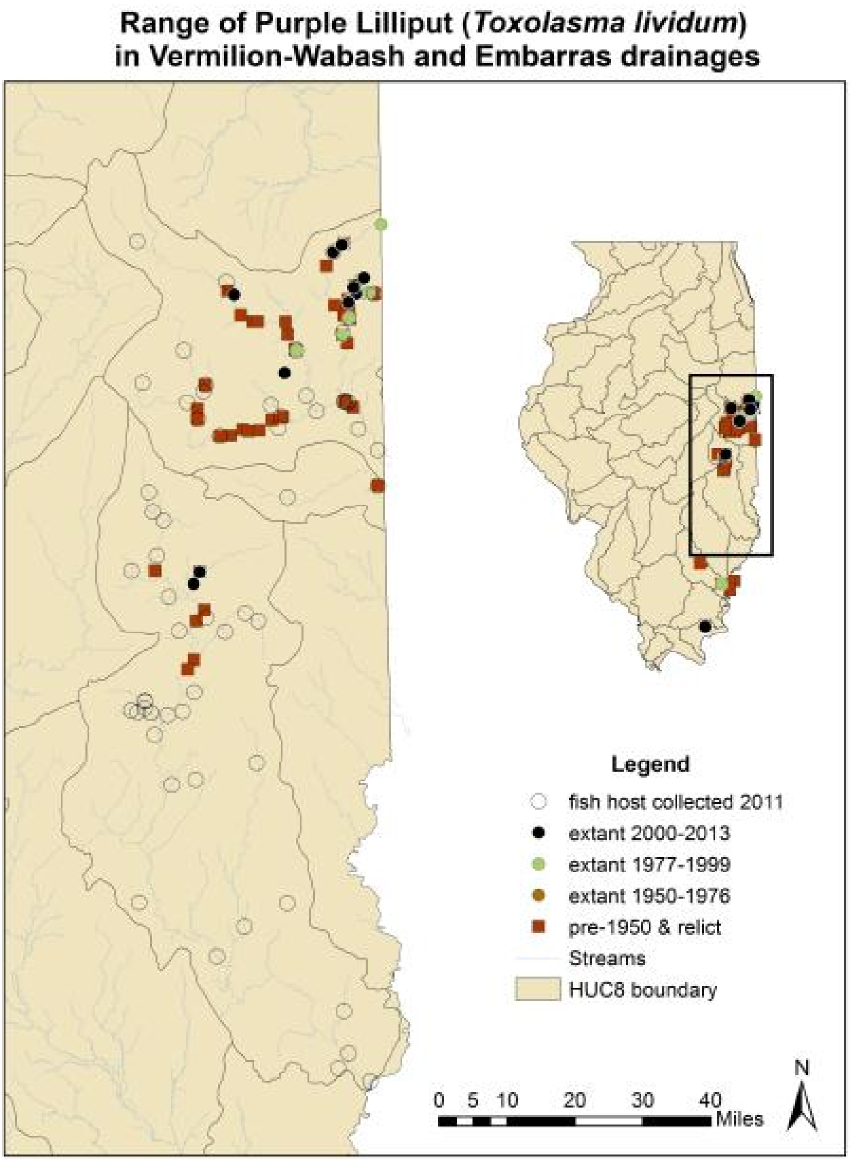




**Figure 2.** Current and historic range for Kidneyshell *Ptychobranchus fasciolaris* and host fish range map for Vermilion River (Wabash drainage) and Embarras River basins.



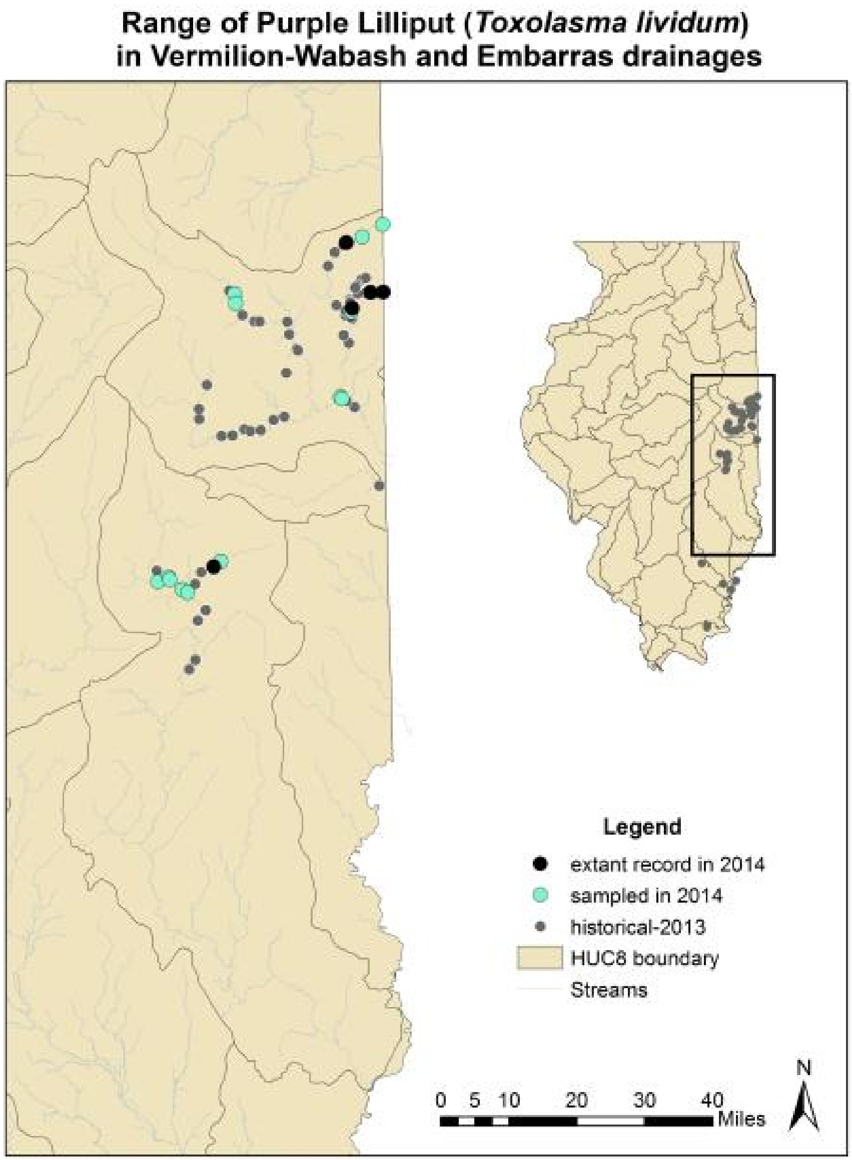




**Figure 3.** Current and historic range for Purple Lilliput *Toxolasma lividum* and host fish range map for Vermilion River (Wabash drainage) and Embarras River basins.

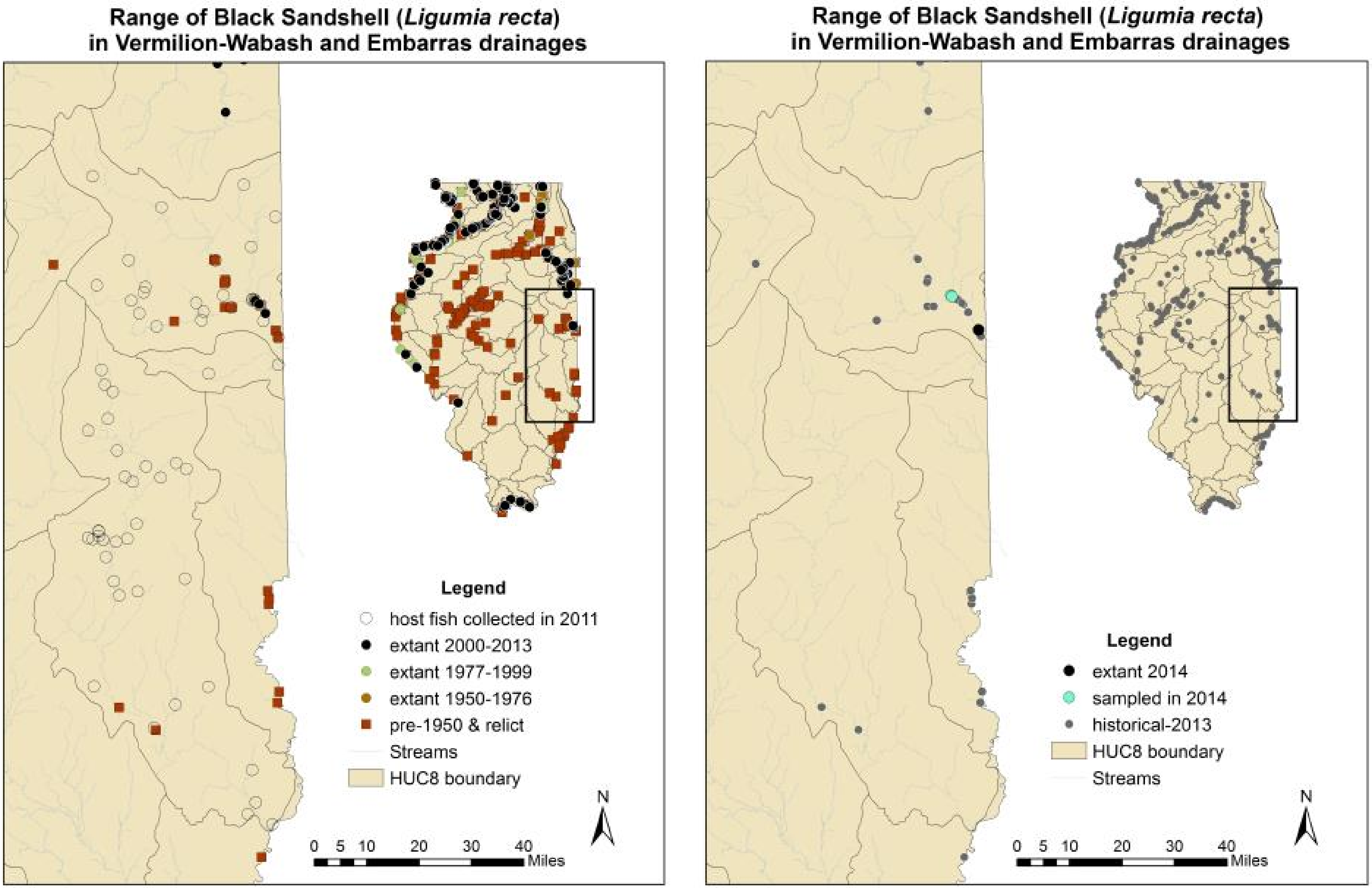



**Figure 4**. Current and historic range for Black Sandshell *Ligumia recta* and host fish range map for Vermilion River (Wabash drainage) and Embarras River basins.

**Figure 5.** Data entry interface for user to enter habitat information for a sampled site.

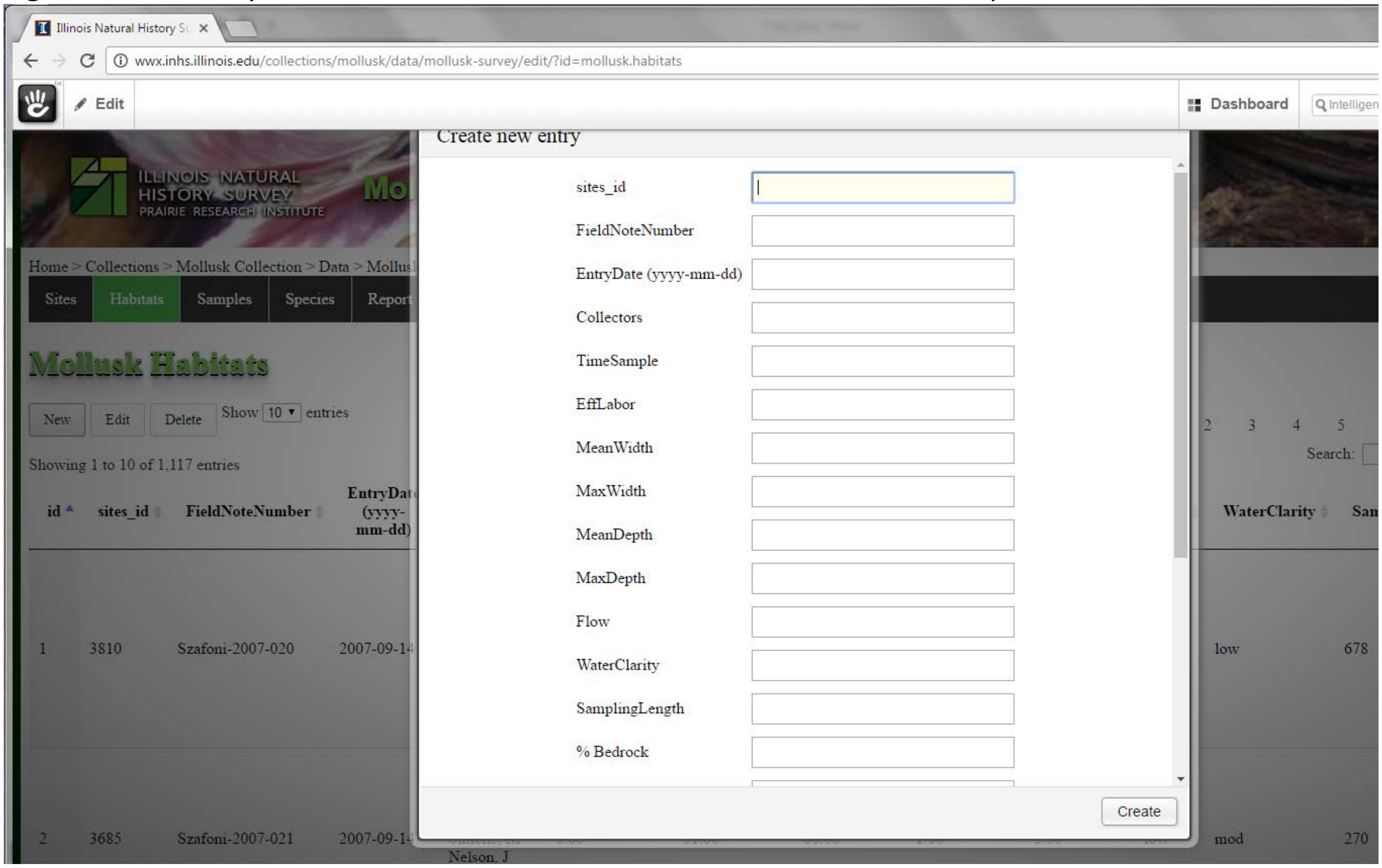


**Figure 6.** An example of a report generated that could be used for required reporting for an Element of Occurrence Record.

**Mussel Indicator Report**

State: Illinois County: McDonough
Stream: Grindstone Creek Significant stream name: 10 LaMoine River
Common Location: at Bergen Road; 5.1 mi S Fandon
Latitude, Longitude: 40.29480,-90.77180
IEPA code: DGIA-01

**Site notes:**

FieldNoteNumber: Price-2012-063
Collection date: 2012-09-11 Collectors: ALP, DKS, MMR, MWW, KLJ
Time sample: 0.80 EFF Labor: 5.00
Comments: Low water, fairly sandy. Some down-cutting, logs in stream.
Width: 15.00 (mean) 20.00 (max)
Depth: 1.80 (mean) 3.00 (max)
Sampling length: 1200.00 Flow: low Water clarity: high
Substrates:

| | | | | | | |
|---|---|---|---|---|---|---|
| 0% bedrock | 0% boulder | 0% cobble | 20% gravel | 40% sand | 40% silt | 0% clay |

**Sample summary (10 entries):**

| Species | Live | Dead | Relict |
|---|---|---|---|
| *Lampsilis cardium* | 5 | 0 | 0 |
| *Lasmigona complanata* | 33 | 0 | 0 |
| *Leptodea fragilis* | 1 | 0 | 0 |
| *Ligumia subrostrata* | 6 | 0 | 0 |
| *Pyganodon grandis* | 0 | 1 | 0 |
| *Quadrula quadrula* | 1 | 0 | 0 |
| *Strophitus undulatus* | 10 | 0 | 0 |
| *Toxolasma parvus* | 6 | 0 | 0 |
| *Tritogonia verrucosa* | 6 | 0 | 0 |
| *Uniomerus tetralasmus* | 1 | 0 | 0 |

(!) intolerant species

Totals: Species: 10 Live: 69 Dead: 1 Relict: 0

Person Hours: 4 Live SP/03 Rings: 1

SR Factor: 5 IS Factor: 2 AB Factor: 3 Rep Factor: 3

MCI: 13

**Appendix 1:** Detangling freshwater mussel recruitment.

# Detangling freshwater mussel recruitment

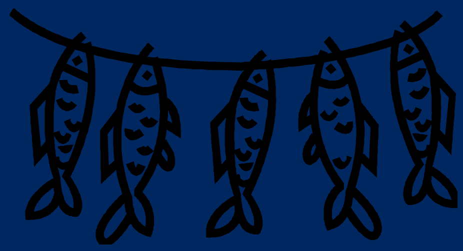
Alison Stodola

Sarah Douglass, Diane Shasteen, Kirk Stodola

Illinois Natural History Survey
Prairie Research Institute
University of Illinois

# Key components of ecology

- Assessment:

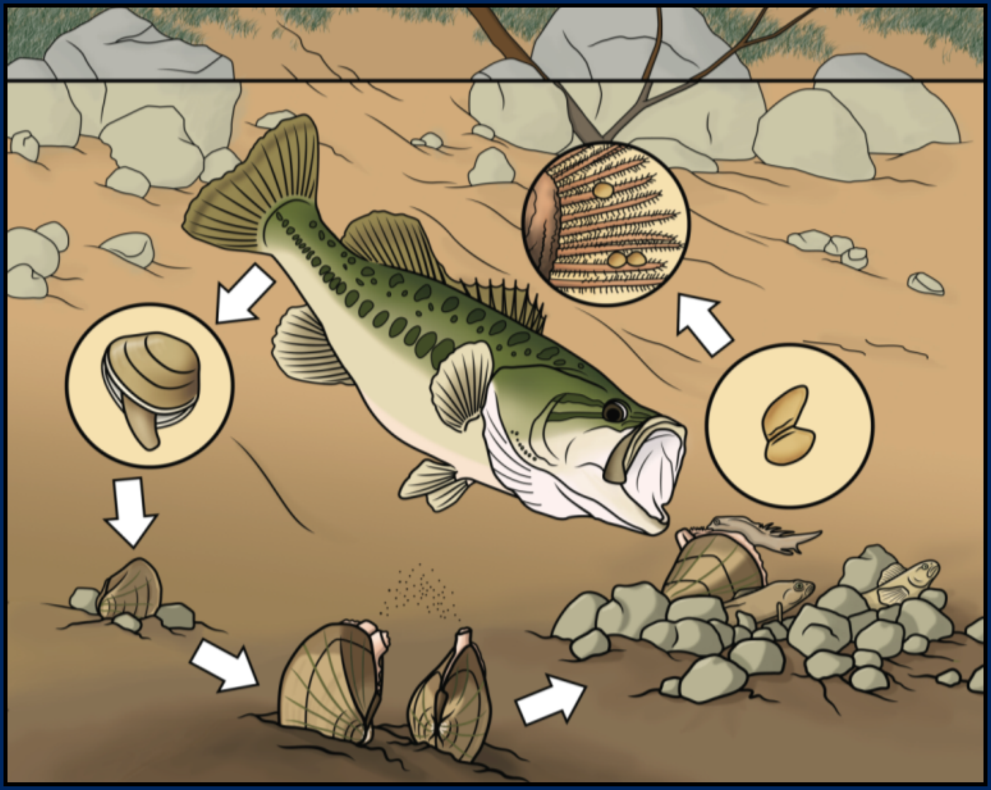


How many?
What kind?
More or less than before?

  - Population growth → Age structure
    - Relative size
    - Dentition, molt, etc
    - Annuli counts


- Assumes capture…

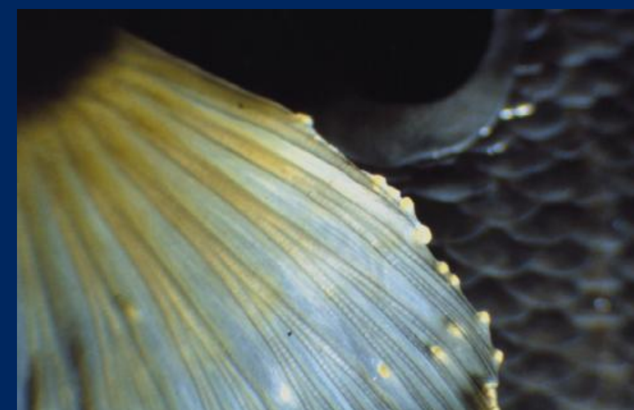
# Juvenile freshwater mussels



- Scenarios at a site with no juveniles:
  - NOT present (occupancy issue)
  - Present yet undetected (detection issue)
- Occupancy modeling accounts for both

# Occupancy versus detection

- Site that is unoccupied:
  - Fish may carry juveniles away from source population

# Occupancy versus detection

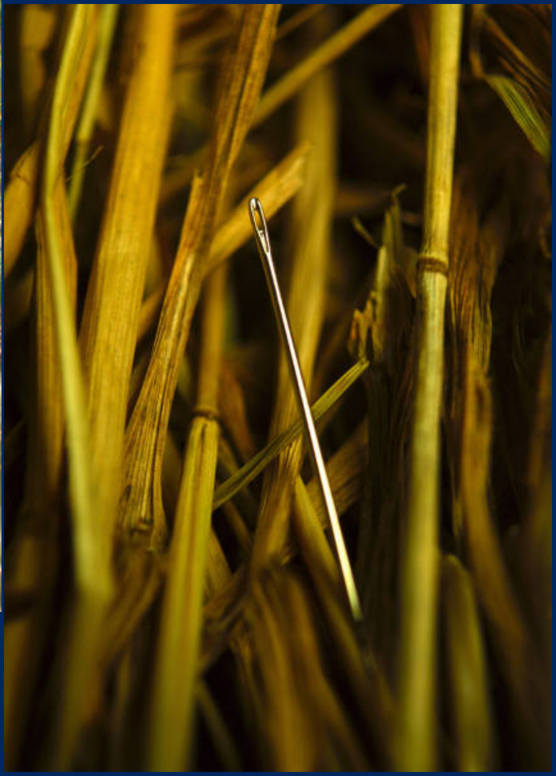
- Site that is unoccupied:
- Juveniles washed out -- Lack anchor, thus subject to drift and shear stress

# Detection versus occupancy

- Site with undetected juveniles:
  - if present, can we find them?
  - Juveniles are smaller than adults

# Detection versus occupancy

- Site with undetected juveniles:
  - May burrow into substrate for several years



# Juvenile sampling in the literature

- Recommended method
  - Excavation + sieving
  - Limitations:
    - Requires knowledge of site (preceded by timed search)
    - Sub-optimal for species richness data
    - Labor intensive!

# Another option?

› Why not use easier, tactile sampling?
  – Biased towards larger, sculptured mussels
  – Juveniles are presumed not at surface

› 1000+ sites of tactile data

# Study Objectives

- Can we find juveniles without digging?
  - Compare timed searches to excavations
- Is our sampling procedure adequate?
  - How much time do we need to determine presence of juveniles?

# Field Methods – tactile searches

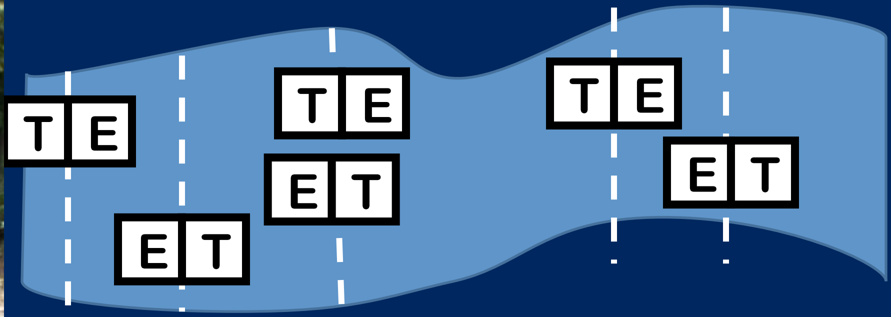
› Haphazard sample of stream section


› Samples separated by hour for replicates

› Age, length, species recorded

# Field Methods - excavations

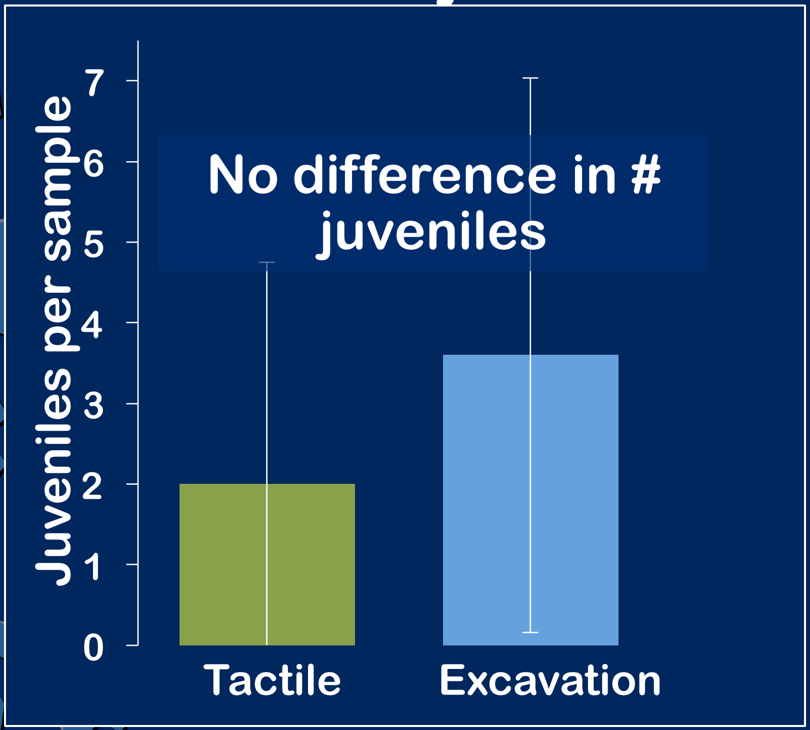
› Quadrat sampling:
  - Full random design, account for differences in stream size & habitat
  - Paired quadrats: Tactile versus Excavated
  - Excavated and sieved to 10cm depth

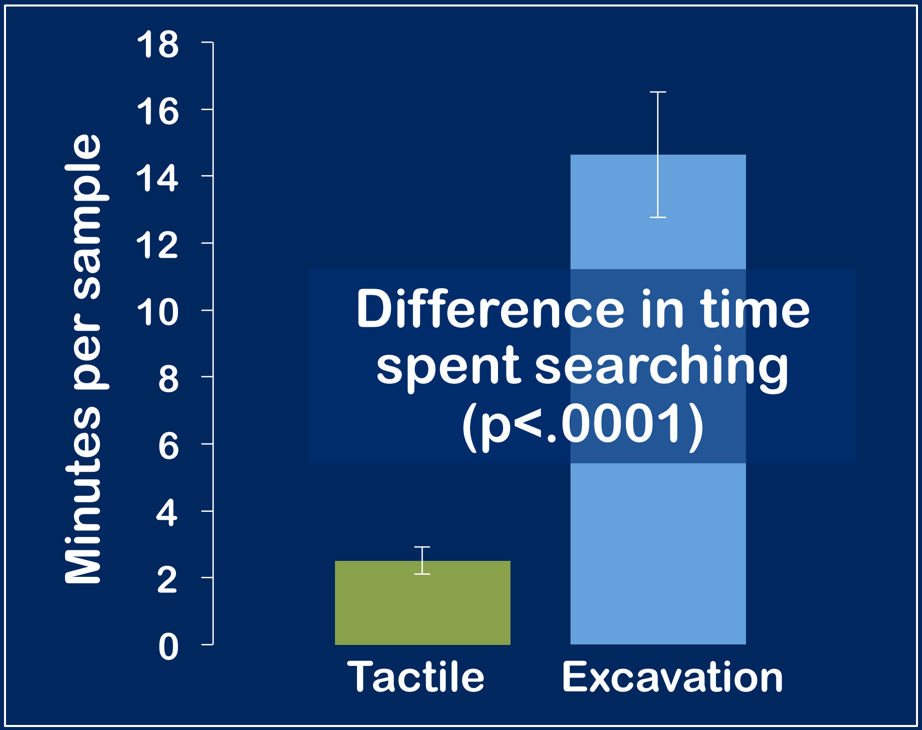
# Excavation results

- Sampled 5 sites in 2013
  - ~10 paired quadrats per site
- 126 total mussels collected (28 juveniles)

Number of juveniles




Amount of effort



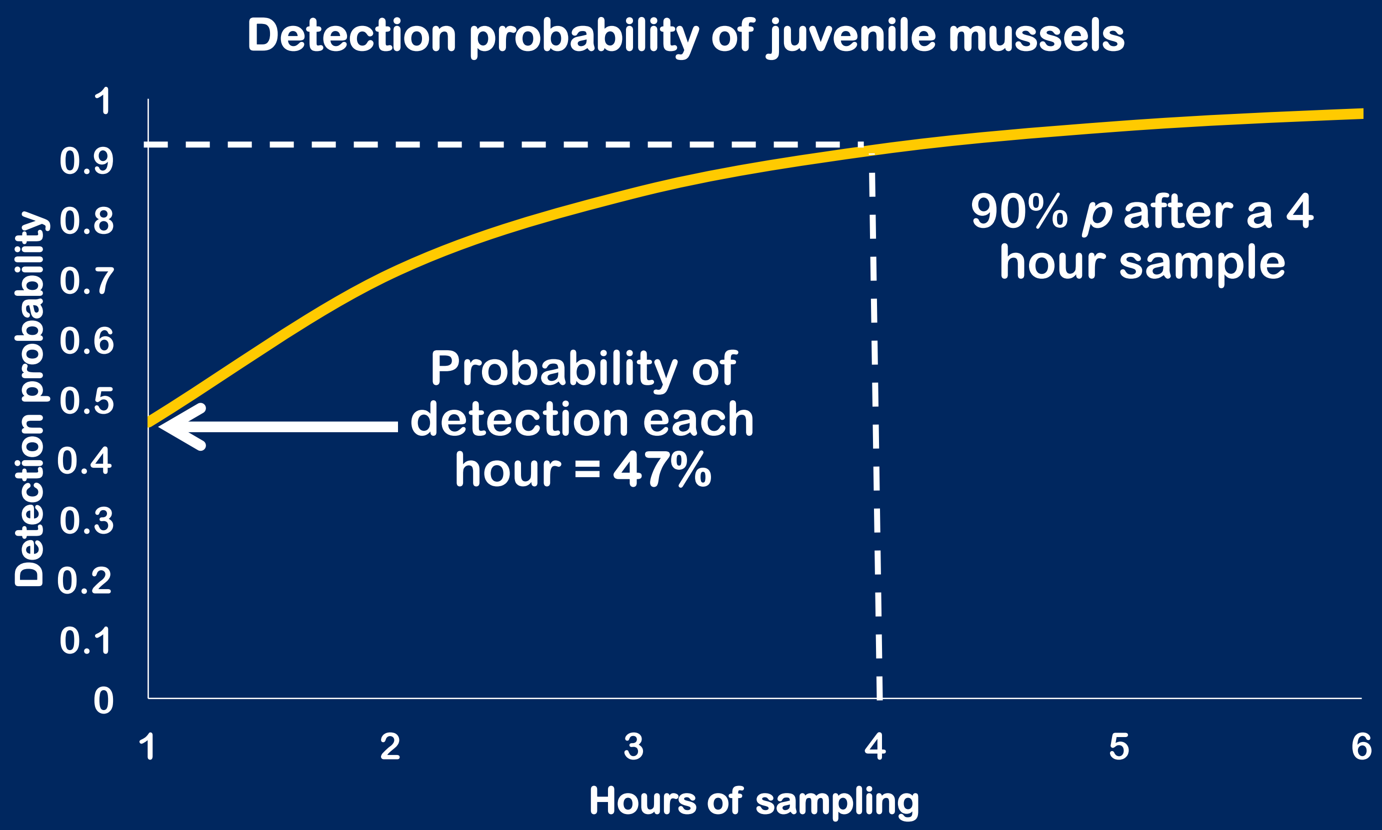
# Analytical Methods



- 1070 sites
  - 46681 adults, 3127 juveniles
- Multi-scale occupancy in MARK
  - Adult and juvenile presence/absence
  - Detection probability adjusted by occupancy
- Fit suite of models, ranked by AIC
- Occupancy Results:
  - Overall site occupancy – 90%
  - Juveniles occupied fewer sites (52%) than adults (96%)
  - Theory supported in literature
    (cyclical reproduction)

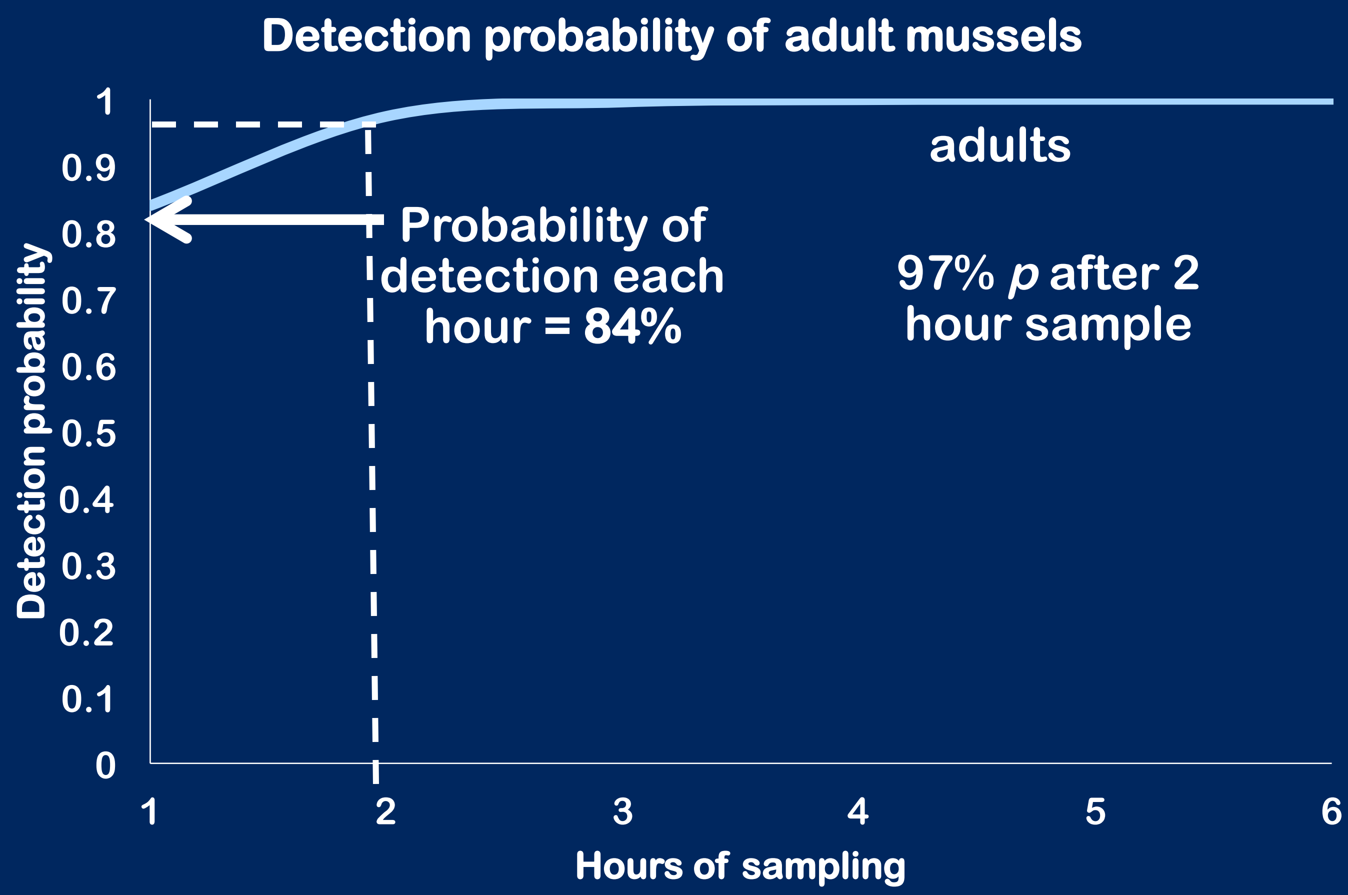
# Model results for juvenile detection

- Habitat variables influence detection
  - (substrate, turbidity, temperature, etc)



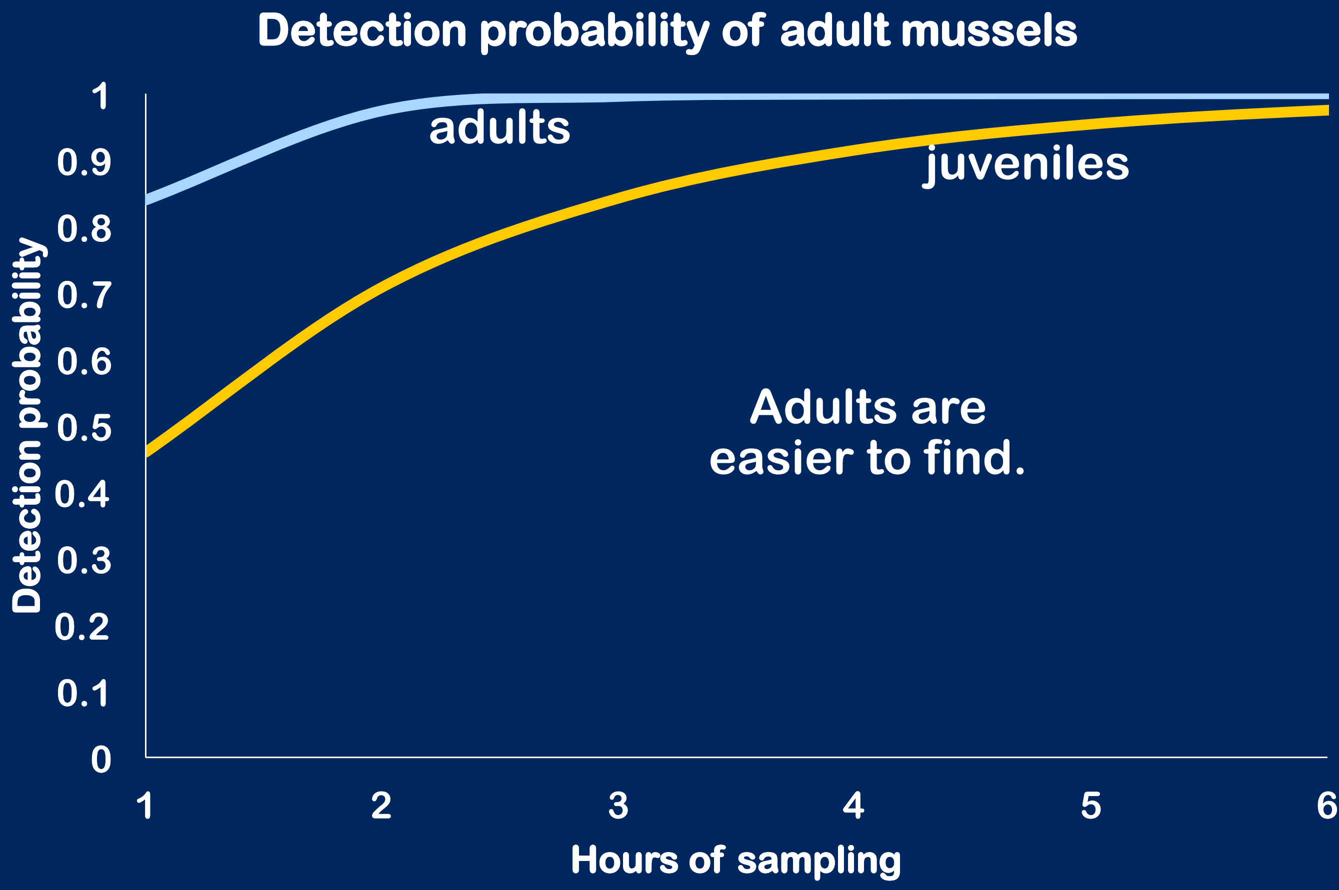
# Model results for adult detection

› Also estimated *p* for adults



# Model results for adult detection

- Also estimated *p* for adults



# Interesting species results

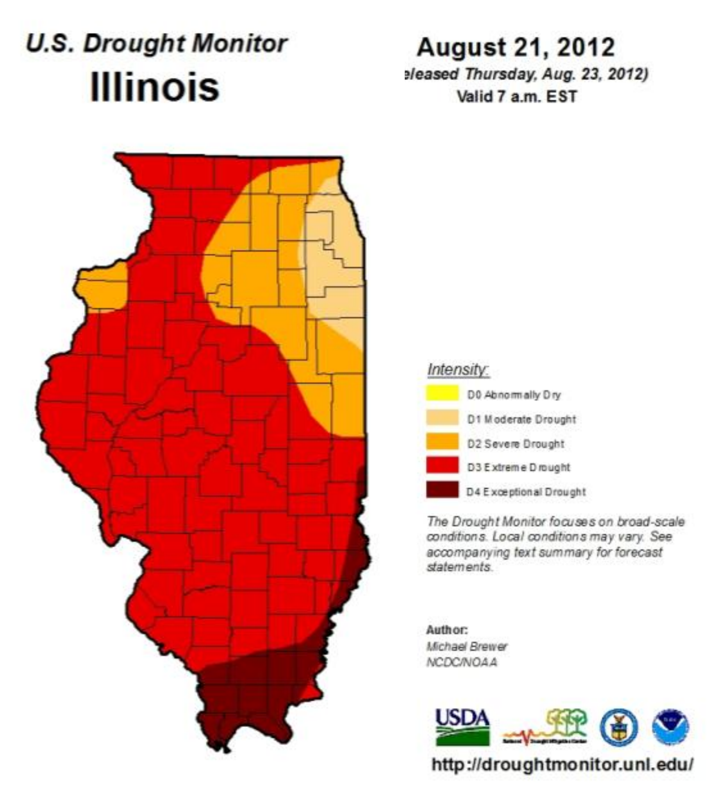
- Some species have byssal threads
- Attach to logs, rocks, adults, etc
- Are they easier to find?

› Species with byssal threads were 1.4 times more likely to be detected than those without

› Important if interested in recruitment of a particular species

# Is recruitment related to phenomena?

- Drought of 2012
- Lots of juveniles found during 2012



# Is recruitment related to phenomena?

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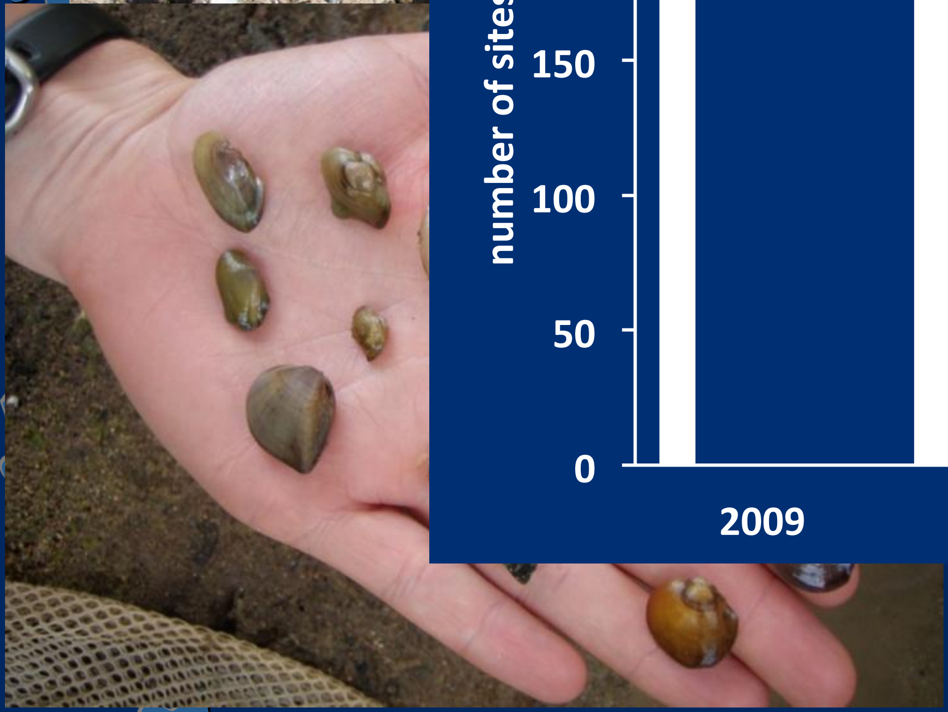

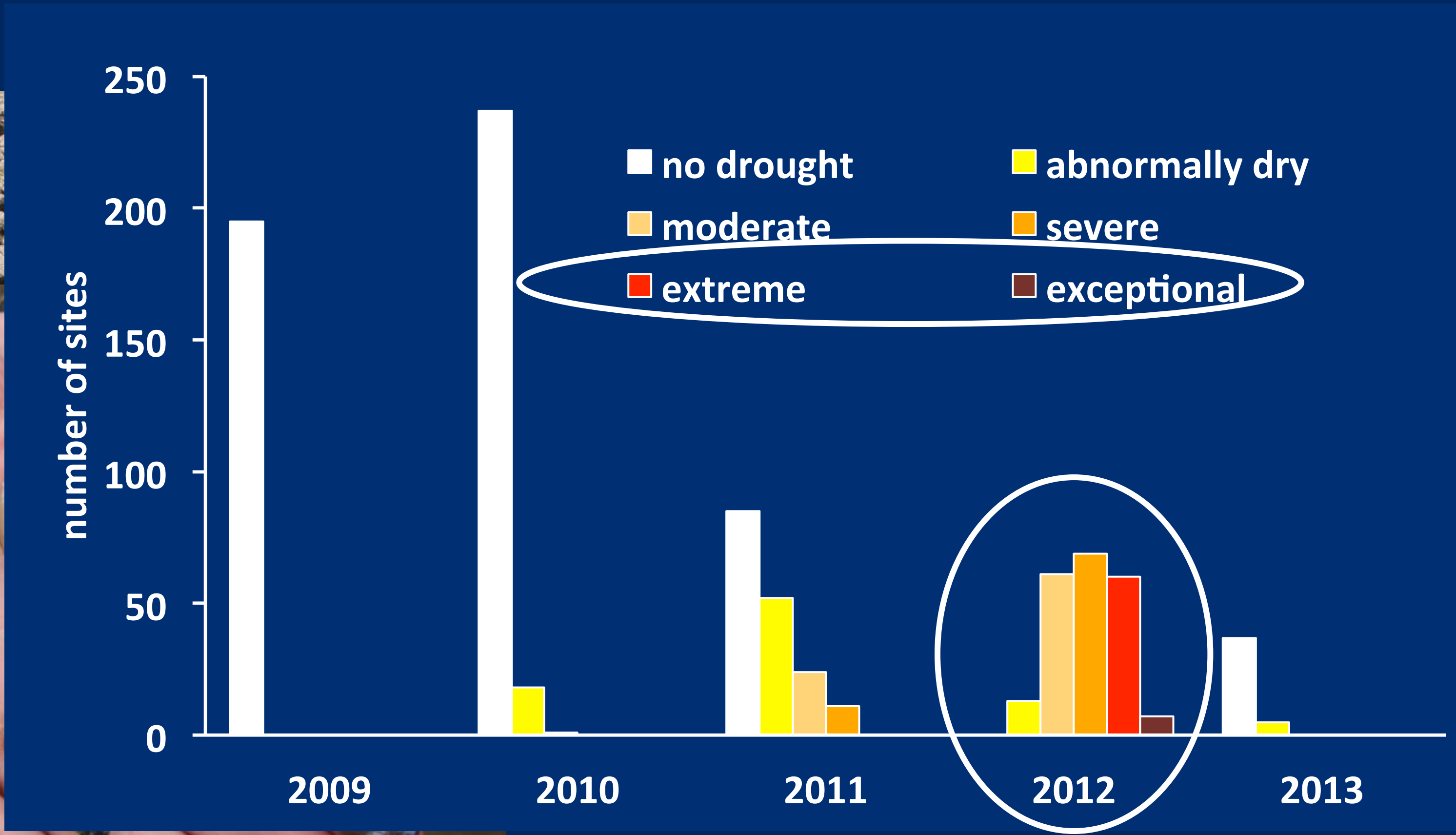

# Testing a drought effect

- Do juveniles occupy more sites during drought?
  - Stuck with fish host?
  - Not washed out in winter?

– Reminder: Occupancy models incorporate detection

– Juveniles 2.8 times more likely to occupy sites in drought than under 'normal' conditions

– Snapshot in time

# Summary

- Juveniles are not comparable to adults
  - Lower rate of detection (and occupancy)
  - Consider when surveying adults
- Timed surveys adequate to detect presence/absence juveniles
  - Investigate species effects
- Models supported theory of drought effect on recruitment
  - Mechanism obscure – needs research

# Acknowlegements

## Funding and Logistical Support:

Illinois DNR, Illinois EPA, US Fish and Wildlife Service, University of Illinois

Kevin Cummings, Ann Holtrop, Bob Szafoni

Many field technicians and volunteers!

**Appendix 2:** Occurrence of the Little Spectaclecase *Villosa lienosa* (Conrad, 1834) (Mollusca: Unionidae) downstream of the Wabash and Ohio River confluence in Illinois.

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accepted 2/9/15

# Occurrence of the Little Spectaclecase *Villosa lienosa* (Conrad, 1834) (Mollusca: Unionidae) Downstream of the Wabash and Ohio River Confluence in Illinois

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## ABSTRACT

Live and fresh-dead specimens of little spectaclecase, *Villosa lienosa* (Conrad, 1834), were discovered in the upper Cache River system near Mt. Pleasant, in Union County, Illinois, during the summers of 2009 and 2013 and deposited in the Illinois Natural History Survey Mollusk Collection, Champaign. Although reported from elsewhere in Illinois, these specimens represent a documented range connection for the little spectaclecase between the eastern third of Illinois and the little spectaclecase populations in the bootheel of southeastern Missouri. A reevaluation of the species' status in Illinois is applicable due to the documented range connection and additional records of the little spectaclecase.

The little spectaclecase, *Villosa lienosa* (Conrad, 1834), is a freshwater mussel (Mollusca: Unionidae) with a thin to moderately thick sub-elliptical to elongate oval shaped shell. The species attains lengths up to 75 mm and is moderately (male) to greatly (female) inflated (Parmalee and Bogan, 1998; Williams et al., 2008). The periostracum is green to dark brown and darkens to black with age. Sub-adults often have green rays and the nacre is usually white, tinged with salmon and purple, iridescent posteriorly (Cummings and Mayer, 1992; Parmalee and Bogan, 1998; Williams et al., 2008; Watters et al., 2009). *Villosa lienosa* inhabits small creeks to medium-sized rivers and is found in stable sand, sandy mud or gravel substrates in slow to moderate current but may also inhabit rocky substrates in moderate to swift current (Cicerello and Schuster, 2003; Williams et al., 2008). The species is often reported as the only mussel found in small coolwater and headwater streams (Williams et al., 2008; Watters et al., 2009).

*Villosa lienosa* is found in the Cumberland and Ohio River drainages and in the Mississippi River basin from central Illinois to the Gulf Coast, where it occurs from the Suwannee River drainage in Florida to the San Jacinto River drainage in Texas (Cicerello et al., 1991; Cummings and Mayer, 1992; Williams et al., 2008; Williams et al., 2014). In Illinois, the species was first reported in 1906 from the Saline River, a pond in Perry County and the Little Vermilion River (Baker, 1906). The first vouchered specimens in Illinois were provided by J. Zetek in 1908 from the Salt Fork Vermilion River near Urbana (FMNH 68045). Since that time, populations have been recorded in several other Wabash River tributaries (Ohio River drainage) including the Vermilion, Little Wabash, and Embarras Rivers along with many of their tributaries (Cummings and Mayer, 1997; Tiemann et al., 2007).

Baker (1906) made reference to *Villosa lienosa* in the Saline River and a pond in Perry County; however, there were no vouchered specimens from the Saline River, Perry County, Bay and Lusk Creeks (Ohio River tributaries) or the Cache River until 2000. Since 2000, the species has been recorded in three Ohio River tributaries in the southern portion of the state: Big Grand Pierre, Saline, and Cache Rivers. Fresh dead specimens were collected by John E. Schwegman in Big Grand Pierre near Heron, in Pope County, Illinois on eight sampling occasions since 2000. Relict shells were collected in 2005 in the North Fork Saline River near Norris City, in Hamilton County, Illinois by Jeremy S. Tiemann. Live specimens were recorded in 2009 and 2013 in the Upper Cache River near Buncombe and Anna, in Union County, Illinois by the authors (Figure 1).

The newly discovered specimens described in this paper represent the first vouchered *V. lienosa* records in direct Ohio River tributaries downstream of the confluence of the Ohio and Wabash Rivers in Illinois (Figure 2). The specimens from these locations were deposited in the Illinois Natural History Survey Mollusk Collection, Champaign, IL (INHS 25205, 27658, 27665, 28986, 31117, 31392, 32652, 40138 [Big Grand Pierre], INHS 31082 [North Fork Saline] and INHS 35063, 35070, and 45481 [Cache River]).

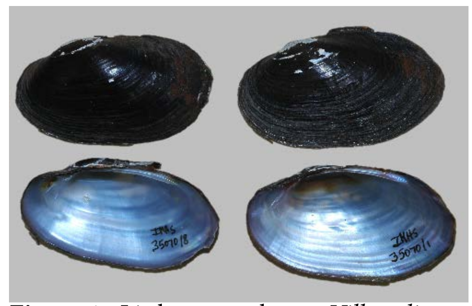

**Figure 1.** Little spectaclecase *Villosa lienosa* from the Cache River near Mt. Pleasant, Union County, Illinois. Female (left) and male (right).

The reported host fishes for *V. lienosa* are centrarchids and include *Lepomis cyanellus* (Green Sunfish), *Lepomis humilis* (Orangespotted Sunfish), *Lepomis macrochirus* (Bluegill), *Lepomis megalotis* (Longear Sunfish), *Lepomis microlophus* (Redear Sunfish), and *Micropterus salmoides* (Largemouth Bass) (Keller and Ruessler, 1997; Daniel and Brown, 2012), which are common in Illinois. Although one ictalurid, *Ictalurus punctatus* (Channel Catfish), has been trialed with one transformation resulting in a single juvenile, ictalurids appear to be poor or unsuitable hosts for *V. lienosa* (Keller and Ruessler, 1997; Daniel and Brown, 2012).

In Illinois, *V. lienosa* is currently listed as

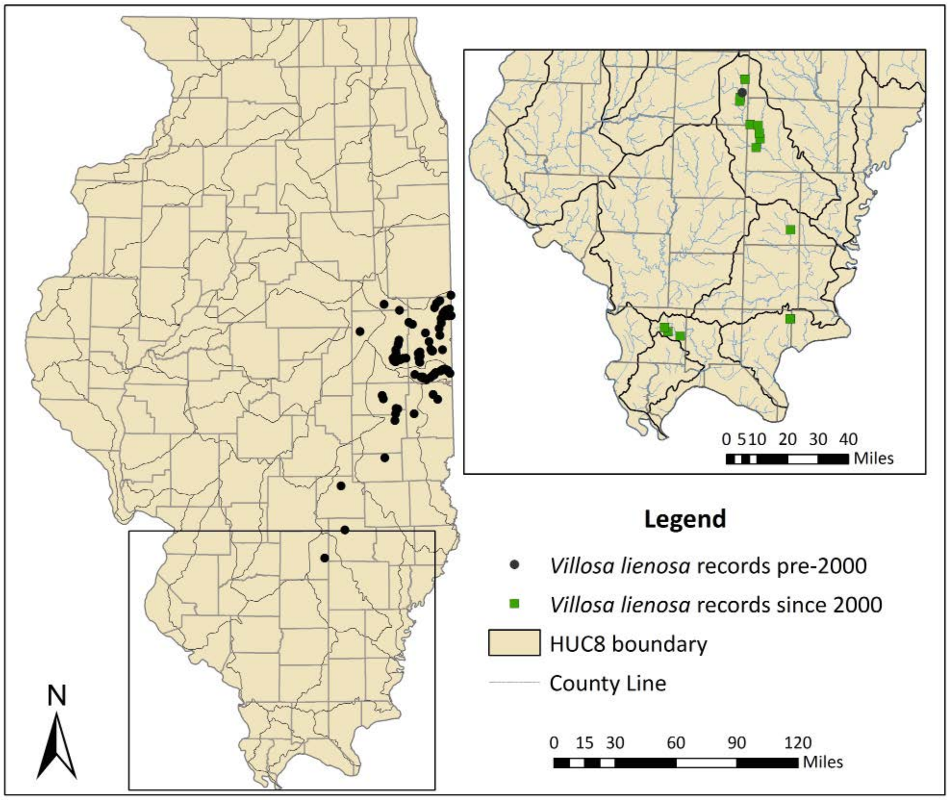


**Figure 2.** Previous records for Illinois and newly recorded records from survey conducted since 2000.

State Threatened due to limited range and small population size within the range. Prior to 1976, *V. lienosa* had 33 known unique locations, primarily in Champaign and Vermilion counties. As mussel sampling efforts increased between 1977 and 1999, the number of unique locations increased to 99 (including the original 33), and the species was recorded alive in several other east central Illinois counties including Coles, Douglas, Edgar, and Iroquois. Since 2000, an additional 83 unique locations have been recorded increasing the total of unique locations to 182 across the state with new populations being located in the southern Illinois counties of Hamilton, Marion, Pope, Union, and Wayne. Thirty-two of these locations were recorded since 2009 due to an intensive mussel survey (1050 sampled sites) that was conducted across the state of Illinois from 2009 to 2013. The increased sampling effort has revealed more unique locations; therefore, it appears that *V. lienosa* is more common than earlier assumed. Illinois is at the northern limit of the species' range and *V. lienosa* is currently described as stable throughout its range (Williams et al., 1993). Given the additional records, we recommend *Villosa lienosa* be downgraded from State Threatened to Species in Greatest Need of Conservation in Illinois.

## ACKNOWLEDGEMENTS

Funding sources were Illinois State Wildlife Grants T-53-P-001 and T-82-R-1 initiated by Ann Holtrop and Robert Szafoni (IDNR). O. Foster and C. McLean provided field assistance for the upper Cache in 2009. Data records were retrieved from the Illinois Natural History Survey Mollusk Collection and Kevin Cummings provided valuable comments on this manuscript.

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**Appendix 3:** Genetic confirmation of putative Louisiana Fatmucket in Illinois.

# GENETIC CONFIRMATION OF PUTATIVE LOUISIANA FATMUCKET IN ILLINOIS

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## Abstract

The range of the Louisiana fatmucket (*Lampsilis hydiana*) spans watersheds in Texas, northward to southern Arkansas, and eastward to western Mississippi. However, specimens with morphological similarities to the Louisiana fatmucket have been collected in watersheds in southern and south-central Illinois for several decades and were presumed to be strangely shaped fatmuckets (*L. siliquoidea*). To determine if both species co-occur in Illinois, specimens were collected from throughout the state and analyzed genetically using DNA sequences of the mitochondrial *cox1* and *nad1* genes. Phylogenetic analysis yielded two genetically distinct clades that support the recognition of two different species – *L. siliquoidea* and putative *L. hydiana*. The presence of *L. hydiana* in Illinois represents a substantial range expansion, so it is imperative that we obtain topotype material to determine if putative Illinois *L. hydiana* is indeed *L. hydiana* or another closely related species.

## Introduction

- The fatmucket, *Lampsilis siliquoidea* (Barnes, 1823), is widespread throughout the Mississippi basin (Figure 1; NatureServe 2015) and is one of Illinois' most common species.
- Louisiana fatmucket, *Lampsilis hydiana*, is a related species found in watersheds in Texas, northward to southern Arkansas, and eastward to western Mississippi, but is previously unknown to Illinois (Figure 2).
- The two fatmuckets are morphologically similar, although differ slightly in size, umbo placement, inflation, and nacre characteristics (Figure 3)
  - Vouchered specimens collected from drainages in southern Illinois share morphological characteristics with *L. hydiana* and prompted a need for further research (Figure 4).

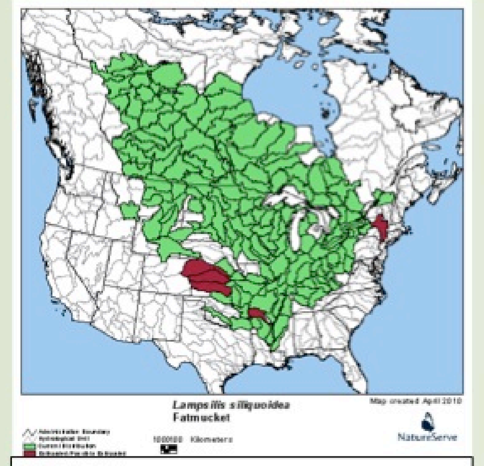
Figure 1. Range of *L. siliquoidea*

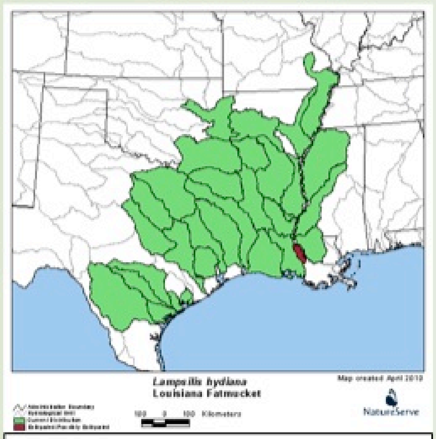
Figure 2. Range of *L. hydiana* (Natureserve 2010)

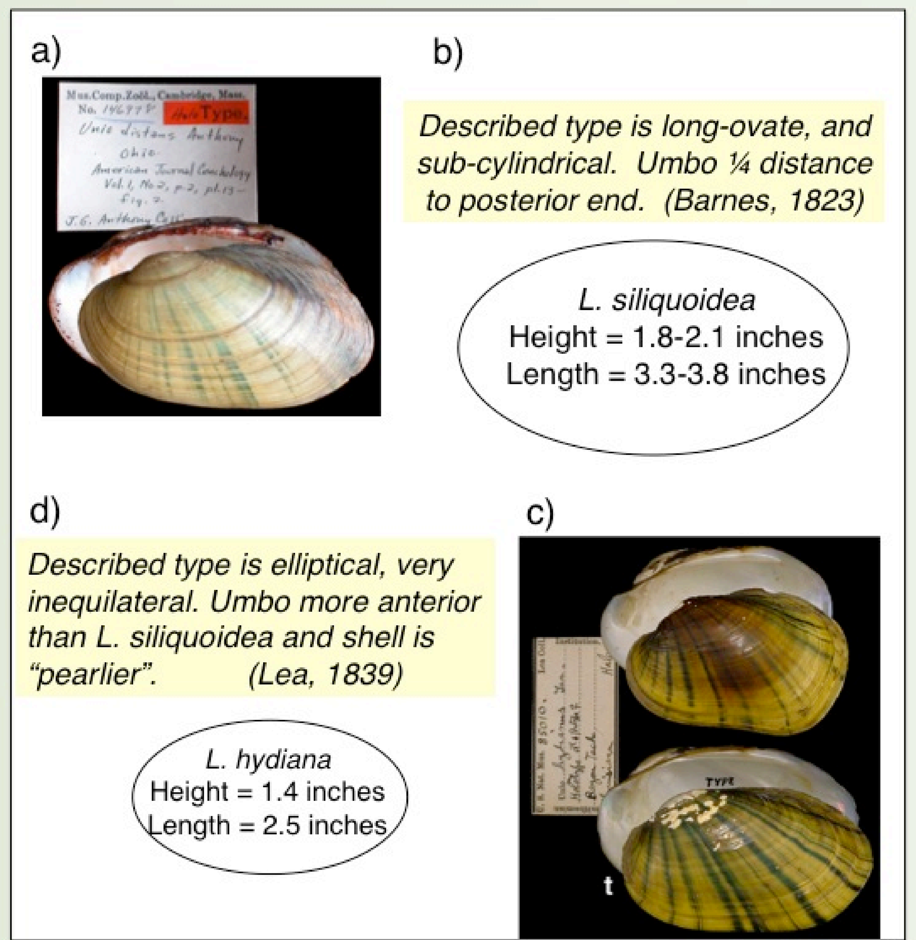

Figure 3. (clockwise from top left) a) Holotype of *Unio distans* (synonym of *L. siliquoidea*) from Ohio; b) description of *L. siliquoidea* from Barnes; c) Holotype of *L. hydiana* from Bayou Teche, Louisiana; d) description of *L. hydiana* from Lea.

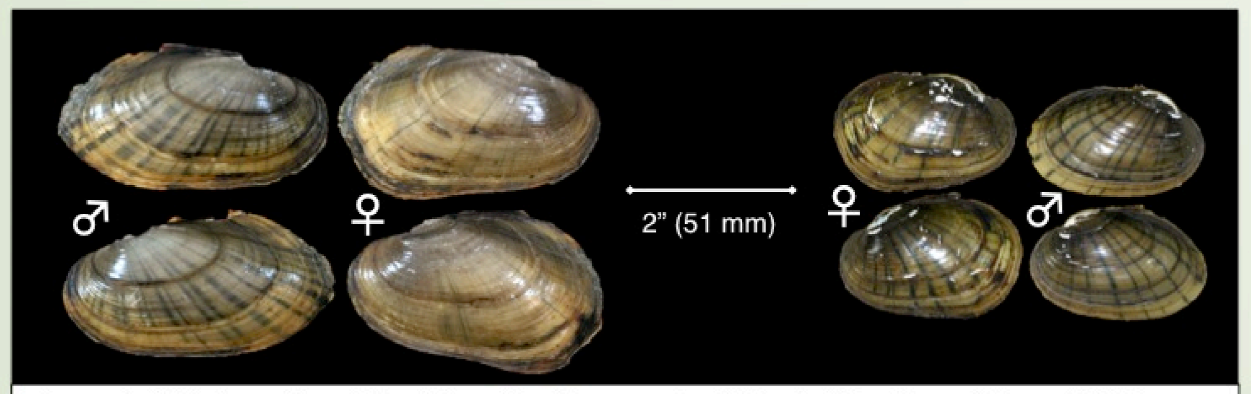

Figure 4. (L) Examples of *L. siliquoidea* from central Illinois (Mackinaw River; INHS 41996). (R) Examples of a *Lampsilis* specimen from southern Illinois (Big Muddy River, INHS 45495). Phenotypic characters closely align with *L. hydiana.*

- Objectives:
  - Does Illinois have more than one genetically distinct fatmucket?
  - If so, what is the extent of the distribution?

## Methods

- We analyzed 82 samples from 19 sites in Illinois.
- We estimated phylogenies of the *nad1* and *cox1* mtDNA genes using neighbor-joining analysis and Bayesian inference.
- We used Genbank sequences for *L. hydiana* (Little Missouri River, Arkansas) and *L. siliquoidea* (Douglas Lake, Michigan) for comparison, as well as *Leptodea fragilis*, *Amblema plicata* (Ohio River, Kentucky) and *Megalonaias nervosa* (Coosa River, Alabama) as outgroup taxa.
- All specimens were deposited in the INHS Mollusk Collection.

## Results

- Phylogenetic analyses of the *cox1* and *nad1* genes revealed that at least 2 genetically distinct fatmucket species exist in Illinois (Figure 5). *L. siliquoidea* and putative *L. hydiana* differed by 7.65%

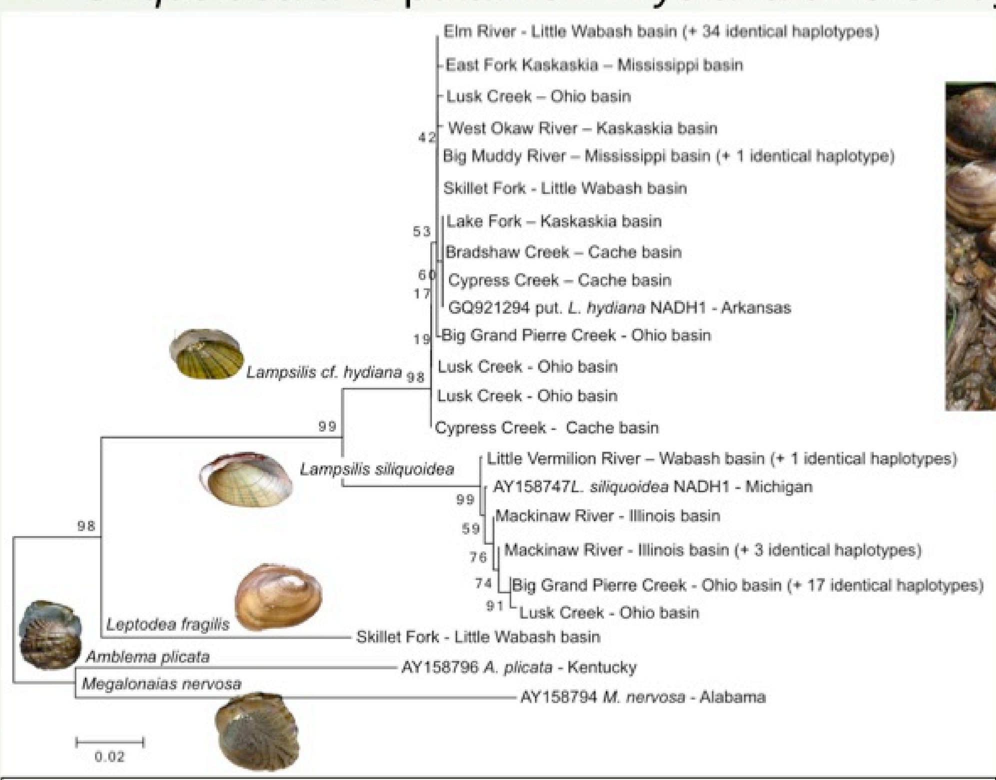

Figure 5. Neighbor-joining analysis for *nad1* gene. Locations are listed for each sample, and identical haplotypes are noted (see Table 1).


A collection of fatmuckets from the Mackinaw River

Table 1. Localities and number of identical haplotypes.

| Listed haplotype | Localities and (n) of identical haplotypes |
|---|---|
| Elm River - Little Wabash | • Big Grand Pierre (n=1) & Lusk Creeks (n=5) - Ohio River<br>• Big Muddy River (n=2)<br>• Bradshaw Creek (n=2) & Cache River (n=1)<br>• East Fork (n=5), Lake Fork (n=2), Okaw River (n=1) & Two Mile Creek (n=1) – Kaskaskia<br>• Elm River (n=1) & Skillet Fork (n=13) - Little Wabash |
| Big Grand Pierre Creek | • Big Grand Pierre (n=7) & Lusk Creeks (n=9) - Ohio River |

- Putative *L. hydiana* are present in the Big Muddy, Cache, Kaskaskia, Ohio and Wabash basins, and two Ohio River tribs (Lusk and Big Grand Pierre Creeks support populations of both *Lampsilis* species.

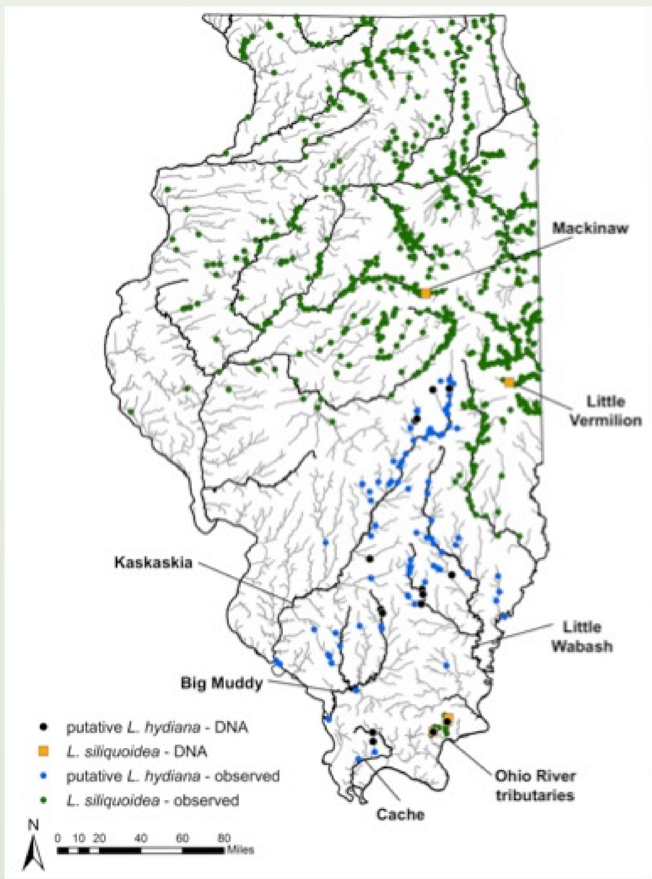

Figure 6. Map of observed (INHS Mollusk Collection Records) and confirmed (DNA) for putative *L. hydiana* and *L. siliquoidea.*

## Discussion

- Genetic material from the source location of the topotype (Bayou Teche, Louisiana) is needed to determine the taxonomic rank of putative Illinois *L. hydiana* and *L. hydiana.*
- What is the the colonization source for putative Illinois *L. hydiana?*
  - Did putative Illinois *L. hydiana* colonize southern Illinois post-glaciation via southern Missouri/northern Arkansas, or Kentucky.
  - Interestingly, we discovered putative *L. hydiana* as far north as Champaign County in the Kaskaskia river drainage (northernmost black dot in Figure 6), and there are no recent records of either fatmucket species in the lower Kaskaskia basin downstream of Carlyle Reservoir. Thus, the theoretical source populations in the lower Mississippi basin are no longer connected to the upper basin—perhaps the Kaskaskia River fatmuckets were introduced via fish stocking or inter-basin flooding?
- The Lusk and Big Grande Pierre Creek populations of fatmuckets are morphologically indistinguishable yet are genetically distinct (Figure 7). This is a conundrum!


A collection of putative Louisiana fatmuckets from the Elm River.


Figure 7. DNA-confirmed *L. siliquoidea* and putative Illinois *L. hydiana.*

## Future Work

- We are currently analyzing *L. siliquoidea* samples from the type locality (Wisconsin River) to determine taxonomic rank of upper Illinois specimens and our confirmed *L. siliquoidea.*
- We are pursuing topotype material to compare to putative Illinois *L. hydiana,* and continuing to collect putative *L. hydiana* from Illinois streams for further analysis.

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**Appendix 4:** Status revision and update for Illinois' freshwater mussel Species in Greatest Need of Conservation.

ILLINOIS NATURAL
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# Status revision and update for Illinois' freshwater mussel Species in Greatest Need of Conservation

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Illinois Natural History Survey
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INHS Technical Report 2014 (47)

Prepared for: Illinois Department of Natural Resources,
State Wildlife Grant/Project Number (T-82-R-1)

Prairie Research Institute, University of Illinois at Urbana-Champaign
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## Preface

A component of State Wildlife Grant T-82-R-1 (Defining expectations for mussel communities in Illinois wadeable streams) is to evaluate species' abundance, distribution, habitat requirements, ecological role and amount of information available regarding the species for all mussel Species in Greatest Need of Conservation (SGNC) in Illinois. This information will be used to update the freshwater mussel SGNC accounts included in the Illinois Comprehensive Wildlife Conservation Plan developed in 2005. This document updates Appendix I and II and Actions for the Streams Campaign for mussel SGNC to include in the 2015 revised Illinois Comprehensive Wildlife Action Plan. Additionally, distribution maps and host fish information for mussel SGNC and other species found currently or historically in Illinois are included.

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## Suggested Citation

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## Contents

# Section 1:

# Illinois Wildlife Action Plan Overview and Appendices Review

## Introduction and Background

The Illinois Comprehensive Wildlife Conservation Plan (hereafter, Plan) was established in 2005 as a condition for receiving funding from Federal programs such as the Wildlife Conservation and Restoration Program and State & Tribal Wildlife Grant Program (IDNR, 2005). These two federal aid programs were established as means for states and tribal areas to fund wildlife conservation projects that address Species in Greatest Need of Conservation (SGNC) and their habitats. The Plan provides information on the occurrence and distribution of SGNC, important habitat and community types, and potential negative impacts.

Eight elements define the Plan, which are paraphrased here:

1. Information on the distribution and abundance of wildlife species, low and declining populations that may be indicative of a species' health and diversity
2. Location description, key habitat and community types essential to a species' conservation
3. Descriptions of problems adversely affecting a species or their habitat, and factors identified that will aid in restoration
4. Conservation actions described which would conserve a species and its habitat
5. Proposed monitoring plans for a species and their habitats
6. Descriptions of procedures for the Plan review at intervals not to exceed ten years
7. Plans for coordinating the development, implementation, review, and revision with federal, state, local, and tribal agencies that manage land and water areas within the state
8. Public participation in the development, revision, and implementation of Plan projects and programs

A primary component of the Plan is the identification of SGNC, which were selected via eight criteria. These criteria were evaluated by applying a combination of objective information (e.g., species distribution, population trends) as well as informed professional judgment.

Much of the information and analysis for identifying mussel SGNC has not been updated since the list was developed in 2005. Specifically, mussel species were evaluated with data from the IDNR BIOTICS database (2004) and distribution maps from the INHS mussel collections (1999). Since then, a large statewide mussel survey was completed that added hundreds of additional surveyed locations (T-53-P-001).

The Plan also requires periodic revisions and updates to measure progress and address emerging issues. Evaluations of the status, distribution, and stresses to SGNC were expected to occur at 2- to 5-year intervals (IDNR, 2005). This report summarizes the first statewide evaluation and update of mussel SGNC since the Plan was developed.

The main components of the Plan were listed in Appendices I, II, and as priority conservation Actions for Illinois wildlife and habitat resources (divided into seven 'campaigns'). This report details the reevaluation and updates of those key appendices and includes suggested priority conservation Actions for the Streams Campaign. For background, we have summarized each Appendix as represented in the 2005 version of the Plan.

Appendix I identified criteria for listing as SGNC:

1. All species listed as threatened or endangered in Illinois, including federally listed species that occur within the state.
2. Species with a global conservation rank indicator of G1, G2, or G3.
3. Species is rare (small or low population size, density or range) or has significantly declined in abundance or distribution from historical levels.
4. Species is dependent upon a rare or vulnerable habitat for one or more life history needs (breeding, migration, wintering).
5. Species is endemic to Illinois, or the Illinois population is disjunct from the rest of the species' range.
6. Illinois' population of a species represents a significant proportion of the species' global population.
7. Species is representative of broad array of other species found in a particular habitat.
8. Species' status is poorly known, but available evidence suggests conservation concern.

Appendix II summarized status, objectives, and stresses to mussel SGNC and the main components consist of:

> Status: population, trend, and listing. Population was based on a population estimator (N) derived from the INHS mussel collection. Trend was estimated for the statewide population and was scored from -2 (strongly decreasing) to +2 (strongly increasing). Listing referred to state or federally threatened or endangered species.
>
> Objectives: population, trend, and listing. Population referred to a targeted N for 2025. Trend was a required trend for a targeted resource level by 2025. No target populations or trends were outlined in the Plan for freshwater mussels. Listing referred to the logical goal of delisting current state or federal endangered species.
>
> Stresses: Habitat stresses, community stresses, and population stresses. Stresses were ranked by experts via rapid assessment and scored on a 3-point scale (1-3, from little or no effect to severe effect on population viability and abundance). Habitat stresses included extent, fragmentation, composition-structure, disturbance/hydrology, invasives/exotics, and pollution-sediment. Community stresses included competitors, predators, parasites-disease, prey-food, hosts, invasives/exotics, and other symbionts. Population stresses included genetics, dispersal, recruitment, and mortality. Direct human stresses included killing, disturbance, and structures – infrastructure. Details regarding each stress are found in the Plan (IDNR, 2005).

Priority conservation Actions are based on a matrix of wildlife and habitat objectives. Each stress or problem was addressed and actions were proposed to improve habitats, prioritize locations, and measure performance. Conservation actions for freshwater mussels were included in the Streams Campaign.

Current distribution maps were developed to inform components of the Plan related to population range and are included in this report (Section 2).

We evaluated the current state of the literature regarding host fish for Illinois mussels (including extirpated and stable species). The life cycle of freshwater mussels is complex and unique among bivalves. Larval mussels (glochidia) are released by the adult female and must attach to gills or fins of a suitable host. The host for most mussel glochidia is a fish, however, several amphibians are also known as glochidia hosts. If glochidia attach to an appropriate host, it remains on the host for several weeks before metamorphosis to a juvenile mussel. Juveniles are released from the host and fall to the river bottom to begin filter-feeding. Mussels also attach to non-suitable hosts; the hosts' immune system eventually rejects the glochidia, which fall off and perish. For each species in Illinois, we compiled references associated with hosts and the infestation or transformation type (Section 3).

## Methods

We reviewed the status of all mussel species with current distributions in Illinois using data from multiple sources, published literature, and professional opinion (in the absence of published or collected data). Recent field data were obtained from State Wildlife Grant T-53-P-001 (Investigating mussel communities in wadeable Illinois streams). Other collection records came from vouchered material maintained by the Illinois Natural History Survey Mollusk Collection, collection records associated with these vouchered materials (e.g., live specimens that were recorded but not vouchered), and verified voucher material from regional academic and museum collections including the Field Museum, the Ohio State University Mollusk Collection, and others.

### *Appendix I*

Plan criteria for selecting SGNC (see Introduction for summary of original Plan Appendices) were revised for the 2015 Plan, which created 4 new categories to classify rarity. We used the revised Appendix I to evaluate all species in Illinois for potential listing as SGNC (Appendix I). All freshwater mussels proposed or previously listed as SGNC in Illinois are found primarily in streams, thus all species listed in Appendix I should be officially associated with the Streams Campaign.

1. Changes to a species' state or federal listing from 2005-2014 were obtained from the U.S. Fish and Wildlife Service Environmental Conservation Online System (ECOS) and the Illinois Endangered Species Protection Board list (ESPB, 2014). We also added our summary of proposed listing changes for species that we believe should be up or downgraded, although these are only intended to provide feedback for future ESPB updates. We distinguished between 2005 listing from the Plan, ESPB (2014) official listing status, and our proposed listing changes.
2. Current global conservation rank was obtained through NatureServe *Explorer* (NatureServe, 2014, accessed June-July 2014).
3 - 6. Rarity, based on population size, density, or range, was based on empirical data, obtained through recent samples collected during T-53 and from the INHS Mollusk Collection. Population size was roughly based on number of extant occurrences (2000-2013), although true estimates of population size are not available due to the qualitative nature of collection and survey data (Strayer and Smith, 2003). Similarly, density was not available from recent surveys or collection records, but we evaluated density to the best of our ability from T-53 surveys and other collections (2000-2013) maintained by the INHS Mollusk Collection compared to densities known historically or as published in

scientific literature. Range was based on the frequency of occurrence in HUC8 watersheds of recent extant records (2000-2013) to previous ranges (1977-1999, 1950-1976, and pre-1950).
7. Habitat requirements for each species were evaluated by literature review, empirical data (from T-53 and INHS Mollusk Collection), and professional opinion.
8 and 9. Endemism, disjunction, and global population significance were evaluated based on information from published range maps in scientific literature or through NatureServe, U.S. Fish and Wildlife recovery plans, or similar resources. No freshwater mussels endemic to Illinois are known at this time.
10. Species in which the Illinois population represents a significant proportion of the species global population was determined through NatureServe or U.S. Fish and Wildlife recovery plans. This category held true for only three federally endangered species: Higgins eye, northern riffleshell, and scaleshell.
11. Representation of a broad array of other species in a particular habitat was reviewed for each species based on scientific literature.
12. Poorly known species were established using records from T-53, the INHS Mollusk Collection, and personal communication with the state malacologist (Kevin S. Cummings). We ranked species with significant knowledge gaps, such as unresolved distributions, taxonomic status, or unknown hosts, as poorly known and gathered further evidence regarding conservation concern from neighboring states' published wildlife action plans or state-listing for freshwater mussels.

Justification for a species' status is addressed in each species' review and specific citations are listed in Section 2. For species extirpated from Illinois, we summarized specific habitat and the global conservation rank (Table 2). Criteria 3-12 were ranked as "0" for each category because no recent data exist for inference. Additionally, if a species did not meet SGNC listing criteria in the 2005 Plan nor in this revision, we only summarized specific habitat and global conservation rank.

## *Appendix II*

Status: We used Appendix II from the Plan (IDNR, 2005) and updated the value of each column when warranted (Appendix II). Population size (*N*) was not prepared for the original Plan evaluation or for this revision because survey data available are not appropriate for population estimation (Strayer and Smith, 2003). Listing status was obtained through NatureServe *Explorer* (NatureServe, 2014), the Illinois Endangered Species Protection Board (ESPB, 2014), or the U.S. Fish and Wildlife Service Environmental Conservation Online System. We determined trend by interpreting range and occurrence data from the distribution maps and trend was expressed as expansion (+ %) or contraction (- %) within Illinois.

Objectives: N (targeted population for 2025) and trend (by 2025) were not addressed, largely due to insufficient information available to propose a population threshold and "trend." These two objectives were not completed in the original Plan evaluation, and targeted population numbers are not available for any species in Illinois at this time. The listing objective for listed species was classified as "delist" in the 2005 Plan, and we support that objective.

Habitat, community, population, and direct human stresses were evaluated by professional opinion and literature review. All stresses were scored on a three-point scale -

1. The threat has had, is having, or is likely to have little or no effect on population viability or abundance.
2. The threat has had, is having, or is likely to have a moderate effect on population viability or abundance.
3. The threat has had, is having, or likely to have a severe effect on population viability or abundance.

Changes to the Appendix II from the 2005 Plan are addressed in each species' review. In general, we believe that the sampling data and literature review conducted during T-53 and T-82 provided valuable information. These data improved our confidence in understanding the extent of habitat, community, population and human stresses and we upgraded the confidence levels accordingly.

### *Suggested Actions for Streams Campaign*

A list of six suggested Actions for the Streams Campaign was developed based upon professional opinion, Illinois Natural History Survey Mollusk Collection records, and literature review and is presented in the discussion section. Other factors incorporated into the suggested Actions include stresses addressed, habitat improvements, priority locations, and performance measurements with outputs and potential outcomes.

### *Species Reviews*

We summarized the information contained in Appendices I and II, as well as any pertinent information we used for evaluating the status of a species (Section 2: Species Reviews). We provided our rationale for recommended status changes (e.g., from stable to SGNC) in each species' review, however, these recommendations are secondary to listing status established by the Illinois ESPB and are only intended to provide feedback for future ESPB updates. In situations where our recommendation differs from the ESPB recommendation, we note the current ESPB status for reference.

### *Distribution maps*

In Section 2, distribution records were divided into time periods to document change in distributions. Time periods selected for this effort were pre-1950, 1950-1976, 1977-1999, and 2000-2013. Time periods were selected based on previous work by Metzke et al. (2012) and represent earliest/historic mollusk records, pre-Clean Water Act, post-Clean Water Act, and current distribution, respectively. Data reflect extant records for each time period except the pre-1950 period. Extant refers to live individuals or recent dead shell (periostracum present, nacre pearly, and soft tissue may be present). The pre-1950 time period data includes extant records and relict shell records (periostracum eroded, nacre faded, shell chalky; based on the condition of the best shell found).

The nomenclature employed follows Turgeon et al. (1998) and Graf and Cummings (2007) except recent taxonomic changes to the ending of the lilliputs (*Toxolasma spp.*), which follow Williams et al. (2008) (Table 1). Maps were created using ESRI ArcMap 10.1.

*Fish Host Information*

In Section 3, we have summarized the available information regarding mussel-host relationships for Illinois' species. Extirpated species (Table 1), stable species (Table 2), and SGNC species (Table 3) are listed separately. Each table is organized by fish family and scientific name, and mussel scientific names are listed as row headings. Due to the space requirements for these data, some of the tables eclipse more than one page.

Abbreviations (Hoggarth, 1992) used in Tables 1, 2, and 3 include the following:

NS: not stated (infestation type not described in literature source)

LI: lab infestation (infestation occurred in experimental conditions, but metamorphosis was not observed)

LT: lab transformation (metamorphosis from glochidia to juvenile observed in experimental conditions)

NI: natural infestation (infestation found on wild-caught fish, but metamorphosis was not observed)

NT: natural transformation (metamorphosis from glochidia to juvenile observed in natural conditions)

## Discussion

*Appendix I and II—Mussel SGNC and non-SGNC status reevaluation summary*

The 2005 mussel SGNC list included 29 species. A reevaluation of each of these species plus 38 non-SGNC and their distribution maps are included in Section 2. The federally endangered species, scaleshell (*Leptodon leptodea*), was recently collected and, thereby, is no longer considered extirpated but listed as state endangered (ESPB, 2014). Several current non-SGNC species were determined to be rare or declining and/or meet one or more SGNC listing criteria requirements in Appendix I. These species include the elktoe, wartyback, Louisiana fatmucket, pocketbook, bankclimber, bleufer, Gulf mapleleaf, and pistolgrip.

Due to increased sampling effort statewide during T-53, new live and extant records for several SGNC species were revealed. Rock pocketbook, by our current assessment, does not meet SGNC listing and three species, black sandshell, slippershell mussel, and little spectaclecase, all currently listed as state threatened, appear to be increasing and likely may not meet requirements for ST status.

Conversely, sampling during T-53 revealed range retractions or fewer collections than expected based on historical comparisons for several state threatened or SGNC species. Based on recent evidence, monkeyface, SGNC, purple wartyback and spike, both currently listed as state threatened, are becoming more rare. Therefore, several mussels with proposed 2015 listing recommendations (Section 2: Species Reviews) differ from the current list established by the ESPB (see Table 1 for current listing status by ESPB).

Based on the changes listed above, the 2015 mussel SGNC list would include 39 species, as 1 species did not meet SGNC status in our review.

## Suggested Actions for the Streams Campaign

1. Fill information gaps for species with unknown distribution or poorly understood taxonomic position. Specifically, the need for genetic research exists to determine whether the observed forms of Louisiana fatmucket, bleufer, and Gulf mapleleaf are more similar to the accepted genotype for these species or are something unique to Illinois or the midwestern region (as in, a new subspecies or species). Additionally, data collected in the southern portions of Illinois during T-53 suggested that a species morphologically similar to cylindrical papershell (*Anodontoides ferussacianus*) may be more closely related to the rayed creekshell (*A. radiatus*) and requires further sampling and genetic testing to determine taxonomic position.

2. Fill information gaps for mussel populations in large rivers through comprehensive large river surveys. Several species are primarily found in the Ohio, Wabash, Mississippi, and Illinois Rivers, yet no systematic samples with appropriate methodology have been conducted in these rivers for many decades. Lower reaches of large tributaries including the Saline, Little Wabash, Big Muddy, Sangamon, Kaskaskia, Kankakee, Rock, Fox Rivers and others are difficult to survey and therefore are often undersampled. Species such as pocketbook, scaleshell, and wartyback have unknown extents due to the paucity of recent large river data, and additional surveys are warranted to better ascertain their population viability or abundance within large rivers and tributaries. Furthermore, additional surveys may elucidate reasons for decline of large river species such as fat pocketbook or sheepnose.

3. Augment targeted populations of mussel Species in Greatest Need of Conservation within 5 years. Federally endangered mussel species likely to benefit from propagation include sheepnose, fat pocketbook, spectaclecase, rabbitsfoot, snuffbox, fanshell, and Higgins eye. Other state threatened or endangered species to consider augmenting populations are ebonyshell, spike, butterfly, elephantear, and kidneyshell. Additionally, we believe efforts to reintroduce purple wartyback and monkeyface in the Rock River should be explored, as extant populations of monkeyface were not discovered in this basin during T-53, despite known extant historical records.

With the exception of spectaclecase (host fish unknown), fish hosts for these mussels include common species of minnows, centrarchids, percids, catfishes, and drum, all easily obtainable for propagation efforts. Populations of these mussels are isolated, have low occurrences, or are extirpated from watersheds within their historic range, thus, augmenting their populations via propagation or inoculated host fish release may restore some historic populations. Ideally, the intention of this effort will be to repopulate or maintain populations with viable, reproducing populations in 50% or more of historic drainages where suitable habitat exists or can be restored. Implementation of an augmentation program would require, at a minimum, investigation of limiting factors for each species and host, and an analysis of feasibility. We recommend determining limiting factors for species listed above and investigating feasibility of augmentation in areas with limited habitat threats within the next 5 years.

4. Preserve and restore in-stream riffle habitat, host fish species (if extirpated), and associated riparian habitat in targeted watersheds to benefit species such as purple wartyback, wavy-rayed lampmussel, flutedshell, snuffbox, and elktoe that thrive in swift, clean and clear currents in or near riffle habitats. Examples of watersheds or portions of watersheds that may benefit from restoration efforts for these particular mussel species include the Vermilion (Wabash River), Embarras, Sangamon, Mackinaw, and/or Kishwaukee Rivers. Increasing riparian zone habitat and limiting runoff within the watershed may also reduce sedimentation within the Saline basin and will improve habitat for the fat pocketbook. Further research to determine limiting factors for each specific watershed is recommended.

5. Removing low-head dams that have no municipal use across the state (e.g., Krape Park, Freeport, Yellow Creek; Bellevidere Park, Bellevidere -Kishwaukee River; Crescent Falls Dam, Hanover-Apple River) or creating fish passages (around dams *and* reservoirs) to re-establish ecological continuity within a stream and ultimately enhance gene flow, dispersal, recruitment efforts and habitat use in depauperate mussel areas.

6. Research effects of water quality degradation on freshwater mussels in Illinois. A specific focus should be on known threats, such as ammonia, chlorination, and/or heavy metals (Wang et al., 2007), in regions of Illinois with acute or chronic inputs of these pollutants.

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Table 1. Current status of Illinois mussel species, based on 2014 Illinois Endangered Species Protection Board list, 2005 Plan, and most recent federal status (USFWS, 2013). The following list provides the scientific name, common name, and current status of each species in Illinois. X – Extirpated in Illinois, FE – Federally endangered, FT – Federally threatened, SE – State endangered, ST – State threatened, SGNC – Species in greatest need of conservation, RI – Reintroduced in Illinois.

| Scientific Name | Common Name | Status |
|---|---|---|
| *Actinonaias ligamentina* | mucket | |
| *Alasmidonta marginata* | elktoe | |
| *Alasmidonta viridis* | slippershell | ST |
| *Amblema plicata* | threeridge | |
| *Amphinaias nodulata* | wartyback | |
| *Amphinaias pustulosa* | pimpleback | |
| *Anodontoides ferussacianus* | cylindrical papershell | |
| *Arcidens confragosus* | rock pocketbook | SGNC |
| *Cyclonaias tuberculata* | purple wartyback | ST |
| *Cyprogenia stegaria* | fanshell | FE, SE |
| *Ellipsaria lineolata* | butterfly | ST |
| *Elliptio crassidens* | elephantear | SE |
| *Elliptio dilatata* | spike | ST |
| *Epioblasma obliquata* | catspaw | FE, X |
| *Epioblasma rangiana* | northern riffleshell | FE, RI |
| *Epioblasma torulosa* | tubercled blossom | FE, X |
| *Epioblasma triquetra* | snuffbox | FE, SE |
| *Fusconaia ebena* | ebonyshell | SE |
| *Fusconaia flava* | Wabash pigtoe | |
| *Fusconaia subrotunda* | longsolid | X |
| *Hemistena lata* | cracking pearlymussel | FE, X |
| *Lampsilis abrupta* | pink mucket | FE, SE |
| *Lampsilis cardium* | plain pocketbook | |
| *Lampsilis fasciola* | wavy-rayed lampmussel | SE |
| *Lampsilis higginsii* | Higgins eye | FE, SE |
| *Lampsilis hydiana* | Louisiana fatmucket | |
| *Lampsilis ovata* | pocketbook | |
| *Lampsilis siliquoidea* | fatmucket | |
| *Lampsilis teres* | yellow sandshell | |
| *Lasmigona complanata* | white heelsplitter | |
| *Lasmigona compressa* | creek heelsplitter | SGNC |
| *Lasmigona costata* | flutedshell | SGNC |
| *Leptodea fragilis* | fragile papershell | |
| *Leptodea leptodon* | scaleshell | FE, SE |
| *Ligumia recta* | black sandshell | ST |
| *Ligumia subrostrata* | pondmussel | |
| *Margaritifera monodonta* | spectaclecase | FE, SE |
| *Megalonaias nervosa* | washboard | |
| *Obliquaria reflexa* | threehorn wartyback | |
| *Obovaria olivaria* | hickorynut | |
| *Obovaria retusa* | ring pink | FE, X |
| *Obovaria subrotunda* | round hickorynut | X |

| | | |
|---|---|---|
| *Plectomerus dombeyanus* | bankclimber | |
| *Plethobasus cicatricosus* | white wartyback | FE, X |
| *Plethobasus cooperianus* | orangefoot pimpleback | FE, SE |
| *Plethobasus cyphyus* | sheepnose | FE, SE |
| *Pleurobema clava* | clubshell | FE, RI |
| *Pleurobema cordatum* | Ohio pigtoe | SE |
| *Pleurobema plenum* | rough pigtoe | FE, X |
| *Pleurobema rubrum* | pyramid pigtoe | X |
| *Pleurobema sintoxia* | round pigtoe | |
| *Potamilus alatus* | pink heelsplitter | |
| *Potamilus capax* | fat pocketbook | FE, SE |
| *Potamilus ohiensis* | pink papershell | |
| *Potamilus purpuratus* | bleufer | |
| *Ptychobranchus fasciolaris* | kidneyshell | SE |
| *Pyganodon grandis* | giant floater | |
| *Quadrula fragosa* | winged mapleleaf | FE, X |
| *Quadrula nobilis* | Gulf mapleleaf | |
| *Quadrula quadrula* | mapleleaf | |
| *Simpsonaias ambigua* | salamander mussel | SE |
| *Strophitus undulatus* | creeper | |
| *Theliderma cylindrica* | rabbitsfoot | FT, SE |
| *Theliderma metanevra* | monkeyface | SGNC |
| *Toxolasma lividum* | purple lilliput | SE |
| *Toxolasma parvum* | lilliput | |
| *Toxolasma texasiensis* | Texas lilliput | |
| *Tritogonia verrucosa* | pistolgrip | |
| *Truncilla donaciformis* | fawnsfoot | |
| *Truncilla truncata* | deertoe | |
| *Uniomerus tetralasmus* | pondhorn | |
| *Utterbackia imbecillis* | paper pondshell | |
| *Utterbackia suborbiculata* | flat floater | |
| *Venustaconcha ellipsiformis* | ellipse | SGNC |
| *Villosa fabalis* | rayed bean | FE, X |
| *Villosa iris* | rainbow | SE |
| *Villosa lienosa* | little spectaclecase | ST |

Table 2. Summary of extirpated species and species that did not meet listing criteria.

| Scientific Name | Habitat Association | 1 - 2005 Listing | 2 - Global Rank |
|---|---|---|---|
| **Species currently believed extirpated in Illinois** | | | |
| *Epioblasma obliquata* (catspaw) | rivers with swift flow, gravel | X, FE | G1 |
| *Epioblasma torulosa* (tubercled blossom) | medium to large rivers, riffles, gravel | X, FE | G2 |
| *Fusconaia subrotunda* (longsolid) | large rivers, gravel | X | G3 |
| *Hemistena lata* (cracking pearlymussel) | medium to large rivers, sand, gravel, muck | X, FE | G1 |
| *Obovaria retusa* (ring pink) | large rivers, sand, gravel | X, FE | G1 |
| *Obovaria subrotunda* (round hickorynut) | medium rivers, flow, sand, gravel | X, SE | G4 |
| *Plethobasus cicatricosus* (white wartyback) | large rivers, riffles, shoals, coarse substrates | X, FE | G1 |
| *Pleurobema plenum* (rough pigtoe) | medium to large rivers, sand, gravel | X, FE | G1 |
| *Pleurobema rubrum* (pyramid pigtoe) | medium to large rivers, swift flow, sand, gravel | X | G2G3 |
| *Quadrula fragosa* (winged mapleleaf) | medium to large rivers, sand, gravel, muck | X, FE | G1 |
| **Species that did not meet listing criteria** | | | |
| *Actinonaias ligamentina* (mucket) | medium to large rivers, sand, gravel | | G5 |
| *Amblema plicata* (threeridge) | rivers or impoundments, sand, gravel, mud | | G5 |
| *Amphinaias pustulosa* (pimpleback) | medium to large rivers, sand, gravel, muck | | G5 |
| *Anodontoides ferussacianus* (cylindrical papershell) | small streams, sand, muck, edges | | G5 |
| *Fusconaia flava* (Wabash pigtoe) | small to large rivers, sand, gravel, muck | | G5 |
| *Lampsilis cardium* (plain pocketbook) | small to large rivers, sand, gravel, muck | | G5 |
| *Lampsilis siliquoidea* (fatmucket) | small to medium rivers, slow flow, sand, gravel, muck | | G5 |
| *Lampsilis teres* (yellow sandshell) | small to medium rivers, sand, muck, slow flow | | G5 |
| *Lasmigona complanata* (white heelsplitter) | small to large rivers, all substrates | | G5 |
| *Leptodea fragilis* (fragile papershell) | small to large rivers, sand, muck | | G5 |
| *Ligumia subrostrata* (pondmussel) | small to medium rivers, sand, muck, edges | | G5 |
| *Megalonaias nervosa* (washboard) | medium to large rivers, in flow, sand to cobble | | G5 |
| *Obliquaria reflexa* (threehorn wartyback) | medium to large rivers, sand, gravel, muck | | G5 |
| *Obovaria olivaria* (hickorynut) | medium to large rivers, swift flow, sand, gravel | | G4 |
| *Pleurobema sintoxia* (round pigtoe) | medium to large rivers, sand, gravel, muck | | G4G5 |
| *Potamilus alatus* (pink heelsplitter) | medium to large rivers, slow flow, fine substrates | | G5 |
| *Potamilus ohiensis* (pink papershell) | medium to large rivers, slow flow, fine substrates | | G5 |
| *Pyganodon grandis* (giant floater) | small to large rivers, lakes, fine substrates | | G5 |
| *Quadrula quadrula* (mapleleaf) | medium to large rivers, reservoirs, all substrates | | G5 |
| *Strophitus undulatus* (creeper) | small to medium rivers, all substrates | | G5 |
| *Toxolasma parvum* (lilliput) | small to medium rivers, fine substrates, edges | | G5 |
| *Toxolasma texasiense* (Texas lilliput) | small to medium rivers, fine substrates, edges | | G4 |
| *Truncilla donaciformis* (fawnsfoot) | medium to large rivers, moderate flow, fine substrates | | G5 |
| *Truncilla truncata* (deertoe) | medium to large rivers, moderate flow, fine substrates | | G5 |
| *Uniomerus tetralasmus* (pondhorn) | small streams, sloughs, slow flow, fine substrates | | G5 |
| *Utterbackia imbecillis* (paper pondshell) | medium to large rivers, slow flow, fine substrates, edges | | G5 |
| *Utterbackia suborbiculata* (flat floater) | medium to large rivers, backwaters, slow flow, fine substrates | | G5 |

Appendix I. 2015 revision of mussel SGNC in Illinois as identified by twelve criteria (1 = species meets criterion, 0 = species does not meet criterion).

| Scientific Name | Habitat Association | 1 - 2005 Listing | 1- 2104 ESPB/USFWS Listing | 1 - 2015 Proposed Listing | 2 - Global Rank | 3 - Rare (Low Population) | 4 - Rare (Limited Sites) | 5 - Declining (Abundance) | 6 - Declining (Range) | 7 - Rare or Vunerable Habitat | 8 - Endemic to IL | 9 - Disjunct population | 10 - Key Population | 11 - Representative Species | 12 - Poorly known status |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Alasmidonta marginata* (elktoe) | medium to large streams, swift flow | | | SGNC | G4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Alasmidonta viridis* (slippershell) | small streams, sand, gravel, muck | ST | ST | SGNC | G4G5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Amphinaias nodulata* (wartyback) | medium to large rivers, sand, gravel, muck | | | SGNC | G5 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Arcidens confragosus* (rock pocketbook) | medium to large rivers, sand, gravel, muck | SGNC | | | G4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Cyclonaias tuberculata* (purple wartyback) | medium to large rivers, swift flow, coarse substrates | ST | ST | SE | G5 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Cyprogenia stegaria* (fanshell) | medium to large rivers, swift flow, gravel | FE, SE | FE, SE | X, FE, SE | G1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| *Ellipsaria lineolata* (butterfly) | large rivers, swift flow, sand, gravel | ST | ST | ST | G4G5 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Elliptio crassidens* (elephantear) | large rivers, swift flow | ST | SE | SE | G5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Elliptio dilatata* (spike) | medium to large rivers, coarse substrates | ST | ST | SE | G5 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Epioblasma rangiana* (northern riffleshell) | medium to large rivers, riffles, coarse substrates | X, FE | FE, SE | FE, SE, RI | G1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| *Epioblasma triquetra* (snuffbox) | medium to large rivers, riffles, coarse substrates | SE | FE, SE | FE, SE | G3 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| *Fusconaia ebena* (ebonyshell) | large rivers, swift flow, sand, gravel | ST | SE | SE | G4G5 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lampsilis abrupta* (pink mucket) | large rivers, swift flow, rocky substrate | FE, SE | FE, SE | FE, SE | G2 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| *Lampsilis fasciola* (wavy-rayed lampmussel) | small to medium rivers, flow, coarse substrates | SE | SE | SE | G5 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| *Lampsilis higginsii* (Higgins eye) | large rivers, sand, gravel | FE, SE | FE, SE | FE, SE | G1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| *Lampsilis hydiana* (Louisiana fatmucket) | small to medium rivers, slow flow, sand, gravel, muck | | | SGNC | G4Q | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Lampsilis ovata* (pocketbook) | small to large rivers, all substrates | | | SGNC | G5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Lasmigona compressa* (creek heelsplitter) | small to medium rivers, sand, gravel | SGNC | | SGNC | G5 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Lasmigona costata* (flutedshell) | medium to large rivers, sand, gravel | SGNC | | SGNC | G5 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Leptodea leptodon* (scaleshell) | medium to large rivers, in flow | X, FE | FE, SE | FE, SE | G1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |

Appendix I. (continued)

| Scientific Name | Habitat Association | 1 - 2005 Listing | 1- 2104 ESPB/USFWS Listing | 1 - 2015 Proposed Listing | 2 - Global Rank | 3 - Rare (Low Population) | 4 - Rare (Limited Sites) | 5 - Declining (Abundance) | 6 - Declining (Range) | 7 - Rare or Vunerable Habitat | 8 - Endemic to IL | 9 - Disjunct population | 10 - Key Population | 11 - Representative Species | 12 - Poorly known status |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ligumia recta* (black sandshell) | medium to large rivers, riffles, gravel to sand | ST | ST | SGNC | G4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Margaritifera monodonta* (spectaclecase) | large rivers, sand, gravel, muck, roots | FC, SE | FE, SE | FE, SE | G3 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| *Plectomerus dombeyanus* (bankclimber) | medium to large rivers, sand, gravel, muck | | | SGNC | G5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Plethobasus cooperianus* (orangefoot pimpleback) | medium to large rivers, swift flow, cobble to sand | FE, SE | FE, SE | FE, SE | G1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Plethobasus cyphyus* (sheepnose) | medium to large rivers, swift flow, cobble to sand | FC, SE | FE, SE | FE, SE | G1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| *Pleurobema clava* (clubshell) | medium to large rivers, swift flow, cobble to sand | FE, SE | FE, SE | FE, SE, R | G1G2 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| *Pleurobema cordatum* (Ohio pigtoe) | medium to large rivers, sand, gravel | SE | SE | SE | G4 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| *Potamilus capax* (fat pocketbook) | medium to large rivers, sand, gravel, muck | FE, SE | FE, SE | FE, SE | G2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Potamilus purpuratus* (bleufer) | medium to large rivers, slow flow, fine substrates | | | SGNC | G5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Ptychobranchus fasciolaris* (kidneyshell) | medium to large rivers, fine to coarse substrates | SE | SE | SE | G4 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| *Quadrula nobilis* (Gulf mapleleaf) | large rivers, sand, gravel, muck | | | SGNC | G4 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| *Simpsonaias ambigua* (salamander mussel) | medium to large rivers, coarse substrates, slab rock | SE | SE | SE | G3 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| *Theliderma cylindrica* (rabbitsfoot) | medium to large rivers, sand, gravel | SE | FT, SE | FT, SE | G3G4 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| *Theliderma metanevra* (monkeyface) | medium to large rivers, sand, gravel | SGNC | | ST | G4 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| *Toxolasma lividum* (purple lilliput) | small to medium rivers, sand, muck, roots, edges | SE | SE | SE | G3 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Tritogonia verrucosa* (pistolgrip) | medium to large rivers, sand, gravel, muck | | | SGNC | G4G5 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Venustaconcha ellipsiformis* (ellipse) | small to medium rivers, swift flow, cobble to sand | SGNC | | SGNC | G3 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| *Villosa fabalis* (rayed bean) | small to large rivers, flow, fine substrates, vegetation | X, FC | X, FE | FE, SE | G2 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| *Villosa iris* (rainbow) | small to medium rivers, sand, gravel | SE | SE | SE | G5 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 |
| *Villosa lienosa* (little spectaclecase) | small to medium rivers, sand, mud, edges | ST | ST | SGNC | G5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Appendix II. 2015 revision to Status and Stresses to mussel SGNC.

| | Status | | | | | Habitat Stress | | | | | | Community Stress | | | | | | | Population Stress | | | | Human Stress | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mussel Species | N (Extant HUC8) | Recent Trend | Change in historic range | 2005 Status | Proposed 2015 Status | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| *Alasmidonta marginata* (elktoe) | 15 | -1 | >25% and <50% decline | | SGNC | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| *Alasmidonta viridis* (slippershell) | 17 | -1 | >25% and <50% decline | ST | SGNC | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| *Amphinaias nodulata* (wartyback) | 21 | 0 | <25% change | | SGNC | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 |
| *Arcidens confragosus* (rock pocketbook) | 23 | 1 | <25% change | SGNC | - | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| *Cyclonaias tuberculata* (purple wartyback) | 5 | -1 | >50% decline | ST | SE | 2 | 3 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| *Cyprogenia stegaria* (fanshell) | 0 | -2 | >50% decline | FE, SE | X, FE, SE | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 1 | 2 | 1 |
| *Ellipsaria lineolata* (butterfly) | 9 | -1 | >25% and <50% decline | ST | ST | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 |
| *Elliptio crassidens* (elephantear) | 3 | -1 | >50% decline | ST | SE | 2 | 2 | 2 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 2 | 2 | 1 |
| *Elliptio dilatata* (spike) | 18 | 0 | >50% decline | ST | SE | 2 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 |
| *Epioblasma rangiana* (northern riffleshell) | 1 | -1 | >50% increase | X, FE | FE, SE | 1 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 3 |
| *Epioblasma triquetra* (snuffbox) | 1 | -2 | >50% decline | SE | FE, SE | 1 | 2 | 3 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | 2 | 1 | 2 | 2 |
| *Fusconaia ebena* (ebonyshell) | 4 | -1 | >50% decline | ST | SE | 1 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 |
| *Lampsilis abrupta* (pink mucket) | 0 | -2 | >50% decline | FE, SE | FE, SE | 1 | 3 | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 1 |
| *Lampsilis fasciola* (wavy-rayed lampmussel) | 1 | -1 | >50% decline | SE | SE | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 |
| *Lampsilis higginsii* (Higgins eye) | 2 | 0 | >50% decline | FE, SE | FE, SE | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 |
| *Lampsilis hydiana* (Louisiana fatmucket) | 12 | 0 | | | SGNC | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *Lampsilis ovata* (pocketbook) | 1 | -2 | >50% decline | | SGNC | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 3 | 3 | 1 | 1 | 2 | 3 |
| *Lasmigona compressa* (creek heelsplitter) | 21 | 1 | <25% change | SGNC | SGNC | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 |
| *Lasmigona costata* (flutedshell) | 12 | -1 | >50% decline | SGNC | SGNC | 1 | 1 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 |
| *Leptodea leptodon* (scaleshell) | 1 | -2 | >50% decline | X, FE | FE, SE | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 3 | 2 | 3 | 1 | 1 | 1 |
| *Ligumia recta* (black sandshell) | 15 | 1 | >50% decline | ST | SGNC | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 3 |
| *Margaritifera monodonta* (spectaclecase) | 1 | -2 | >50% decline | FE,SE | FE,SE | 1 | 3 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 2 | 2 | 1 |
| *Plectomerus dombeyanus* (bankclimber) | 2 | 2 | >50% increase | | SGNC | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 |
| *Plethobasus cooperianus* (orangefoot pimpleback) | 0 | -2 | >50% decline | FE, SE | FE, SE | 1 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 1 | 1 | 3 |
| *Plethobasus cyphyus* (sheepnose) | 3 | -2 | >50% decline | FC, SE | FE, SE | 3 | 3 | 2 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 3 | 3 | 1 | 1 | 2 | 2 |
| *Pleurobema clava* (clubshell) | 1 | -2 | >50% decline | FE, SE | FE, SE | 1 | 3 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 3 | 3 | 2 | 1 | 2 | 3 |
| *Pleurobema cordatum* (Ohio pigtoe) | 1 | -2 | >50% decline | SE | SE | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 |
| *Potamilus capax* (fat pocketbook) | 5 | -1 | >50% decline | FE, SE | FE, SE | 1 | 3 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 1 |
| *Potamilus purpuratus* (bleufer) | 4 | 0 | <25% change | | SGNC | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| *Ptychobranchus fasciolaris* (kidneyshell) | 2 | -1 | >50% decline | SE | SE | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 3 | 3 | 2 | 1 | 2 | 2 |
| *Quadrula nobilis* (Gulf mapleleaf) | 2 | -1 | >25% and <50% decline | | SGNC | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 |
| *Simpsonaias ambigua* (salamander mussel) | 1 | -2 | >50% decline | SE | SE | 2 | 2 | 3 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 2 | 1 |
| *Theliderma cylindrica* (rabbitsfoot) | 2 | -2 | >50% decline | SE | FT, SE | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 3 |
| *Theliderma metanevra* (monkeyface) | 15 | -1 | >25% and <50% decline | SGNC | ST | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 |
| *Toxolasma lividum* (purple lilliput) | 3 | 0 | >50% decline | SE | SE | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 3 | 2 | 1 | 1 | 2 | 1 |
| *Tritogonia verrucosa* (pistolgrip) | 29 | 0 | <25% change | | SGNC | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 |
| *Venustaconcha ellipsiformis* (ellipse) | 15 | -1 | >25% and <50% decline | SGNC | SGNC | 2 | 2 | 3 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 |
| *Villosa fabalis* (rayed bean) | 1 | -2 | >50% decline | X. FC | FE, SE | 2 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 3 | 3 | 1 | 1 | 1 | 2 |
| *Villosa iris* (rainbow) | 1 | -2 | >50% decline | SE | SE | 1 | 3 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 3 | 2 | 2 | 1 | 1 | 3 |
| *Villosa lienosa* (little spectaclecase) | 6 | 1 | >25% and <50% decline | ST | SGNC | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |

# Section 2:

# Review Rationale and Related Components

## Elktoe (*Alasmidonta marginata*)

**Specific Habitat:** Occurs in small to medium-sized streams (rare in large rivers), it is more typical of smaller streams (Wilson and Clark, 1914; Goodrich and van der Schalie, 1944; Parmalee, 1967; Buchanan, 1980; Oesch, 1984). Ortmann (1919) described it as a riffle species that is found in swift current in firmly packed fine to coarse gravel.

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Criteria in Appendix I:**

6 - Species has declined in range since 2000

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |

**Rationale:** The current extant range has declined by 35% (15 HUC8s) from historical range (23 HUC8s) in Illinois. Although wide-ranging, this species occurs in very small numbers at most extant locations in Illinois (with a few exceptions), survey efforts often yield only one or two individuals at a site and few sites indicate recent recruitment. All neighboring states list the elktoe as imperiled or vulnerable, thus adjoining populations appear to be declining as well.

We believe the most significant threats to elktoe populations are declining habitat in the form of fragmentation, degradation, hydrologic disturbance, and sedimentation, due to the fact that elktoe are found in swift current in fine or coarse gravel. Host fish are numerous and most are common in Illinois (Section 3: Table 3), although many are associated with specific habitat (e.g., silt-free rivers for redhorse species or Hornyhead Chub) and may be declining in Illinois (Smith, 1979; Metzke, 2012).

Slippershell mussel (*Alasmidonta viridis*)

**Specific Habitat:** Creeks and small rivers, in sand, gravel, and muck habitat (van der Schalie, 1938; Cummings and Mayer, 1992; Watters, 1995).

**2005 status:** State Threatened (ESPB, 2014)

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:** None

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 3 | 1 |
| 2015 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |

**Rationale:** Although the historic range (25 HUC8s) still exceeds the current extant range (17 HUC8s), slippershells have remained stable or have increased in range since 1977. Extant HUC8 count in 1977-1999 was 12, and slippershell are now known in 17 HUC8s in 2000-2013, an increase of 41% of extant range. We believe this change is due to an increased sampling effort in smaller streams, which revealed more live and extant locations for this species. Small streams are widespread throughout Illinois and threats in small-stream ecosystems are spread among many tributaries. However, channelization can significantly alter habitat in creeks and small streams for decades. Regardless, we believe slippershell populations are still low but are stable or increasing and continue to persist and even thrive in these altered habitats.

In Appendix II, we downgraded hydrologic disturbance and direct human disturbance to moderate threats to population viability or abundance. During T-53, we encountered slippershell populations frequently and individuals are common in many small drainages in central Illinois. Host fish are believed to be Mottled and Banded Sculpin (*Cottus bairdi* and *C. carolinae*) and Johnny Darter (*Etheostoma nigrum*), although no recent trials have been completed (Section 3: Table 3). Johnny Darters are widespread and common in Illinois (Smith, 1979). We also believe we have greater confidence in dispersal and recruitment values following T-53.

## Wartyback (*Amphinaias nodulata*)

**Specific Habitat:** Medium to large rivers or reservoirs in mud, sand, or gravel (Cummings and Mayer, 1992).

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 1 |

**Rationale:** The current extant range is nearly the same as the historic range (21 HUC8s versus 22 HUC8s), which is less than a 5% decline. However, few individuals have been collected within its range and wartybacks are generally considered rare, compared to closely related species that are generally abundant, such as pimpleback (*A. pustulosa*) or mapleleaf (*Quadrula quadrula*).

We believe the most significant threats to wartyback populations are hydrologic disturbance, invasives/exotics, sedimentation, dispersal, and human disturbance. Because wartyback live almost exclusively in large rivers, they are at increased risk to impacts from invasive zebra mussels (*Dreissena* spp.), sedimentation, and hydrologic barriers that limit dispersal ability between sparse populations. Host fish are several species of catfish, many of which are common throughout Illinois (Section 3: Table 3).

## Rock pocketbook (*Arcidens confragosus*)

**Specific Habitat:** Medium to large rivers, low gradient, mud and sand bottom pools in standing to slow flowing water; typical of large lowland streams (Parmalee and Bogan, 1998).

**2005 status:** Species in Greatest Need of Conservation

**Proposed 2015 status:** None

**Changes to Criteria in Appendix I:**

Removal of Rare (low population) designation

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |

**Rationale:** Although the historic range (26 HUC8s) still exceeds the current extant range (23 HUC8s), rock pocketbooks have increased in range since 1977-1999. Extant HUC8 count in 1977-1999 was 21, which is an increase of 8%. We believe this change is due to an increased sampling effort in streams in the southern half of Illinois, an area not extensively sampled in the past. These new samples revealed more live and extant records for this species. Rock pocketbook habitat requirements, low gradient, mud or sand bottom pools, are not limited in Illinois, thus we believe populations are likely to increase.

In Appendix II, we believe we have greater confidence in host knowledge, dispersal and recruitment values following T-53. We downgraded the risk of human disturbance, hosts, invasive species and recruitment, as we believe these to be limited threats to population viability or abundance. Rock pocketbooks are generalists and use many host fish, most of which are common in Illinois (Section 3: Table 3; Smith, 1979).

## Purple wartyback (*Cyclonaias tuberculata*)

**Specific Habitat:** Medium to large rivers in gravel or mixed sand/gravel; prefers riverine conditions with stronger flow (Cummings and Mayer, 1992; Watters, 1995).

**2005 status:** State Threatened (ESPB, 2014)

**Proposed 2015 status:** State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 |
| 2015 | 2 | 3 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |

**Rationale:** The current extant range (5 HUC8s) for purple wartybacks has declined 28% from 1977-1999 (7 HUC8s) and 80% historically (26 HUC8s). Also, the Rock River and Ohio River populations are disjunct and widely separated, thus genetic mixing between each watershed is unlikely. Purple wartybacks are generally found in medium to large rivers, which are at increased risk of threats such as an accumulation of industrial or municipal contaminants, sedimentation, or hydrologic alterations in the form of dams. This species is also listed as state endangered in Wisconsin, threatened in Iowa, and as special concern in Michigan.

In Appendix II, we ranked habitat extent, fragmentation, composition, population dispersal, and structures/infrastructure (i.e., dams) as threats likely to have a moderate effect on population viability for reasons listed above. We do not believe invasive species, natural mortality of existing individuals, or human killing are as great a threat. Host fish for purple wartyback are several catfish species (Section 3: Table 3), all of which are widespread and stable in Illinois. However, because purple wartyback rely on large-bodied fishes that may migrate long distances, hydrologic alterations that impact the host fishes should be considered. We also believe we have greater confidence in dispersal and recruitment values following T-53.

## Fanshell (*Cyprogenia stegaria*)

**Specific Habitat:** Medium to large rivers in gravel riffles (Cummings and Mayer, 1992); river habitats with gravel substrates and a strong current, in both deep and shallow water (Ortmann, 1919; Parmalee, 1967).

**2005 status:** Federally Endangered, State Endangered

**2015 status:** Extirpated, Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 3 | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | 1 |
| 2015 | 3 | 3 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 1 |

**Rationale:** Fanshell are likely no longer extant in Illinois with the most recent record in Illinois collected in the Wabash River in 1984. The extirpation of fanshell populations are likely due to a combination of factors, including but not limited to impacts from dams, dredging, pollution, and navigation projects (NatureServe, 2014). Fanshell require larger rivers and stable gravel substrates, which are limited in Illinois and unlikely to persist in the future.

In Appendix II, we ranked habitat extent, fragmentation, composition, hydrologic disturbance as likely to have a severe effect on population viability for reasons listed above. Dispersal was ranked as a moderate effect on population viability, because most existing populations are isolated. Host fish for fanshell are sculpins and several darter species (Section 3: Table 3), which are species sensitive to water quality degradation.

## Butterfly (*Ellipsaria lineolata*)

**Specific Habitat:** Large rivers in sand or gravel (Cummings and Mayer, 1992); prefers large rivers in stretches with pronounced current and substrate of coarse sand and gravel but has adapted to impoundments in the Cumberland and Tennessee Rivers (Parmalee and Bogan, 1998).

**2005 status:** State Threatened

**2015 status:** State Threatened

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 |
| 2015 | 2 | 2 | 2 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 |

**Rationale:** Butterfly declined from 18 HUC8s to 9 HUC8s, a 50% decrease, but have remained relatively stable since 1977-1999 (10 HUC8s, a 10% decline). In Illinois, extant populations are in the Ohio, Mississippi, and extreme lower Rock Rivers and populations appear healthy based on recent survey data. Large river habitats are difficult to sample, thus survey data represent a small proportion of the existing community. Individuals of this species were not collected during T-53 and are rarely present in wadeable streams. We recommend more thorough sampling of large rivers to fully assess current threats or population levels.

In Appendix II, we ranked habitat extent, fragmentation, composition, and dispersal as likely to have moderate effects on population viability, mainly because large rivers are subject to threats such as hydrologic disturbance, accumulated pollution and sedimentation. Freshwater Drum have been confirmed as a host for butterfly (Boyer et al., 2011; Section 3: Table 3), which are common throughout the butterfly's range, thus we believe host availability has little to no effect on the population viability of butterfly.

Elephantear (*Elliptio crassidens*)

**Specific Habitat:** Large rivers with swift current in mud, sand, gravel and rocky substrates (commonly limestone) (Grier, 1922; Dawley, 1947; van der Schalie and van der Schalie, 1950; Cummings and Mayer, 1992; Brim Box et al., 2002; Gagnon et al., 2006).

**2005 status:** State Threatened

**2015 status:** State Endangered (ESPB, 2014)

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 1 |
| 2015 | 2 | 2 | 2 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 2 | 2 | 1 |

**Rationale:** The current extant range (3 HUC8s) for elephantear has declined 40% from 1977-1999 (5 HUC8s) and 82% historically (17 HUC8s). The only remaining populations in Illinois are in the Wabash and Ohio Rivers, and these populations appear to be mainly mature, non-reproducing individuals. Elephantear was recently upgraded to state endangered (ESPB, 2014). They are large river species and may have an increased risk of threats such as an accumulation of industrial or municipal contaminants, sedimentation, or hydrologic alterations in the form of dams. Elephantear are stable in southern parts of its range, outside of Illinois, but declining or disappearing in the Midwest, thus conservation measures to prevent future loss should be taken.

In Appendix II, we ranked habitat extent, fragmentation, composition, and dispersal as threats likely to have a moderate effect on population viability. Host fish are not known, but are speculated to be Skipjack Herring (Section 3: Table 3), a migratory riverine fish that may be negatively impacted by dams (Smith, 1979). More research is needed to test transformation success on this host and others.

## Spike (*Elliptio dilatata*)

**Specific Habitat:** Medium to large rivers in gravel or mixed sand/gravel; prefers riverine conditions with stronger flow (Cummings and Mayer, 1992; Watters, 1995).

**2005 status:** State Threatened (ESPB, 2014)

**Proposed 2015 status:** State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
7 - Species is dependent upon rare or vulnerable habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 1 |
| 2015 | 2 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |

**Rationale:** The current extant range (18 HUC8s) has declined 55% historically (40 HUC8s), although remained stable or increased since 1977-1999 (15 HUC8s, a 20% increase). While an increase was seen since 1977-1999, several of these new records are isolated points within a drainage that historically held widespread, abundant populations. Hence, we believe that remaining spike populations may be aging or non-reproducing. Habitat requirements for spike are swift rivers with mixed gravel and sand substrates. The habitat that remains in Illinois rivers may be separated by hydrologic disturbances like dams or have increasing sedimentation. Spike are common and abundant in areas outside of Illinois, thus the decline of this species in Illinois is puzzling and conservation measures to prevent future loss should be taken.

In Appendix II, we ranked habitat extent, fragmentation, composition, and structures/infrastructure as threats likely to have a moderate effect on population viability for reasons listed above. Spike use several hosts from different families, including sculpin, a darter, and Rock and Largemouth Bass (Section 3: Table 3). Largemouth Bass are common and widespread, yet do not share similar habitat requirements as spike. The remaining hosts generally prefer clear, rocky-bottomed streams (Smith, 1979) and may be sensitive to habitat degradation.

Northern riffleshell (*Epioblasma rangiana*)

**Specific habitat:** Medium to large rivers in clear, gravel riffles (Cummings and Mayer, 1992).

**2005 status:** Extirpated, Federally Endangered, State Endangered

**2015 status:** Federally Endangered, State Endangered, Reintroduced

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
9 - The Illinois population of this species is disjunct from the rest of the species' range
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 3 |

**Rationale:** Northern riffleshell were historically present in 2 HUC8s, the Wabash River (Ohio River) and Vermilion River (Wabash River) basin. They were believed extirpated in Illinois by the early 1990s (Cummings and Mayer, 1992) and in Indiana by early 2000s (Fisher, 2006). The extirpation of northern riffleshell populations is likely due to a combination of factors including but not limited to poor water quality, siltation, loss of host fish (NatureServe, 2014), and impacts from dams within the Vermilion River system.

Efforts to repopulate northern riffleshell into the Middle Fork Vermilion and Salt Fork Vermilion River were undertaken in 2011-2014 because no live northern riffleshell had been observed in decades. Population monitoring is on-going, and the majority of translocated adults are surviving as of 2014.

## Snuffbox (*Epioblasma triquetra*)

**Specific habitat:** Medium to large rivers in clear, gravel riffles (Cummings and Mayer, 1992) in swift current, often deeply buried (Baker, 1928; Parmalee and Bogan, 1998).

**2005 status:** State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
9 - The Illinois population of this species is disjunct from the rest of the species' range
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 2 | 3 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | 2 | 1 | 2 | 2 |

**Rationale**: Snuffbox was listed as federally endangered in February of 2012. Historical records indicate snuffbox occurred in 17 HUC8 drainages, but have dramatically decreased by 94% to 1 HUC8 drainage. Currently, it persists at limited sites within the Embarras River above Lake Charleston reservoir.

In Appendix II, we upgraded fragmentation, composition-structure, hosts, dispersal, and structures to likely having a moderate or severe threat to snuffbox population viability or abundance. We believe lack of habitat connectivity due to dams and a large reservoir on the Embarras River is likely having a negative effect on host fish population viability and dispersal, thereby severely limiting dispersal and recruitment efforts by snuffbox. Snuffbox distribution continues to decline and become increasingly isolated. Altered substrate composition from increased sedimentation, turbidity**,** and altered flow impacts riffles, utilized by snuffbox and their hosts. Snuffbox host fish include riffle-dwelling species like percids (*Percina* spp*.)* and cottids (Section 3: Table 3). Within the Embarras River, only *Percina* spp*.* are present but rare (2011 IDNR surveys). We believe we have greater confidence in understanding community stressors including host fish following T-82 and recent IDNR fish surveys.

## Ebonyshell (*Fusconaia ebena*)

**Specific habitat:** Large rivers in swift water and stable sandy to gravely shoals; thrives in rivers with current in sand, silt, and mud at water depths of 3 to 5 meters (Cummings and Mayer, 1992; Parmalee and Bogan, 1998).

**2005 status:** State Threatened

**2015 status:** State Endangered (ESPB, 2014)

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 |
| 2015 | 1 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 3 |

**Rationale:** Ebonyshell are currently extant in 4 HUC8s in Illinois, a 78% decline from their historic range (18 HUC8s) and a 43% decline since 1977-1999 (7 HUC8s). Ebonyshell was recently upgraded to state endangered (ESPB, 2014), due to continued range restrictions and low population abundance.

In Appendix II, we upgraded fragmentation, dispersal, and recruitment to having a moderate threat on population viability or abundance. Confirmed host fish for ebonyshell include the Skipjack Herring *Alosa chrysochloris* and, potentially, Goldeneye *Hiodon alosoides* (Section 3: Table 3). Skipjack Herring are an anadromous, migratory species in large rivers that prefer fast water over sand and gravel substrate (Smith, 1979). Structures such as dams can impede their passage, and, thereby, lead to fragmented, isolated populations with minimal dispersal ability for ebonyshell. Another continued severe threat to ebonyshell populations is the invasive zebra mussel *Dreissena polymorpha* within the Mississippi River system.

## Pink mucket (*Lampsilis abrupta*)

**Specific Habitat:** Large rivers with strong current, rocky or boulder substrates, in depths up to 1 meter; also found in deeper waters with slower currents and sand and gravel substrates (USFWS, 1985; Gordon and Layzer, 1989).

**2005 status:** Federally Endangered, State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 3 | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 3 | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 1 |

**Rationale:** Pink mucket have declined drastically throughout their range and are believed to have always been a small component of the mussel fauna (USFWS, 1985). The most recent extant record in Illinois was collected as dead shell in the Ohio River in 2011. Population declines are likely due to a combination of factors, including but not limited to impacts from dams, dredging, pollution, and navigation projects (NatureServe, 2014). We recommend more thorough sampling of large rivers to fully assess current threats or population levels.

In Appendix II, all values remained unchanged except hosts and dispersal. One of the primary threats to future existence of pink muckets is the lack of dispersal ability, thus we ranked this as a moderate threat to population viability. Known host fish include *Micropterus* spp. and Sauger (Barnhart and Riusech, 1997; Section 3: Table 3). These fish are common in Illinois, although they may not exist concurrently with remaining the population of pink mucket.

## Wavy-rayed lampmussel (*Lampsilis fasciola*)

**Specific habitat:** Small to medium-sized rivers at depths of up to 1 meter in clear, stable riffles with clean substrates of gravel and sand, stabilized with cobble and boulders (Cudmore et al., 2004).

**2005 status:** State Endangered

**2015 status:** State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
7 - Species is dependent upon rare or vulnerable habitat
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 |

**Rationale:** Wavy-rayed lampmussel continues to persist within one drainage (HUC8), the Vermilion River (Wabash River) basin, although historically it occurred in 3 drainages. The Vermilion River basin is the westernmost part of its range within the continental United States. Wavy-rayed lampmussel is listed as a species of special concern in Indiana, state threatened in Michigan, and apparently secure in Kentucky.

In Appendix II, we upgraded fragmentation and dispersal as having a moderate threat to population viability or abundance. Populations within the North Fork Vermilion River remain isolated from other extant populations within the Vermilion River system due to low head dams and a reservoir present thus limiting dispersal and genetic flow between populations. We ranked our confidence interval from very low confidence or no information to high confidence since recent host fish trials confirmed several centrarchids (*Micropterus* spp., Longear Sunfish) as main hosts for wavy-rayed lampmussel (Section 3: Table 3). These centrarchids are common in Illinois and occur within the wavy-rayed lampmussel distribution.

## Higgins eye (*Lampsilis higginsii*)

**Specific habitat:** The Mississippi and Illinois River in gravel or sand substrates (Cummings and Mayer, 1992).

**2005 status:** Federally Endangered, State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
10 - Illinois hosts a significant proportion of the species' global population

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 2 | 2 | 2 | 2 | 1 |
| 2015 | 1 | 1 | 1 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 |

**Rationale**: Higgins eye historically occurred in 12 drainages (HUC8), but range dramatically decreased by 83% and is extant only in the upper Mississippi River (2 HUC8s). Since 2006-2010, efforts to reintroduce Higgins eye into the Rock River near the mouth to the Mississippi River were undertaken, but a recent survey in 2014 for Higgins eye in the Rock River revealed only two live individuals (INHS Mollusk Collection).

In Appendix II, we upgraded invasive species, competitors, dispersal and structures/infrastructures as having moderate or severe threats on Higgins eye population viability or abundance. Higgins eye populations in the Mississippi River continue to be plagued by the invasive zebra mussel *Dreissena polymorpha*. In addition, dispersal rates may be hindered by reproduction failure due to zebra mussel-infested Higgins eye.

With recent propagation efforts at Genoa National Fish Hatchery (initiated in 2000) and their subsequent success of released juveniles and inoculated host fish throughout the upper Mississippi, we believe fragmentation and host fish (Largemouth and Smallmouth Bass, Walleye; Section 3: Table 3) are not a limiting factor. We also believe hydrology, pollutants-sediment and human stresses such as killing and disturbance are less of a threat on population viability or abundance than others stated above.

## Louisiana fatmucket (*Lampsilis hydiana*)

**Specific Habitat:** Medium to small rivers, and reservoirs in mud, mud and sand, or gravel in areas of backwater and slow flow (Howells et al., 1996).

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

4 - Species exists at limited sites
12 - Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

**Rationale:** Louisiana fatmuckets were unconfirmed in Illinois prior to genetic work completed as part of T-82, but were recently confirmed in several drainages in southern Illinois. Their entire distribution is still unknown and the exact taxonomic rank is yet to be determined. While individuals tested are genetically similar to Louisiana fatmuckets, further testing is required to determine whether Illinois populations are true Louisiana fatmuckets. The distribution map presented in this revision reflects the state of our knowledge as of October 2014. We believe more data regarding this species' distribution and true taxonomic status is warranted. Additionally, they are morphologically similar to fatmucket (*L. siliquoidea*) and coexist in at least one drainage, thus more samples and genetic testing may reveal the extent of the range overlap.

In Appendix II, we estimated threats to the Louisiana fatmucket relative to threats to similar mussels with ranges in southern Illinois. We believe the greatest threats to population viability are hydrologic disturbance and sedimentation, both of which are presumed threats to most freshwater mussels. Known hosts are Green Sunfish and Blue and Channel Catfish (Section 3: Table 3), common species (with the exception of Blue Catfish) in the current range of Louisiana fatmucket in Illinois.

## Pocketbook (*Lampsilis ovata*)

**Specific habitat:** Large rivers in coarse sand or gravel (Cummings and Mayer, 1992).

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

4 - Species exists at limited sites
12 - Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 3 | 3 | 1 | 1 | 2 | 3 |

**Rationale:** The pocketbook is often confused with plain pocketbook (*L. cardium*) and current extent in Illinois is unknown. Historically, pocketbook was present in the Wabash and Ohio Rivers (4 HUC8s) bordering Illinois and currently occurs sporadically within the Ohio River (75% decline, 1 HUC8). It likely is extirpated from the Wabash River where it appears to have been replaced by *L. cardium* (Cummings and Mayer, 1997). Fisher (2006) reported live, reproducing populations of pocketbook in the upper Wabash mainstem and its lower tributary, East Fork White River in Indiana. Pocketbook is currently not listed in Indiana, and state endangered in Kentucky and Ohio. According to NatureServe (2014), pocketbook is imperiled in Indiana.

No known host fish information is available in the current literature (Watters et al., 2009). We recommend upgrading to Species in Greatest Need of Conservation because key components of the species' biology and distribution are poorly understood. Further research on the extent of this species in Illinois would be beneficial.

Creek heelsplitter (*Lasmigona compressa*)

**Specific Habitat:** Usually found in creeks and headwaters of small to medium rivers. Prefers fine gravel or sand and typically is in slow-moving currents near the edge or above or below riffles (van der Schalie, 1938; Cummings and Mayer, 1992; Watters, 1995).

**2005 status:** Species in Greatest Need of Conservation

**2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:** None

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 3 | 1 |
| 2015 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 |

**Rationale:** The current extant range (21 HUC8s) is nearly the same as the historic range (22 HUC8s), and creek heelsplitters have slightly increased in range since 1977-1999 (19 HUC8s). We believe this change is due to an increased sampling effort in smaller streams, which revealed more live and extant records for this species. Small streams are widespread throughout Illinois and threats in small-stream ecosystems are spread among many tributaries. However, channelization can significantly alter habitat in creeks and small streams for decades. Creek heelsplitters comprise a very small portion of the mussel fauna, thus populations at each site are low but appear stable.

In Appendix II, we downgraded hydrologic disturbance, mortality, hosts, and direct human disturbance to low or moderate threats to population viability or abundance. Creek heelsplitters use hosts from many fish families, and most of the host species are common throughout Illinois (Section 3: Table 3). We also believe we have greater confidence in dispersal and recruitment values following T-53 and these are low and moderate threats to population viability, respectively.

## Flutedshell (*Lasmigona costata*)

**Specific habitat:** In medium-sized rivers in sand/mud, coarse sand and gravel, or fine gravel in slow to moderate flow (Cummings and Mayer, 1992; Parmalee and Bogan, 1998).

**2005 status:** Species in Greatest Need of Conservation

**2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

4 - Species exists at limited sites
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 |
| 2015 | 1 | 1 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 |

**Rationale:** Flutedshell is known from 27 drainages (HUC8) and experienced a 48% range reduction (14 HUC8s) according to surveys during 1977-1999. Since 2000, it continued to decline and is currently found in 12 HUC8s (approximately 14% range reduction since 1977-1999, and a 55% decline overall).

In Appendix II, we upgraded composition-structure, dispersal, and structures-infrastructures (i.e., dams) to moderate threats on flutedshell population viability or abundance. Flutedshell are often found in stable substrates of coarse sand, gravel, and riffle habitat with moderate flow. Substrates could be subject to change through sedimentation, hydrology variances, and structures such as dams, thereby influencing fish and mussel communities inhabiting it.

We downgraded host fish, mortality, and human stresses such as killing and disturbance to having little or no threat on population viability or abundance. Recent host fish studies reveals flutedshell to be a host generalist with the potential to utilize numerous fishes within and across several families (Section 3: Table 3). Even though flutedshell can host on numerous fish, dispersal limitations should still be considered as a moderate threat to their population due to more imminent habitat stressors, increasingly isolated populations, physical barriers, and competition of utilizing host species, for instance.

## Scaleshell (*Leptodea leptodon*)

**Specific Habitat:** Medium to large rivers with moderate to high gradients in a variety of substrates including gravel, cobble, boulders, and occasionally mud or sand (Buchanan, 1980; Oesch, 1995), particularly in areas with stable channels (Buchanan, 1980).

**2005 status:** Extirpated

**2015 status:** Federally Endangered, State Endangered (ESPB, 2014)

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
9 - The Illinois population of this species is disjunct from the rest of the species' range
10 - Illinois hosts a significant proportion of the species' global population
12 - Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 3 | 2 | 3 | 1 | 1 | 2 |

**Rationale:** Scaleshell were believed extirpated in Illinois prior to a recent find during a river drawdown in the Illinois River in 2013, the only recent extant record for Illinois. The individual collected was less than 10 years old via external aging, thus recent reproduction from a source population is likely. Location of the source population remains unknown. Sporadic records from 9 HUC8s in Illinois mean that scaleshell have declined at least 88% from their historic range. Scaleshell have a burrowing nature that makes them difficult to find and are primarily found in large rivers. Scaleshell were not collected during T-53, and we recommend more thorough sampling of large rivers to fully assess current threats or population levels.

Scaleshell have declined throughout their range and most remaining populations are tenuous or in need of more data (NatureServe, 2014). Reasons for decline include channel alteration, sedimentation, hydrologic disturbance, degraded water quality, and genetic isolations, all of which are future threats. We ranked stresses in Appendix II accordingly. Freshwater Drum have been confirmed as a host for scaleshell (Barnhart et al., 1998; Section 3: Table 3), which are common throughout the Illinois River, thus we believe host availability has little to no effect on the population viability.

## Black sandshell (*Ligumia recta*)

**Specific habitat:** Medium to large rivers in riffles or raceways in gravel or firm sand (Cummings and Mayer, 1992).

**2005 status:** State Threatened (ESPB, 2014)

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:** None

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 1 |
| 2015 | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 3 |

**Rationale:** Although black sandshell historically occurred in 32 drainages (HUC8), since 1977-1999 it remained stable and increased in range by approximately 36% (15 HUC8s from 11 HUC8s). We believe this change is due to an increased sampling effort during T-53 in tributaries to large rivers, which revealed more live and extant records for this species. We believe populations are stable and increasing in smaller streams and larger rivers such as the Rock River.

In Appendix II, we downgraded hydrology, pollutants-sediment, hosts, recruitment, mortality, killing, and disturbance to having little or no threat on population viability or abundance. Black sandshell is a host generalist, utilizing common species such as Bluegill, Largemouth Bass, Crappie, Walleye, and Sauger (Section 3: Table 3). A few of these sportfish species are readily stocked in the state. Hence, this gives us a moderate to high confidence that host fish are not a limiting factor in black sandshell population viability or abundance. Of special note, the zebra mussel within the Rock River system historically has not been present, but a few individuals have been collected within the last several years. Monitoring zebra mussel infestation in the Rock River system should be an important future consideration.

We upgraded fragmentation, dispersal, and structures-infrastructures to having moderate or severe threats to population viability or abundance. Several dams are present throughout the Rock River system and elsewhere in the black sandshell's range. Dispersal (via host fish) and fragmentation should still be of concern. To increase population viability and repopulate some of its historical range, access (via fish passage for instance) is necessary for migratory host fishes.

## Spectaclecase (*Margaritifera monodonta*)

**Specific habitat:** In medium to large rivers in mud, sand gravel, cobble, and boulders in relatively shallow riffles and shoals with slow to swift current; found in tree stumps and in beds of rooted vegetation; may aggregate under slab boulders or bedrock shelves (Buchanan, 1980; Oesch, 1995; Parmalee and Bogan, 1998; Baird, 2000).

**2005 status:** Federally Endangered, State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
11- Species is representative of a broad array of other species found in particular habitat
12 - Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 3 | 2 | 2 | 2 | 1 |
| 2015 | 1 | 3 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 2 | 2 | 1 |

**Rationale:** Since 2000, spectaclecase has been found extant in only a few locations within the Mississippi River bordering Illinois (1 HUC8 of 6 HUC8s historically). It is considered extirpated from Indiana and Kansas, and limited extant populations are known in Missouri and the upper Mississippi River near St. Croix, Wisconsin.

In Appendix II, we upgraded fragmentation, disturbance/hydrology, and dispersal as having a moderate to severe effect on population viability or abundance. Spectaclecase populations are becoming increasingly isolated and disjunct often leading to local, extirpated populations thereby becoming more vulnerable and susceptible to habitat, community and population stresses. Even with many host trials on a multitude of fish species, there remains no known host for spectaclecase (Section 3: Table 3). This lack of information limits resource managers in decision-making to best augment spectaclecase's dwindling populations. Continued research into the life history of spectaclecase is vital to effectively manage their current populations.

Bankclimber (*Plectomerus dombeyanus*)

**Specific habitat:** Medium to large rivers, oxbow lakes, and lowland ditches with slow to moderate current in clay, mud, sand or rocky substrates (Oesch, 1984, Williams et al., 2008).

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

4 - Species exists at limited sites
12- Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 |

**Rationale:** In 2012, bankclimber was recently discovered in the Ohio River bordering Illinois (Tiemann et al., 2013). It occurs within Gulf Coast drainages of Alabama's Mobile Basin to eastern Texas' San Jacinto River and then northwardly in the Mississippi River to the mouth of the Ohio River (Oesch, 1995, Howells et al., 1996, Williams et al., 2008). It appears to be expanding its range with documented occurrences in the lower Tennessee River in Kentucky and Tennessee (Parmalee and Bogan, 1998).

Host fish for bankclimber remain unknown.

We recommend upgrading to Species in Greatest Need of Conservation because key components of the species' biology and distribution are poorly understood.

## Orangefoot pimpleback (*Plethobasus cooperianus*)

**Specific habitat:** Medium to large rivers in sand, gravel, and cobble in riffles and shoals, in deep water and steady currents as well as shoals and riffles (Bogan and Parmalee, 1983; USFWS, 1984; Gordon and Layzer, 1989; Cummings and Mayer, 1992).

**2005 status:** Federally Endangered, State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 3 | 2 | 2 | 3 | 1 |
| 2015 | 1 | 2 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 1 | 1 | 3 |

**Rationale:** Orangefoot pimpleback are known from the Ohio River, with records dating pre-1950 and the latest extant record in Illinois in1994 (INHS Mollusk Collection). It is considered extirpated in much of its range including Indiana, Ohio, and Pennsylvania. Cummings and Mayer (1995) reported, “though considered rare, live individuals have been regularly documented in the Ohio River in the vicinity of Metropolis, Illinois.”

In Appendix II, we upgraded genetics, dispersal, and structures-infrastructures as having a moderate to severe threat to population viability or abundance. Due to the isolated populations, dispersal and gene flow are especially vulnerable. There are no known host fish for *P. cooperianus* although other *Plethobasus* species (*P. cyphyus*) utilize small-bodied cyprinids for main hosts (Section 3: Table 3). Large structures such as dams could deter viable population dispersal via host fish. Although this species may have been commercially harvested at one time, direct human threats such as harvesting are no longer occurring for this particular species in Illinois; therefore, we downgraded human killing and disturbance as having little or no threat to population viability or abundance.

## Sheepnose (*Plethobasus cyphyus*)

**Specific Habitat:** Medium to large rivers; often associated with riffles and gravel or cobble substrates in depths greater than two meters in slight to swift currents; sand, mud or gravel bottoms (Gordon and Layzer, 1989; Parmalee and Bogan, 1998).

**2005 status:** Federal Candidate, State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
9 - The Illinois population of this species is disjunct from the rest of the species' range
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 2 | 1 | 2 | 1 | 3 | 2 | 2 | 2 | 1 |
| 2015 | 3 | 3 | 2 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 3 | 3 | 1 | 1 | 2 | 2 |

**Rationale:** The current extant range for sheepnose has declined 50% from 1977-1999 (3 versus 6 HUC8s) and 81% historically (16 HUC8s). The Kankakee River supports the most extant records, with others in the Rock and Mississippi Rivers. Sheepnose have declined throughout their range and now may be below the critical level to persist (NatureServe, 2014). Population declines are likely due to a combination of factors, including impacts from dams, dredging, pollution, and commercial harvest. The availability of cobble riffles with adequate water depth is likely a limiting factor, as well as connectivity between individuals and populations for reproduction and dispersal.

In Appendix II, we ranked habitat extent, fragmentation, hydrologic disturbance, dispersal, and recruitment as likely to have a severe effect on population viability, and habitat composition, invasive species, and structures (e.g., dams) are likely to have a moderate effect on population viability. Recent host trials demonstrated that sheepnose may use many minnow species as hosts (Section 3: Table 3), several of which are common throughout Illinois, thus we do not believe that hosts are a limiting factor for sheepnose.

## Clubshell (*Pleurobema clava*)

**Specific habitat:** Medium to large rivers in gravel, mixed gravel and sand, clean, coarse sand and cobble in current; often buries several inches in depth (Cummings and Mayer, 1992; Watters et al., 2009).

**2005 status:** Federally Endangered, State Endangered

**2015 status:** Federally Endangered, State Endangered, Reintroduced

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
9 - The Illinois population of this species is disjunct from the rest of the species' range
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 3 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 3 | 3 | 2 | 1 | 2 | 3 |

**Rationale:** Pre-1950, clubshell was found in 5 drainages (HUC8) and then sharply declined to being extant in one HUC8, the Vermilion River (Wabash River) drainage. Within the Vermilion River basin, extant shell records from the last decade exist only from the Middle Branch North Fork Vermilion River.

In Appendix II, we upgraded fragmentation, composition-structure, genetics, dispersal, and structures-infrastructures to moderate or severe threats to population viability or abundance. Several low head dams exists within the Vermilion River system, causing population fragmentation, low dispersal and genetic depression that has severely impacted the clubshell population within the Vermilion River system, especially since host fish mainly include small-bodied cyprinids (Section 3: Table 3).

Efforts to repopulate clubshell into the Middle Fork Vermilion and Salt Fork Vermilion River were undertaken in 2011-2014 since no live clubshell has been observed in decades. Population monitoring is on-going, and the majority of translocated adults are surviving as of 2014.

## Ohio pigtoe (*Pleurobema cordatum*)

**Specific habitat:** Medium to large rivers in sand or gravel in areas of moderate flow; favors areas with strong current in firm sand and gravel substrates (Cummings and Mayer, 1992; Parmalee and Bogan, 1998).

**2005 status:** State Endangered

**2015 status:** State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
9 - The Illinois population of this species is disjunct from the rest of the species' range

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 |
| 2015 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 |

**Rationale:** The Ohio pigtoe was historically present in 5 drainages (HUC8); but currently persists only in the Ohio River (1 HUC8). It is a species of concern in Indiana but not state-listed in Kentucky. Further studies for Ohio pigtoe populations within the Ohio River bordering Illinois should be considered to gain a better understanding as to whether this species is persisting and reproducing. Identifying whether their populations are stable can assist in downgrading state status and, ultimately, delisting this species.

In Appendix II, we downgraded hosts, mortality and human stresses such as killing and disturbance to having little or no known effect on population viability or abundance. Host fish studies within the last decade identified a couple small-bodied cyprinids as (potential) main host, however further host and life history studies are warranted for this mussel species. Continued habitat stresses, dam structures, and minimal migration of small-bodied host fishes can become limiting factors in successful dispersal and recruitment opportunities for fragmented populations throughout the Ohio River; therefore, we upgraded genetics, dispersal, recruitment, and structure-infrastructure to having a moderate or severe effect on population viability or abundance.

## Fat pocketbook (*Potamilus capax*)

**Specific Habitat:** Medium to large rivers, in sand, mud, and fine gravel substrates and flowing water (USFWS, 1989), or in slow-flowing water (often near the bank) in mud or sand (Cummings et al., 1990). Recently found to be tolerant of depositional areas that are usually unfavorable to other mussels (USFWS, 1989), such as man-made ditches and bayous, sloughs, and streams (Miller and Payne, 2005).

**2005 status:** Federally Endangered, State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 1 |
| 2015 | 1 | 3 | 1 | 3 | 2 | 3 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 1 |

**Rationale:** Fat pocketbooks have declined 54% from their historic range (5 HUC8s versus 11 HUC8s). In Illinois, the only remaining extant populations are in the Wabash and Ohio Rivers and a few tributaries. Fat pocketbooks are common in the lower Wabash and Ohio, but densities are low. Large river habitats are difficult to sample, thus survey data represent a small proportion of the existing community.

In Appendix II, we ranked fragmentation and hydrologic disturbance as severe threats to population viability, because the Wabash and Ohio Rivers have increasing amounts of sedimentation and have major hydrologic disturbances. Freshwater Drum have been confirmed as a host for fat pocketbook (Section 3: Table 3), which are common throughout their range, thus we believe host availability has little to no effect on the population viability of fat pocketbook.

Bleufer (*Potamilus purpuratus*)

**Specific Habitat:** Large rivers in mud or mixed mud and gravel in areas of backwater or slow flow (Cummings and Mayer, 1992; Parmalee and Bogan, 1998).

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

4 - Species exists at limited sites
12 - Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 2 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |

**Rationale:** Bleufer are at the edge of their northern range in Illinois and are sporadic in the state. The historic range of bleufer is 5 HUC8s and current extant records are in 4 HUC8s, two of which are new records for the state. The current range of this species is unknown, thus we believe more data regarding this species' distribution is warranted. Additionally, bleufer resemble pink heelsplitter (*P. alatus*), thus genetic testing of nearby populations of pink heelsplitter may elucidate distributions. Bleufer's preferred habitats (e.g., slow flow in mud or gravel) are not limited in Illinois, thus we believe populations are likely to increase. Low gradient, backwater areas were not sampled extensively in T-53 or historically, thus this species may be more widespread than current data suggest.

In Appendix II, we estimated threats to the bleufer relative to threats to similar low gradient stream mussels, given our limited knowledge of bleufer's preferred habitat. Hosts are assumed to be Warmouth and Golden Shiner, and, potentially, Freshwater Drum (as with other *Potamilus* spp.) although there are no host trial confirmations (Howells, 1995; Section 3: Table 3). All are common species in the current range of bleufer in Illinois. We recommend upgrading to Species in Greatest Need of Conservation because key components of the species' biology and distribution are poorly understood.

## Kidneyshell (*Ptychobranchus fasciolaris*)

**Specific habitat:** Medium to large rivers in gravel (Cummings and Mayer, 1992). Appears tolerant to a variety of habitats with the most suitable including moderately strong current and coarse gravel and sand substrates (Parmalee and Bogan, 1998).

**2005 status:** State Endangered

**2015 status:** State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
9 - The Illinois population of this species is disjunct from the rest of the species' range
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 3 | 3 | 2 | 1 | 2 | 2 |

**Rationale:** Kidneyshell have declined 71% from their historic range (7 HUC8s versus 2 HUC8s). They currently exist in the Vermilion (Wabash River drainage) and Embarras river drainages. Survey efforts during T-53 only revealed dead shell in the Vermilion drainage, but populations within the Embarras River system appear to be persistent.

In Appendix II, we upgraded fragmentation, dispersal, and structures-infrastructure as having a moderate or severe threat to population viability or abundance. Kidneyshell primarily utilize darters as hosts (*Etheostoma* spp. and *Percina* spp., similar to other *Ptychobranchus* species; Haag and Warren 2007; Section 3: Table 3). Due to the specialized mussel-host relationship, we believe factors that negatively impact host fish (e.g., sedimentation, hydrologic disturbance, other habitat loss) are a moderate threat to kidneyshell population viability or abundance. Further, kidneyshell may be too far below the population threshold in the Vermilion River (Wabash River) drainage to successfully recolonize its former range within this basin. Conservation of remaining stocks is critical, and this species may be a candidate for future restoration efforts.

## Gulf mapleleaf (*Quadrula nobilis*)

**Specific habitat:** Large rivers in swift to sluggish water in mud to sand or gravel substrates (Williams et al., 2008).

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
12- Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 3 |

**Rationale:** Gulf mapleleaf occurs within the Gulf Coast drainages of Alabama's Mobile Basin to eastern Texas' San Jacinto River and then northwardly in the Mississippi River to the Ohio River in northwestern Kentucky (Howells et al., 1996, Serb et al., 2003). Historical records indicate the Gulf mapleleaf occurred in 3 drainages in Illinois. Since 2000, extant records exist for 2 drainages—a live occurrence in the Ohio River bordering Illinois and, additionally, a population discovered in the Saline River (Ohio River drainage) in 2005. Southern Illinois appears to be the northernmost edge of its extant range.

Gulf mapleleaf utilize ictalurids as host fish with observed transformation success on Channel Catfish (*Ictalurus punctatus*) and Flathead Catfish (*Pylodictis olivaris*) (Section 3: Table 3). Hosts are stable and common throughout Illinois, thus we do not believe they are a limiting factor to Gulf mapleleaf's population persistence.

Gulf mapleleaf are morphologically similar to mapleleaf (*Q. quadrula*) and often cannot be distinguished without genetic analysis. Future research or analysis of genetic material is necessary to grasp the current distribution of this species in Illinois. We recommend upgrading to Species in Greatest Need of Conservation because taxonomic placement and distribution are poorly understood.

## Salamander mussel (*Simpsonaias ambigua*)

**Specific Habitat:** Found where its host, *Necturus maculosus* exists, in areas of silt or sand within medium to large rivers or lakes, often under large flat stones (Cummings and Mayer, 1992; Watters, 1995).

**2005 status:** State Endangered

**Proposed 2015 status:** State Endangered, consider as a Federal candidate

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 2 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 1 |
| 2015 | 2 | 2 | 3 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 3 | 2 | 1 | 1 | 2 | 1 |

**Rationale:** The salamander mussel is currently found in 1 HUC8, a 91% decline from historic levels (12 HUC8s) and a 50% decline from 1977-1999 (2 HUC8s). Salamander mussel records are sporadic throughout the state, and requires habitat specific to the host, mudpuppy (Section 3: Table 3). Both host and mussel are cryptic and difficult to locate via normal methods (e.g., electrofishing and tactile surveys), because animals are often in currents under large slab rocks. We recommend more thorough, targeted samples for salamander mussels in areas with historic records and suitable habitats.

No live salamander mussels have been collected in Illinois, although fresh shell vouchers from 2000-2014 have been collected. If populations do exist, they are likely low abundance and density and at risk of extirpation. We believe salamander mussels should be considered for federal listing status, as habitat extent, fragmentation, composition, hydrologic disturbance, sedimentation, host availability, genetic stresses, dispersal, recruitment and human disturbance are moderate or severe risks to population viability.

## Rabbitsfoot (*Theliderma cylindrica*)

**Specific habitat:** Medium to large rivers in sand and gravel in depths up to 3 meters (Cummings and Mayer, 1992). In addition, found in small to medium rivers in gravel and cobble bars with moderate to swift current (Gordon and Layzer, 1989)**.**

**2005 status:** State Endangered

**2015 status:** Federally Threatened, State Endangered

**Changes to Criteria in Appendix I:**

1 - Illinois or federal threatened or endangered species
3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 1 | 3 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 3 | 2 | 1 | 2 | 3 |

**Rationale:** Rabbitsfoot was listed as federally threatened in October 2013. In Illinois, it is extant in two drainages, the Vermilion River (Wabash River) basin and the Ohio River. Current extant records in the Ohio River basin are extremely sparse (1 live individual), and the current extent for rabbitsfoot in the Ohio River is unknown; intensive survey effort is recommended to determine its current range and status. Threats to the Ohio River are numerous, including hydrologic disturbance, sedimentation, and invasive species. Rabbitsfoot persists within the North Fork Vermilion River system but is likely extirpated in the rest of the Vermilion River (Wabash River) basin.

In Appendix II, we upgraded fragmentation, dispersal and structures-infrastructures as having a moderate to severe threat on population viability or abundance. Re-colonization of rabbitsfoot to its historic range within the Vermilion River basin is unlikely due to host fish (small-bodied cyprinids; Section 3: Table 3) dispersal barriers in the form of a reservoir and multiple dams on the North Fork Vermilion River and Vermilion River.

## Monkeyface (*Theliderma metanevra*)

**Specific Habitat:** Medium to large rivers in gravel or mixed sand and gravel (Cummings and Mayer, 1992).

**2005 status:** Species in Greatest Need of Conservation

**Proposed 2015 status:** State Threatened

**Changes to Criteria in Appendix I:**

4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 1 |
| 2015 | 1 | 2 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 |

**Rationale:** The current extant range (15 HUC8s) has declined 31% historically (22 HUC8s). Furthermore, extant records are isolated in several drainages in Illinois and may not persist during a stochastic mortality event (e.g., drought, pollutant spill, etc.).

In Appendix II, we ranked fragmentation and dispersal as threats likely to have a moderate effect on population viability for reasons listed above. Monkeyface hosts are most recently shown to be mainly smaller bodied minnow species (Section 3: Table 3), several of which are common in Illinois (e.g., Creek Chub, *Semotilus atromaculatus*, Smith, 1979). However, because the hosts are small-bodied, they may have limited mobility, which could further hinder dispersal in fragmented habitat (e.g., due to dams).

## Purple lilliput (*Toxolasma lividum*)

**Specific Habitat:** Inhabits small to medium-sized rivers, in slow to swift currents, in mud, sand and gravel substrates or shallow, rocky gravel points and sandbars (Cummings and Berlocher, 1990; Parmalee and Bogan, 1998; Williams et al., 2008). Recent sampling in T-82 revealed most individuals in silty areas along stream edges.

**2005 status:** State Endangered

**2015 status:** State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 2 | 2 | 2 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 1 | 1 | 2 | 1 |

**Rationale:** Purple lilliputs have declined 57% from their historical range (7 HUC8s compared to 3 HUC8s), although they have remained stable since 1977-1999 (3 HUC8s). Although their range has declined, recent targeted sampling in T-82 revealed several healthy populations in two watersheds and it may be more common than previously believed. However, lilliput (*T. parvum*) are found throughout the entire range of purple lilliput and *T. parvum* are found in similar habitats and are typically locally abundant. This suggests that *T. lividum* may have a specific habitat or life history requirement that makes it vulnerable to population decline.

In Appendix II, we ranked habitat fragmentation, hydrologic disturbance, predation, and dispersal as moderate or severe threats to population viability due to the isolation of existing populations, the predation risk due to edge-preference, and the lack of mobility of host fish. Known hosts are Green and Longear Sunfish, species common throughout Illinois (Section 3: Table 3), although recent host trials have not been completed.

## Pistolgrip (*Tritogonia verrucosa*)

**Specific habitat:** Medium to large rivers in swift to sluggish water in mud, sand and/or gravel substrates (Williams et al., 2008).

**2005 status:** None

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 2 |

**Rationale:** Historically present in 38 drainages (HUC8), pistolgrip declined in range and was found in 23 HUC8s during 1977-1999. Since 2000, pistolgrip has been found in 29 drainages. We believe this change, in part, is due to an increased sampling effort during T-53, which revealed more live and extant records for this species. Although pistolgrip can be found across the state, it appears to be shrinking within its range, particularly the northern and western edges. We also see this retraction occurring in its northern and westernmost range within the continental United States, as pistolgrip is state threatened in Wisconsin and state endangered in Iowa. It is considered critically imperiled in the Dakotas and imperiled in Minnesota (NatureServe, 2014).

Primary threats to pistolgrip include hydrology disturbances, sedimentation, dispersal and recruitment efforts, and structures (i.e., dams). Pistolgrips are a host family specialist, primarily utilizing bullheads, Channel and Flathead Catfish (Section 3: Table 3). These species are common throughout Illinois, but may be unable to traverse dams or other impediments to disperse juvenile mussels. Although pistolgrip is commonly found in soft substrates along edges, it is not found in very silty areas thus increases in sedimentation is likely to have a moderate effect on population viability or abundance.

Ellipse (*Venustaconcha ellipsiformis*)

**Specific Habitat:** Found in small to medium-sized streams with swift current in clear water with sand and/or gravel. (van der Schalie and van der Schalie, 1963; Cummings and Mayer, 1992; Watters, 1995).

**2005 status:** Species in Greatest Need of Conservation

**2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 2 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 1 |
| 2015 | 2 | 2 | 3 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 |

**Rationale:** Ellipse have declined 28% from their historical range (21 HUC8s compared to 15 HUC8s in 2000-2013), although they have slightly increased in range (15%) since 1977-1999 (13 HUC8s). We believe this change is due to an increased sampling effort in smaller streams, which revealed more live and extant records for this species. Ellipse seem to prefer clear streams, and may be at risk to sedimentation and hydrologic disturbance.

In Appendix II, we ranked habitat fragmentation, composition, population dispersal and recruitment as moderate or severe threats to population viability due to ellipse's habitat specificity and isolated populations in some watersheds. Ellipse rely primarily on sculpins and darters as hosts (Section 3: Table 3), which are species sensitive to water quality degradation that also have limited long-distance mobility.

## Rayed bean (*Villosa fabalis*)

**Specific habitat:** Lakes, small to large streams in sand or gravel (Cummings and Mayer, 1992); often associated with being buried among roots of vegetation (e.g., water willow, water milfoil) in and adjacent to riffles and shoals (Ortmann, 1919).

**2005 status:** Extirpated, Federal Candidate, State Endangered

**2015 status:** Federally Endangered, State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
9 - The Illinois population of this species is disjunct from the rest of the species' range
11- Species is representative of a broad array of other species found in particular habitat
12 - Species' status is poorly known

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population Stresses | | | | Human Stresses | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2015 | 2 | 2 | 2 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 3 | 3 | 3 | 1 | 1 | 1 | 2 |

**Rationale:** Rayed bean were historically present in 2 HUC8s, the Embarras River and Vermilion River (Wabash River) basins. Rayed bean were considered extirpated in Illinois by the mid-1990s (Cummings and Mayer, 1997). The extirpation of rayed bean was likely due to limiting factors such as poor water quality, habitat loss due to siltation, loss or limited dispersal of host fish (NatureServe, 2014), and impoundment impacts from dams within the Vermilion and Embarras River systems.

A shell was vouchered in 2011 (catalogued as recently dead, or considered extant) from the North Fork Vermilion River during T-53 surveys [INHS 41377]. If populations do exist, they are low abundance and density. We believe habitat extent, fragmentation, composition, hydrologic disturbance, sedimentation, host availability, genetic stresses, dispersal, recruitment and human disturbance are moderate or severe risks to population viability. Targeted sampling in specific habitats (i.e., along vegetation patches near riffles or shoals) is required to determine whether any viable rayed bean populations remain in Illinois. Further, confirmed fish hosts for rayed bean are not present in Illinois, thus fish hosts for Illinois populations are unknown.

Rainbow (*Villosa iris*)

**Specific habitat:** Small to medium-sized streams in coarse sand or gravel (Cummings and Mayer, 1992). Occurs in riffles, along emerging vegetation edges and in gravel and sand in moderate to strong current (Parmalee and Bogan, 1998).

**2005 status:** State Endangered

**2015 status:** State Endangered

**Changes to Criteria in Appendix I:**

3 - Species has low population numbers
4 - Species exists at limited sites
5 - Species has declined in abundance since 2000
6 - Species has declined in range since 2000
7 - Species is dependent upon rare or vulnerable habitat
9 - The Illinois population of this species is disjunct from the rest of the species' range
11- Species is representative of a broad array of other species found in particular habitat

**Changes and additions to Appendix II:**

| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 3 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 3 | 2 | 2 | 1 | 1 | 3 |

**Rationale:** Historically, rainbow was present in 15 drainages (HUC8); it is currently extant only in the Vermilion River (Wabash River) drainage. This population is isolated from the nearest populations in Wisconsin (state endangered) and Indiana (unlisted).

In Appendix II, we upgraded fragmentation, prey/food, genetics, dispersal and structures-infrastructure to having moderate or severe effects on population viability or abundance. On-going threats to dispersal and gene flow include hydrologic disturbance and structures, as several low head dams and a reservoir separate the North Fork Vermilion populations from the remaining populations. This species is frequently observed buried or partially buried along edges and near or within riffles. Predation may be a threat due to rainbow's small, thin shell, although not much is known regarding mussel predation. Rainbow is a host generalist, using centrarchids, percids, small-bodied cyprinids, *Gambusia,* and a cottid species (Section 3: Table 3). These fish are relatively common in Illinois yet have limited dispersal ability.

Little spectaclecase (*Villosa lienosa*)

**Specific habitat:** Small creeks to medium-sized rivers usually along the banks in slower currents; prefers sand or mud substrates particularly when rich in detritus (Clench and Turner, 1956; Heard, 1979).

**2005 status:** State Threatened (ESPB, 2014)

**Proposed 2015 status:** Species in Greatest Need of Conservation

**Changes to Criteria in Appendix I:**

Removal of Rare (low population) designation

**Changes and additions to Appendix II:**

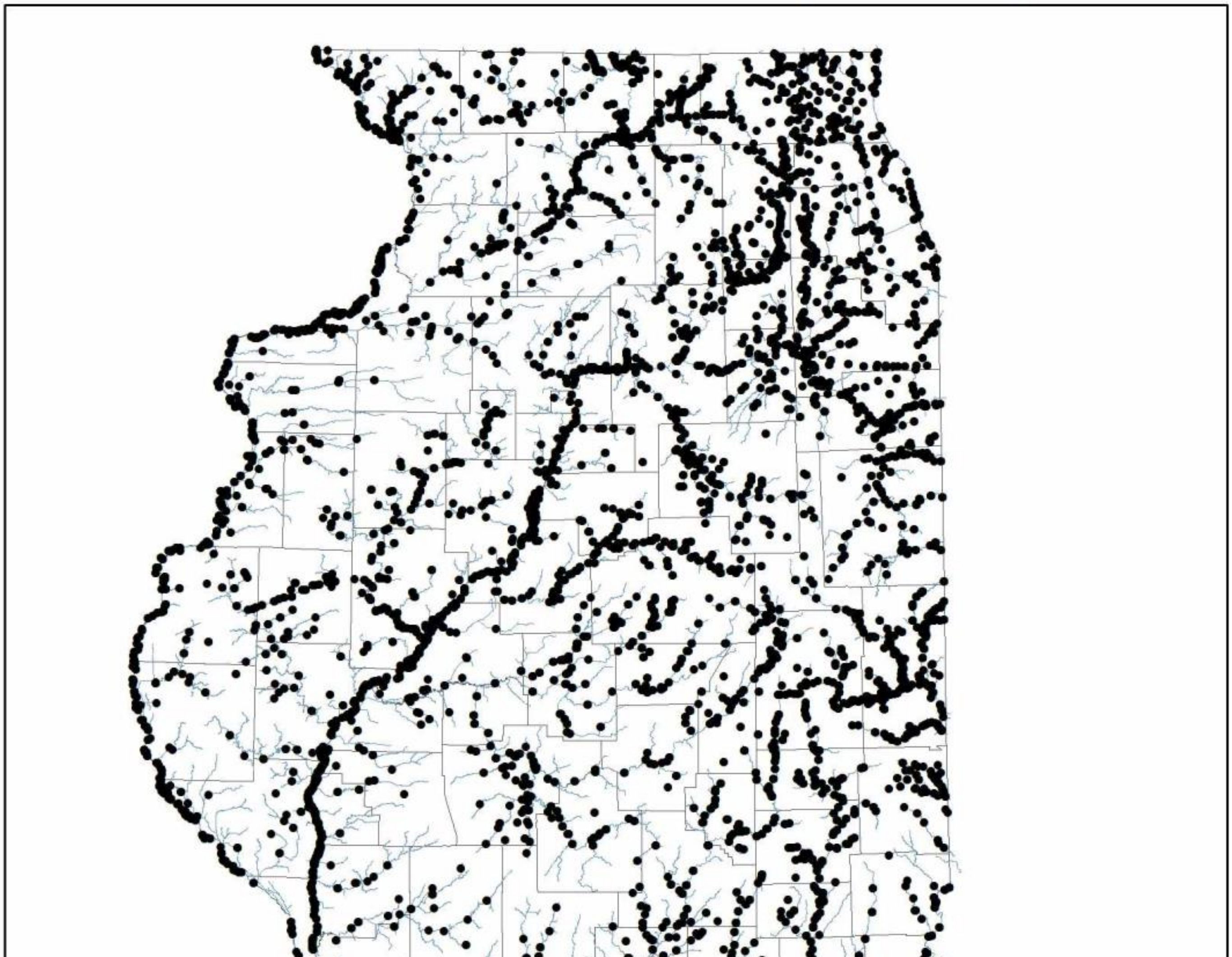
| | Habitat Stresses | | | | | | Community Stresses | | | | | | | Population | | | | Human | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Extent | Fragmentation | Composition-structure | Disturbance/Hydrology | Invasives/Exotics | Pollutants-Sediment | Competitors | Predators | Parasites/Disease | Prey/Food | Hosts | Invasive/Exotics | Other Symbionts | Genetics | Dispersal | Recruitment | Mortality | Killing | Disturbance | Structures/Infrastructure |
| 2005 | 1 | 1 | 1 | 2 | 1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |
| 2015 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 1 |

**Rationale:** Little spectaclecase was historically present in 10 drainages (HUC8) and decreased in range by 50% (5 HUC8s) by 1977-1999. Since 2000, little spectaclecase occurrence has increased by 40% (7 HUC8s). In addition, during T-53 and T-82 surveys we encountered extant populations in southern Illinois (for further information see Shasteen et al., in press). The increased sampling effort has revealed more extant locations; therefore, it appears that little spectaclecase is more common than earlier assumed. Illinois is at the northern limit of the species' range and it is currently described as stable throughout its range (Williams et al., 1993).

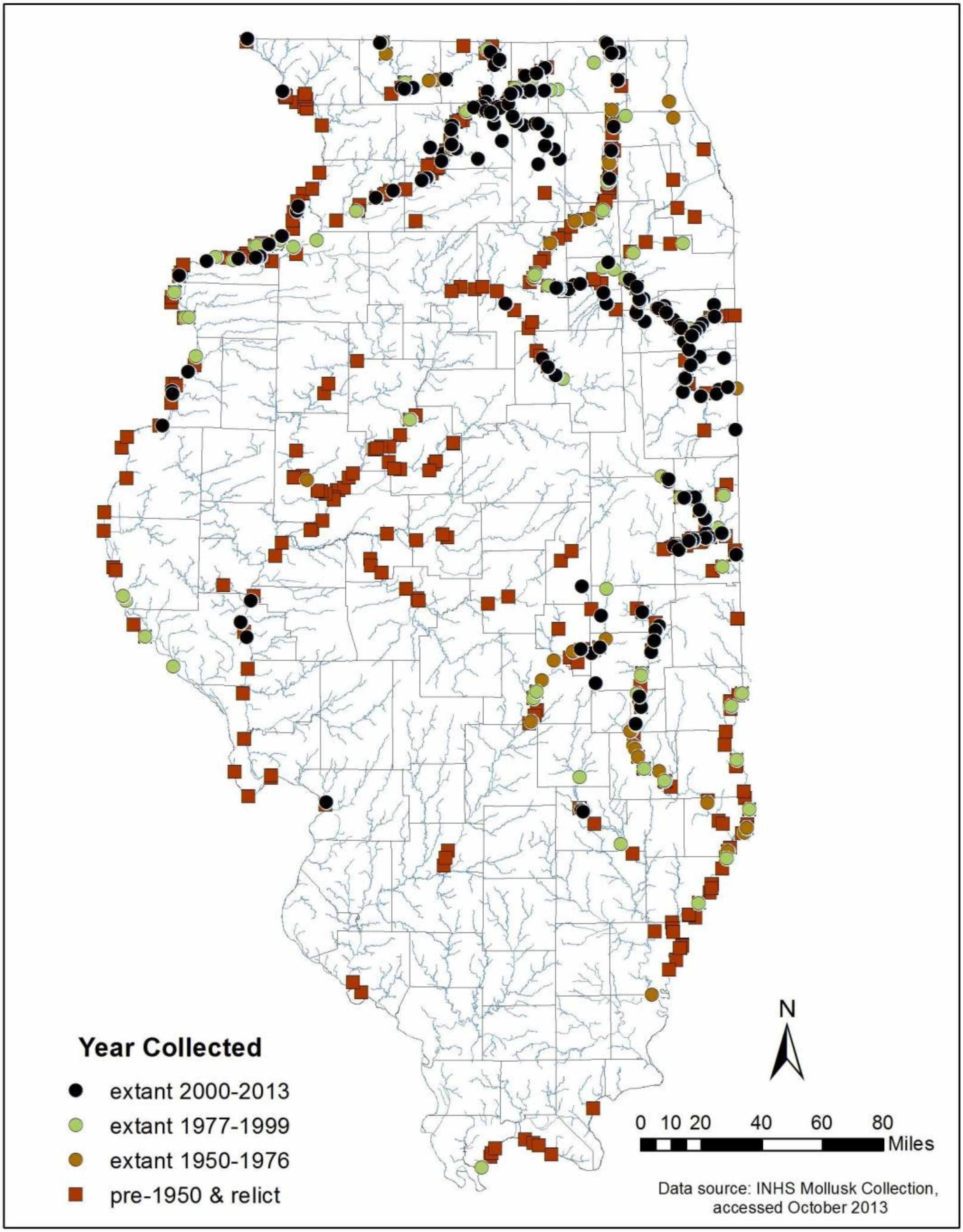
In Appendix II, we downgraded pollutants-sediment and hosts to having a moderate and little or no threat to population viability or abundance. Recent host fish trials confirm common centrarchids as primary host fish for little spectaclecase (Section 3: Table 3) thus increasing our confidence level that host fish are not a limiting factor in little spectaclecase population viability or abundance.

Little spectaclecase readily persist in soft substrates such as mud and silt/sand mixtures hence, downgrading pollutants-sediments to having a moderate effect on population viability or abundance.

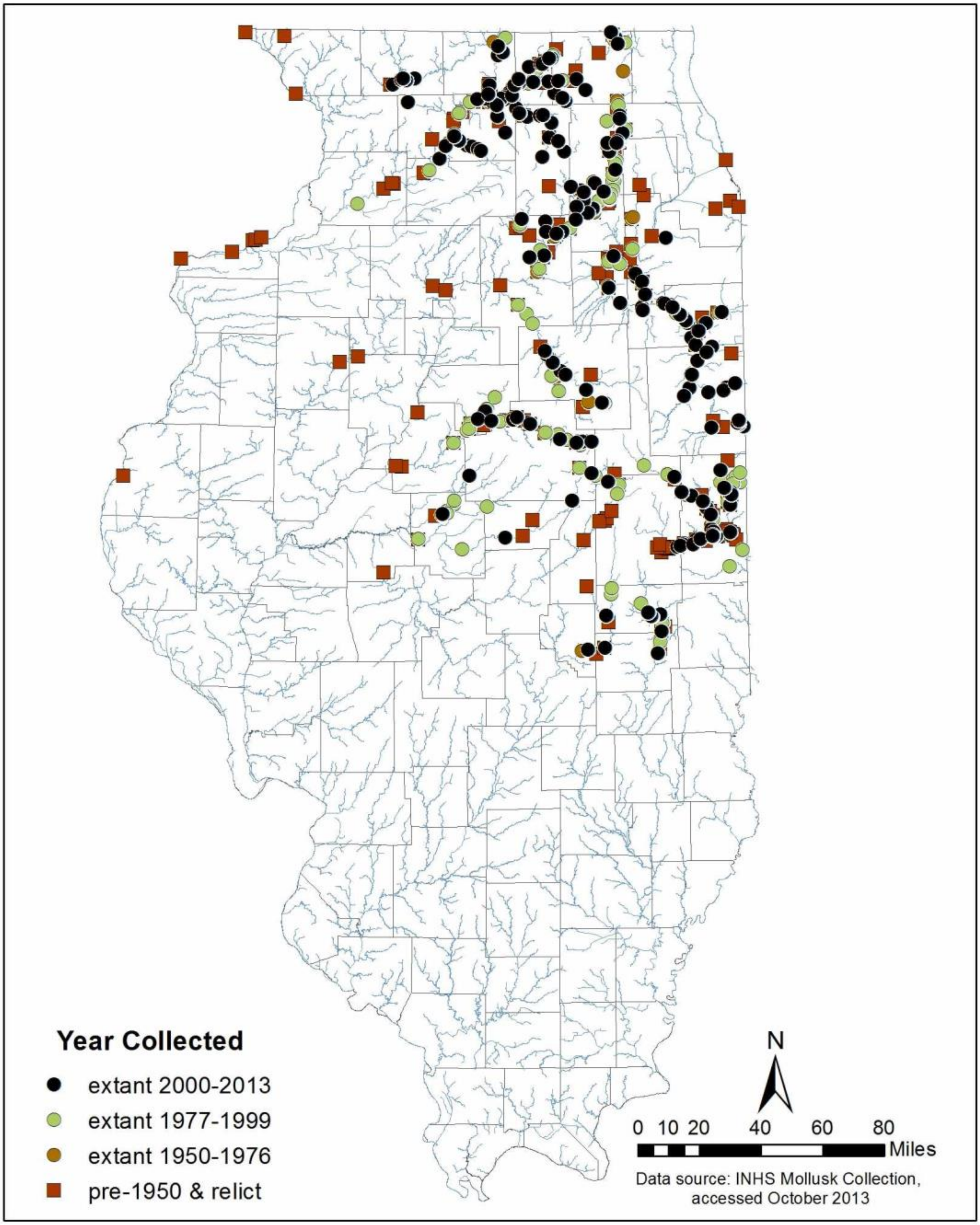
Mollusk collections in Illinois (1861-2013)



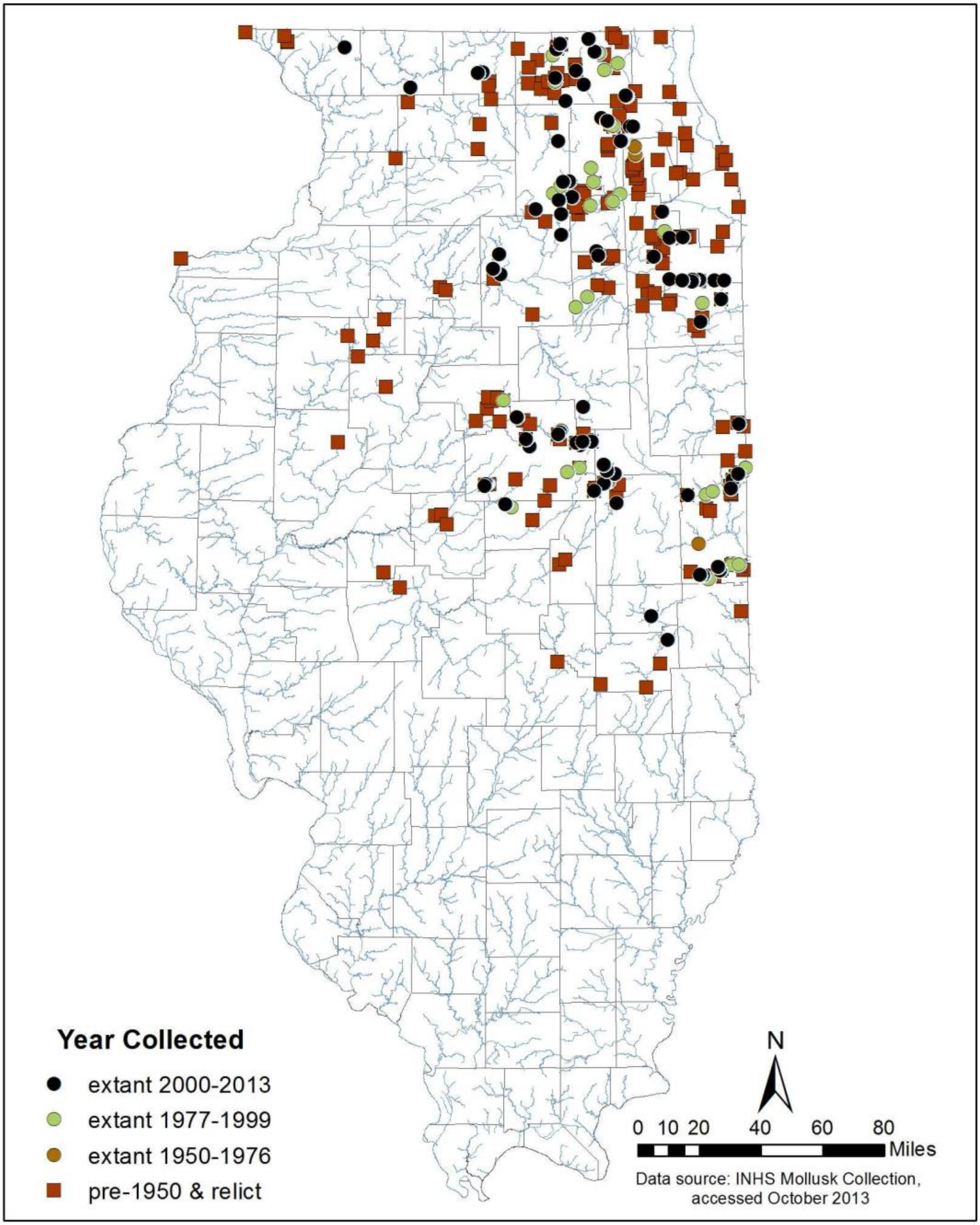
## Mucket (*Actinonaias ligamentina*)



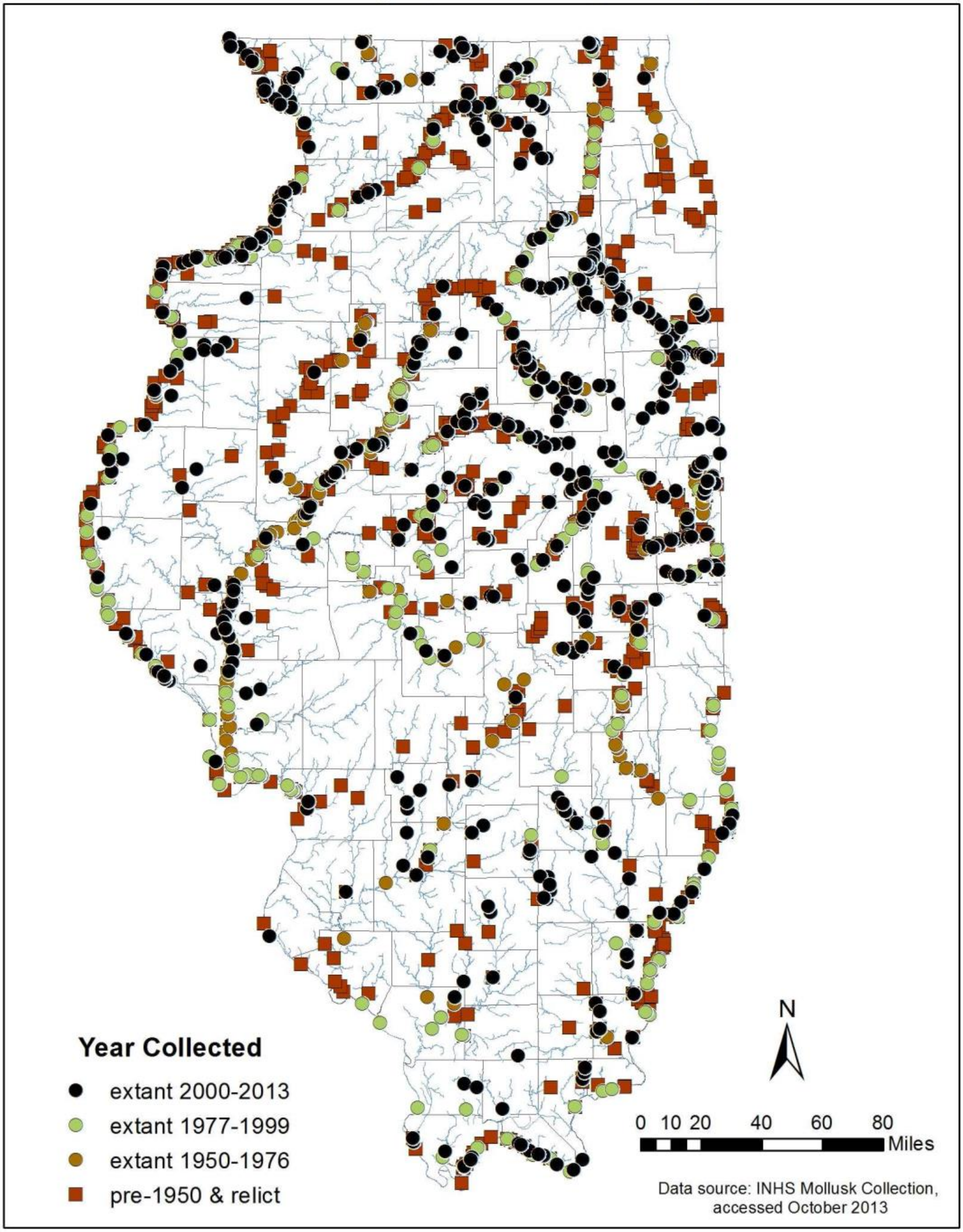
# Elktoe (*Alasmidonta marginata*)



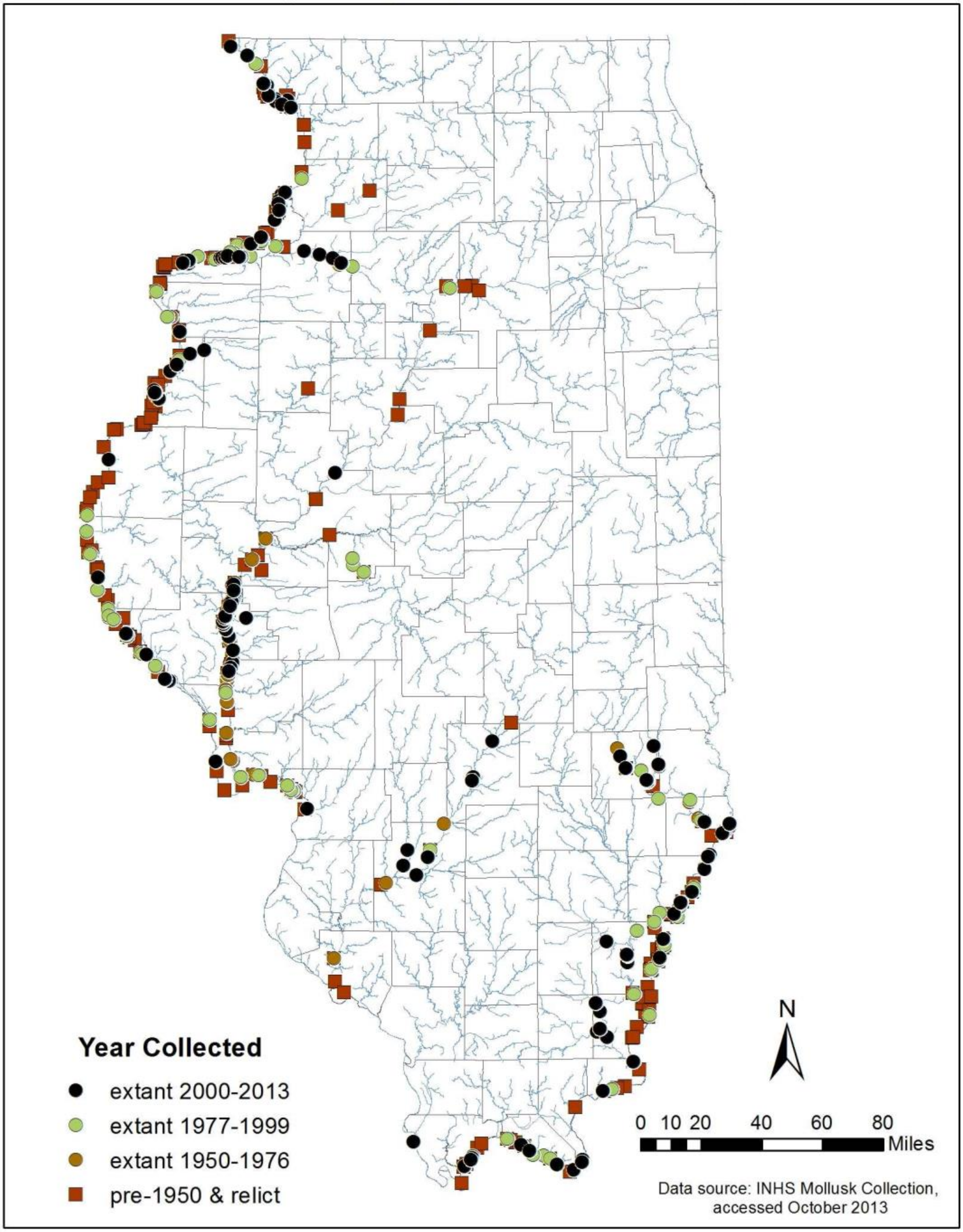
# Slippershell mussel (*Alasmidonta viridis*)



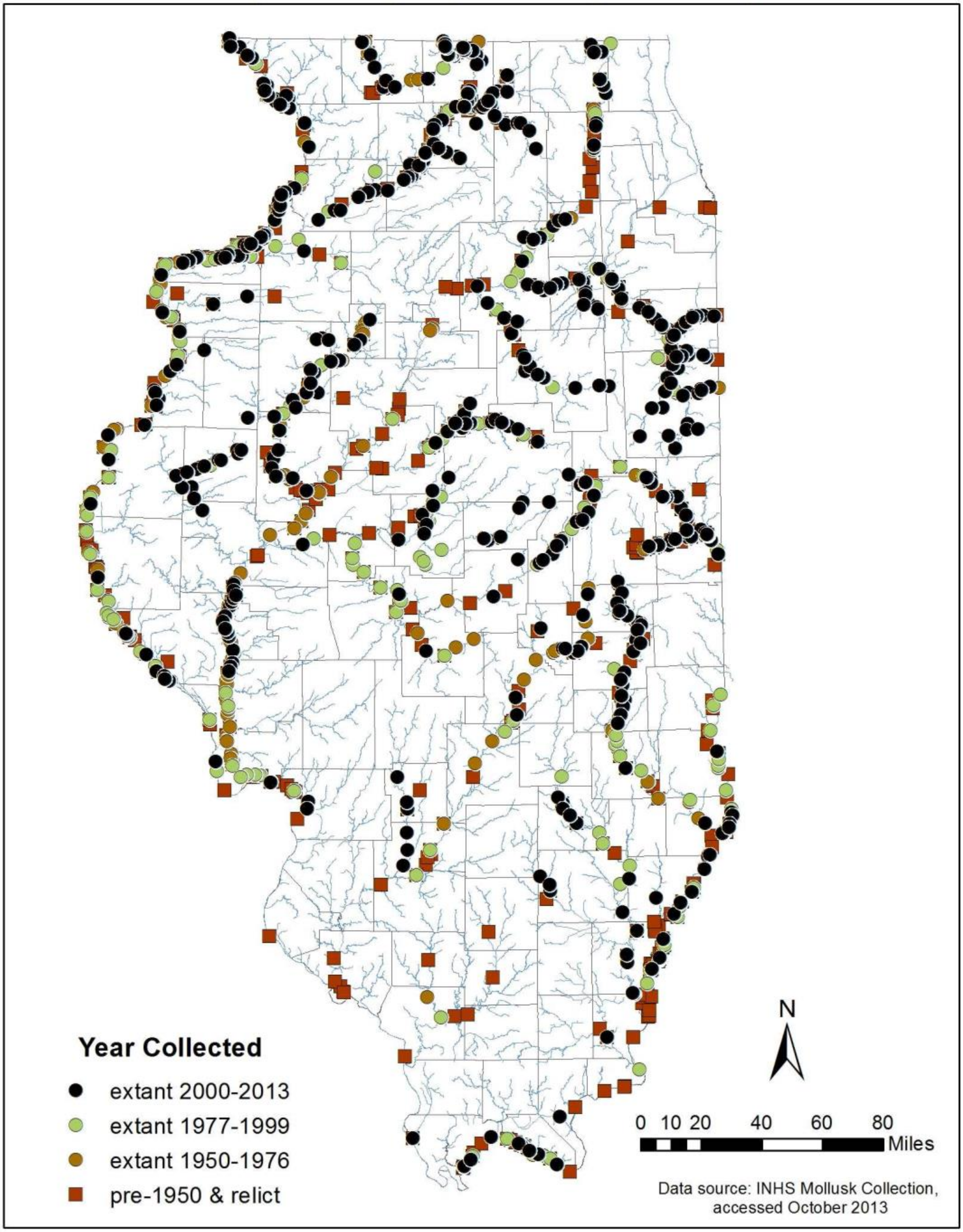
# Threeridge (*Amblema plicata*)



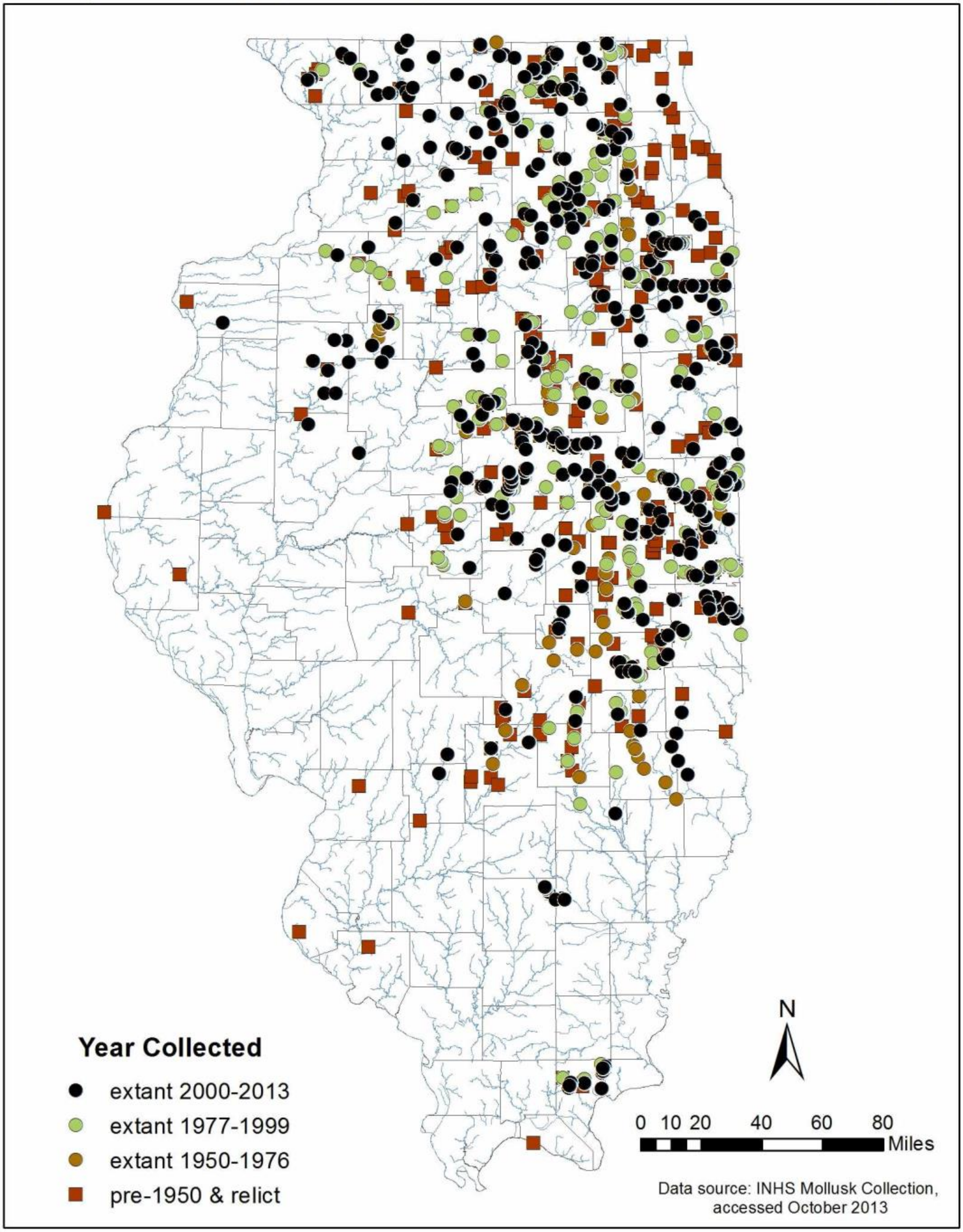
## Wartyback (*Amphinaias nodulata*)



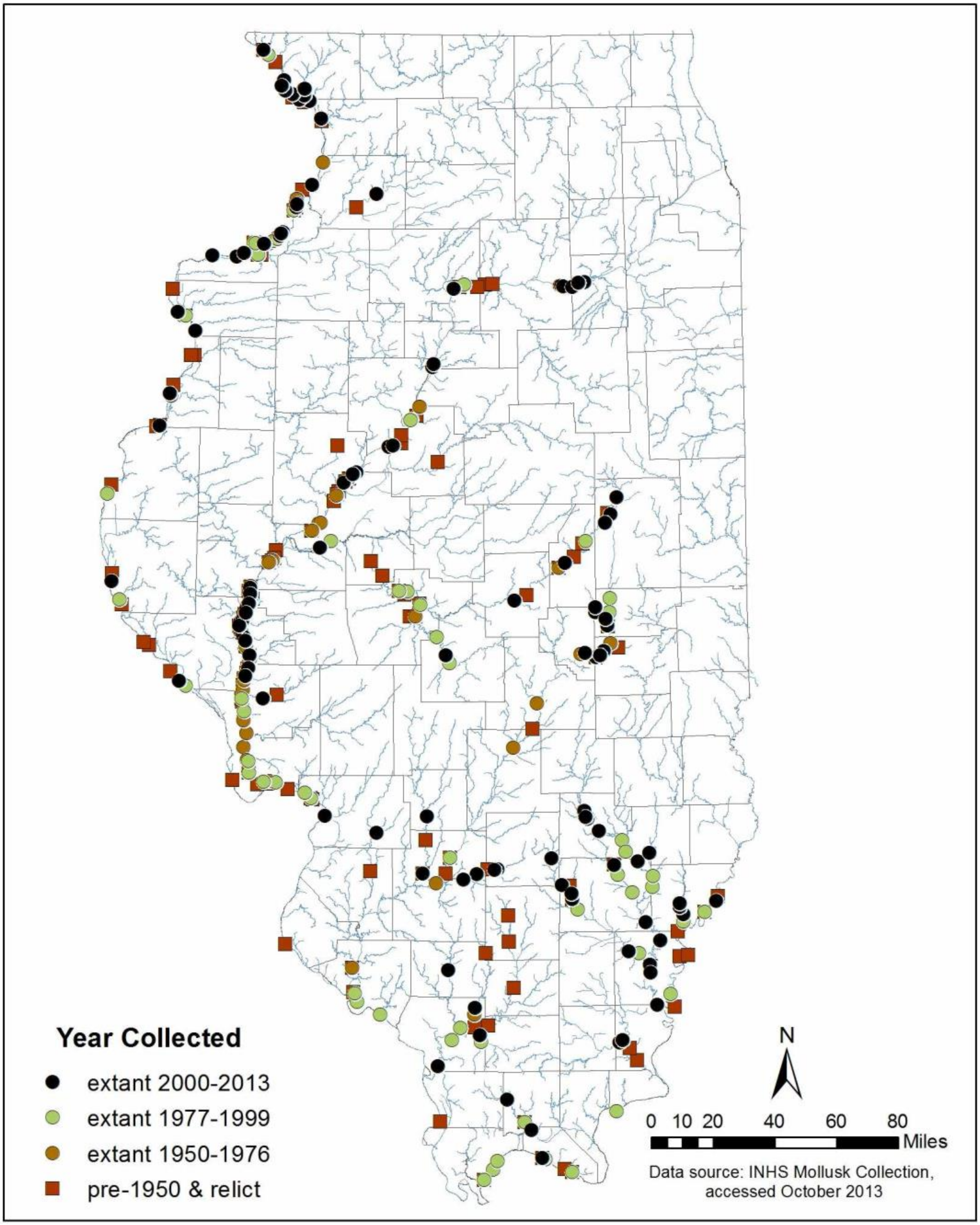
## Pimpleback (*Amphinaias pustulosa*)



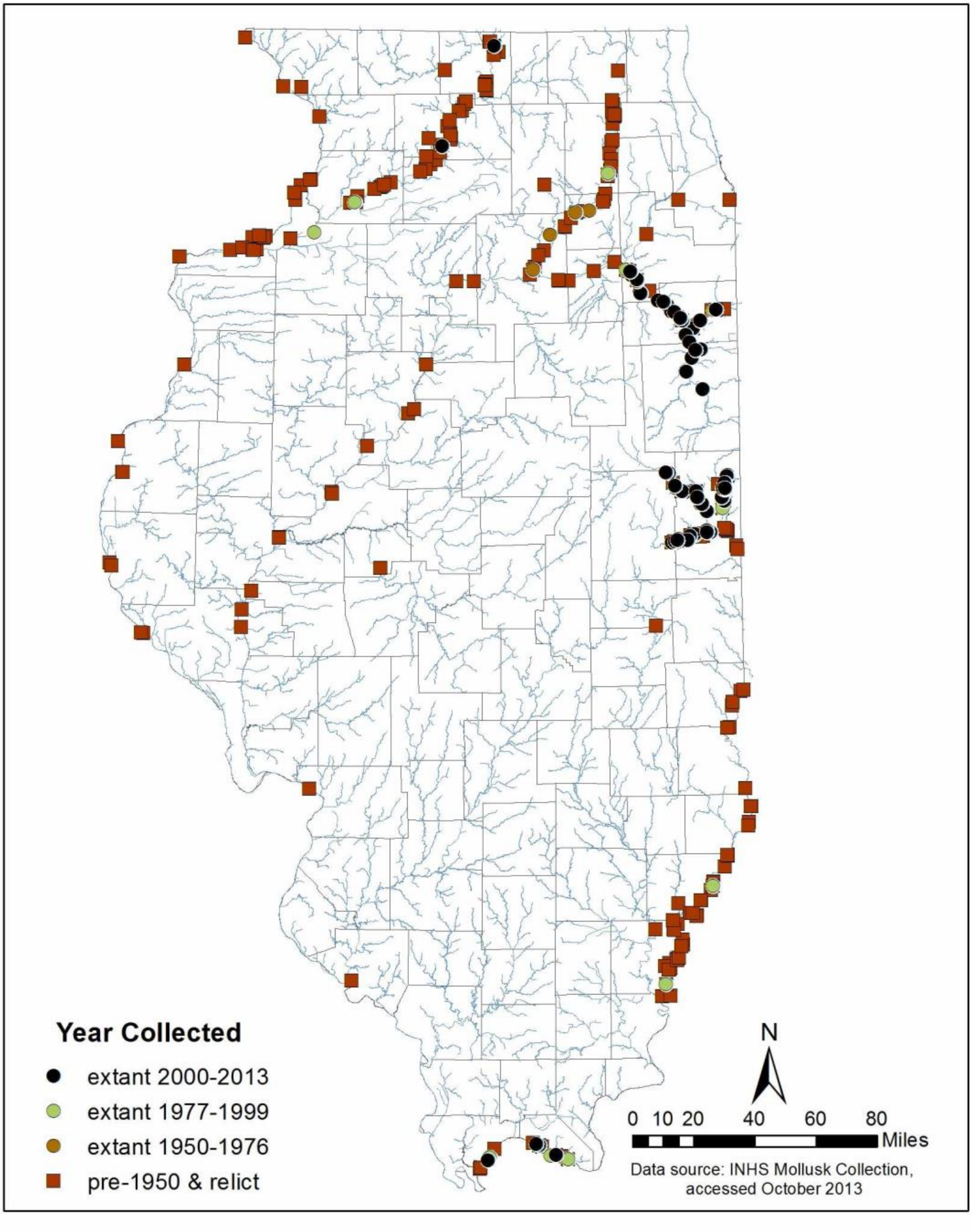
# Cylindrical papershell (*Anodontoides ferussacianus*)



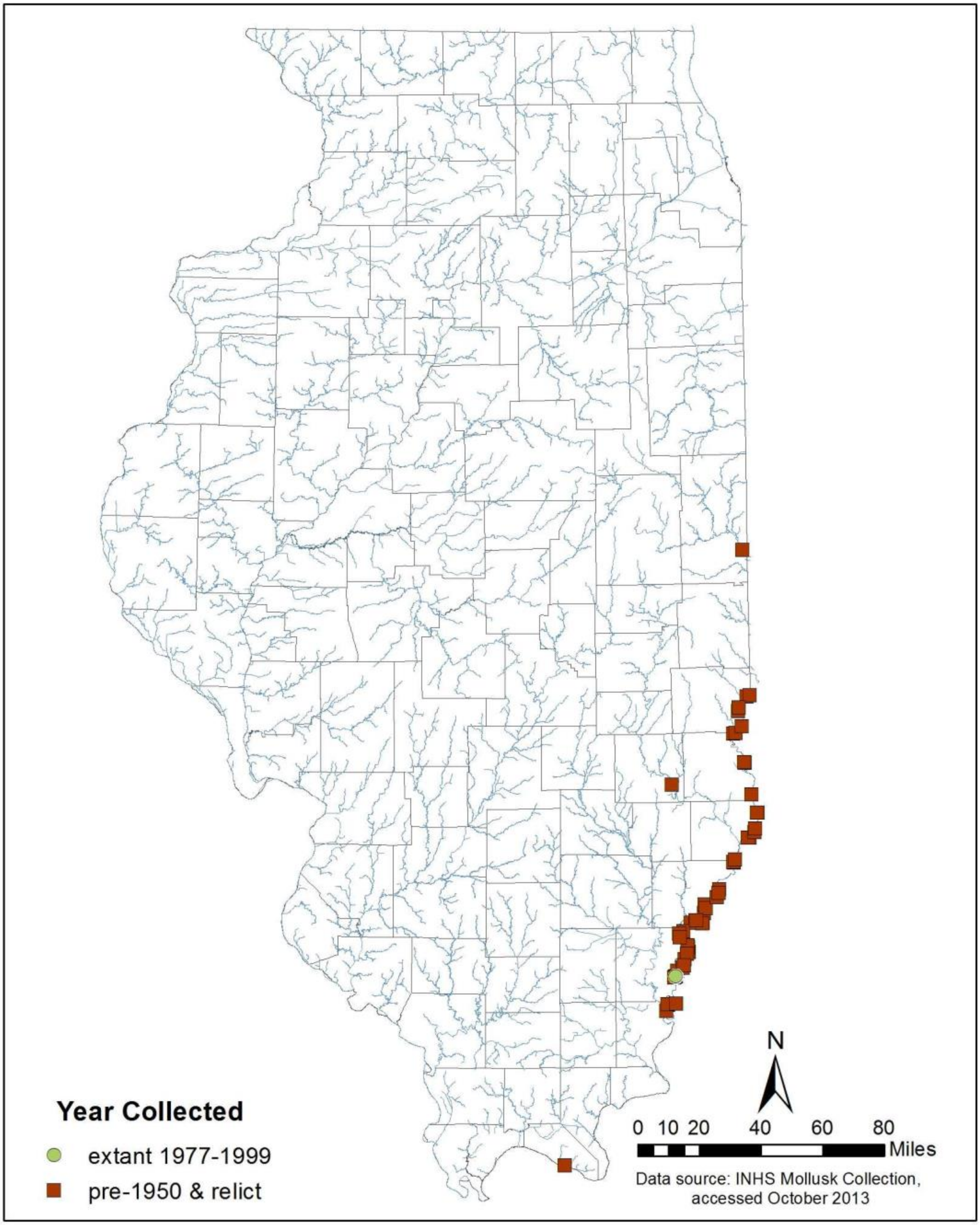
# Rock pocketbook (*Arcidens confragosus*)

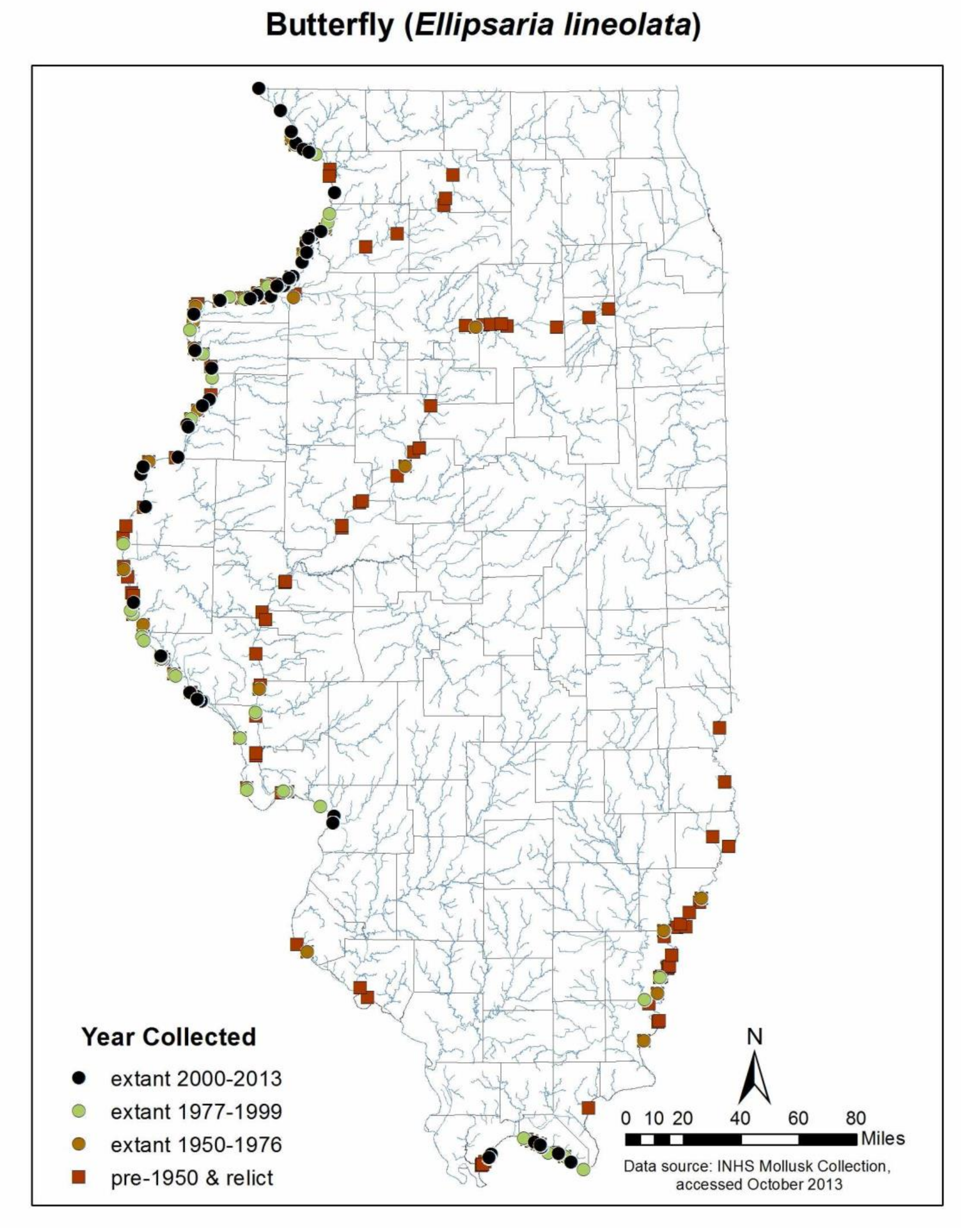


# Purple wartyback (*Cyclonaias tuberculata*)

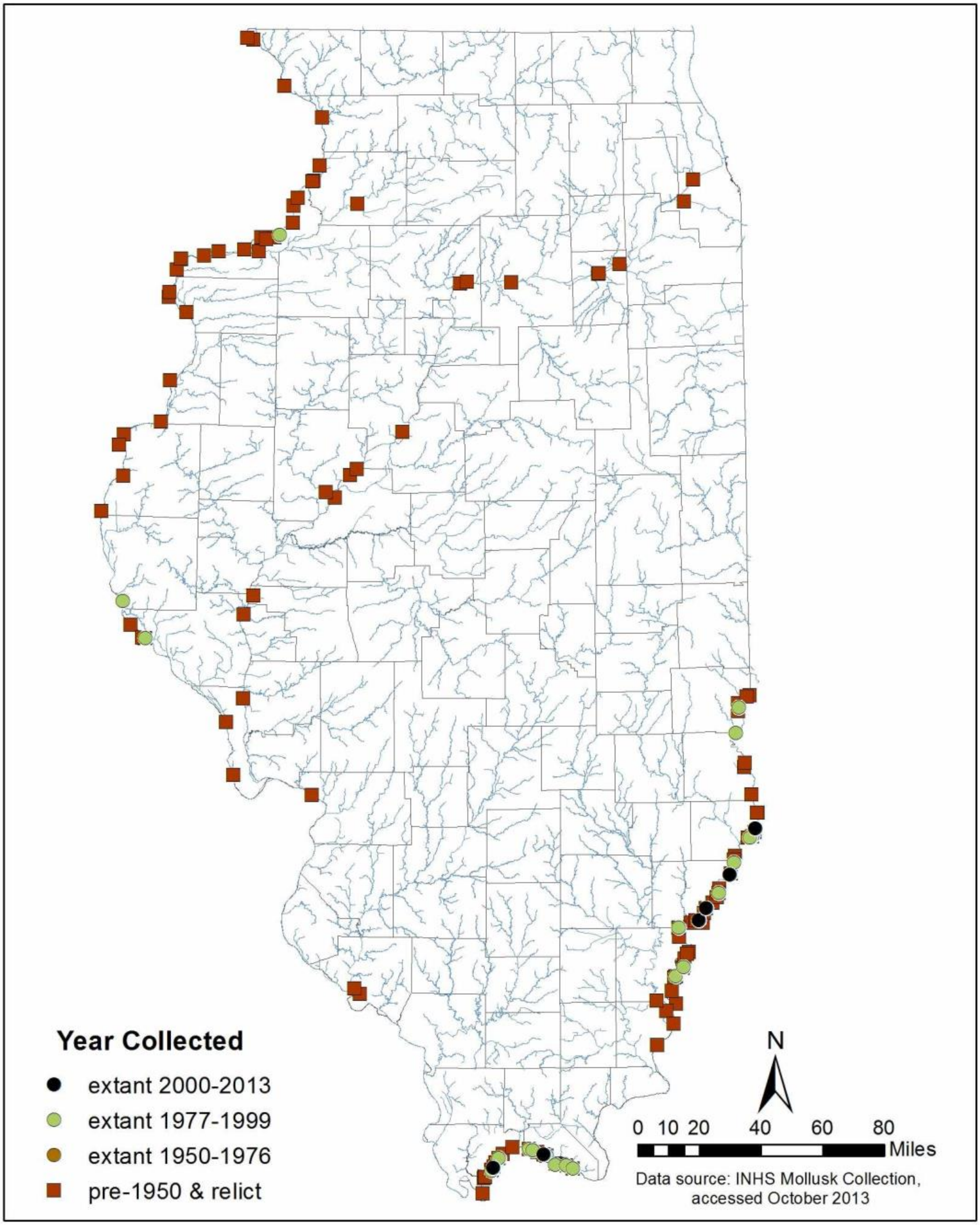


# Fanshell (*Cyprogenia stegaria*)

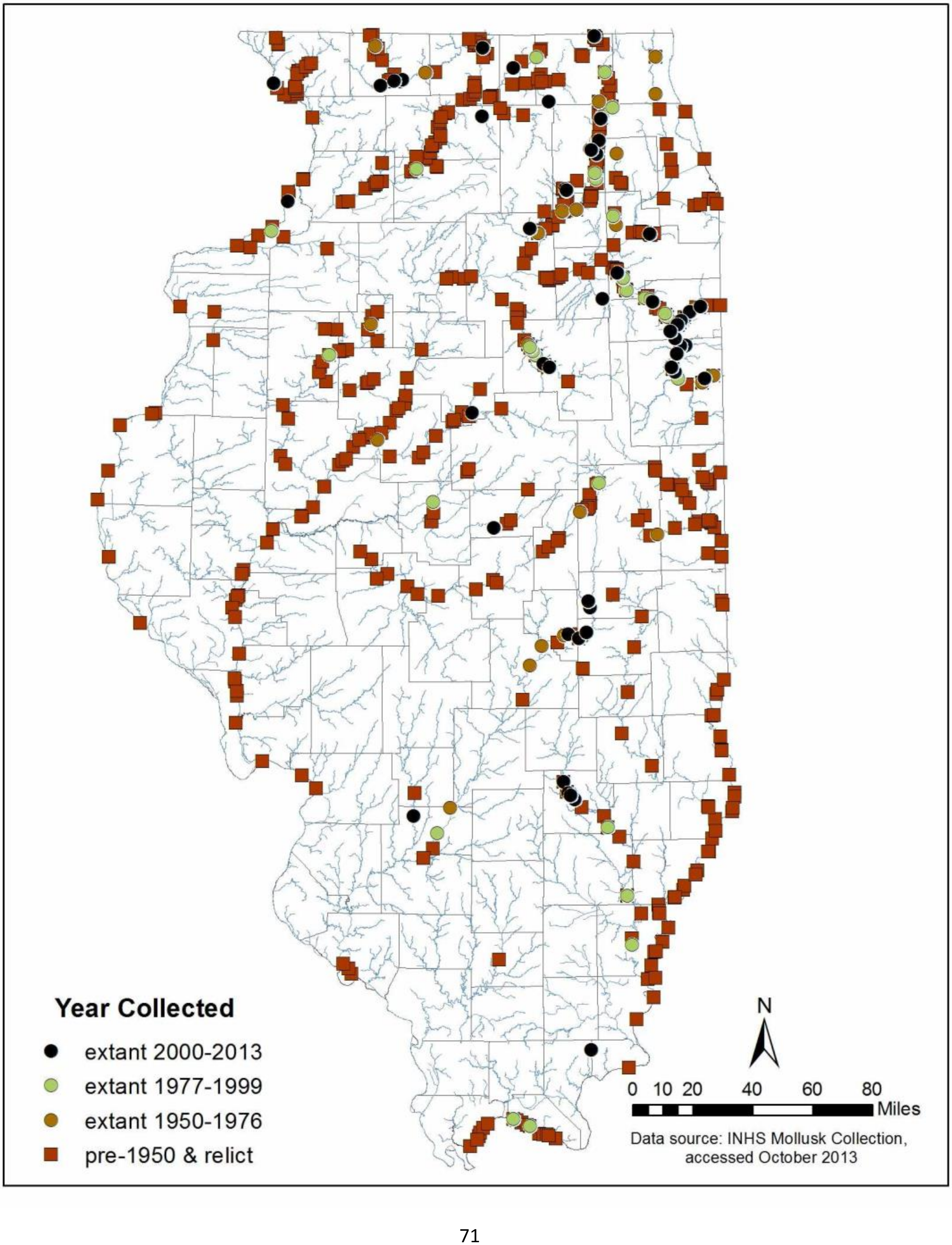



Butterfly (*Ellipsaria lineolata*)
Year Collected
extant 2000-2013
extant 1977-1999
extant 1950-1976
pre-1950 & relict
N
0 10 20 40 60 80
Miles
Data source: INHS Mollusk Collection, accessed October 2013

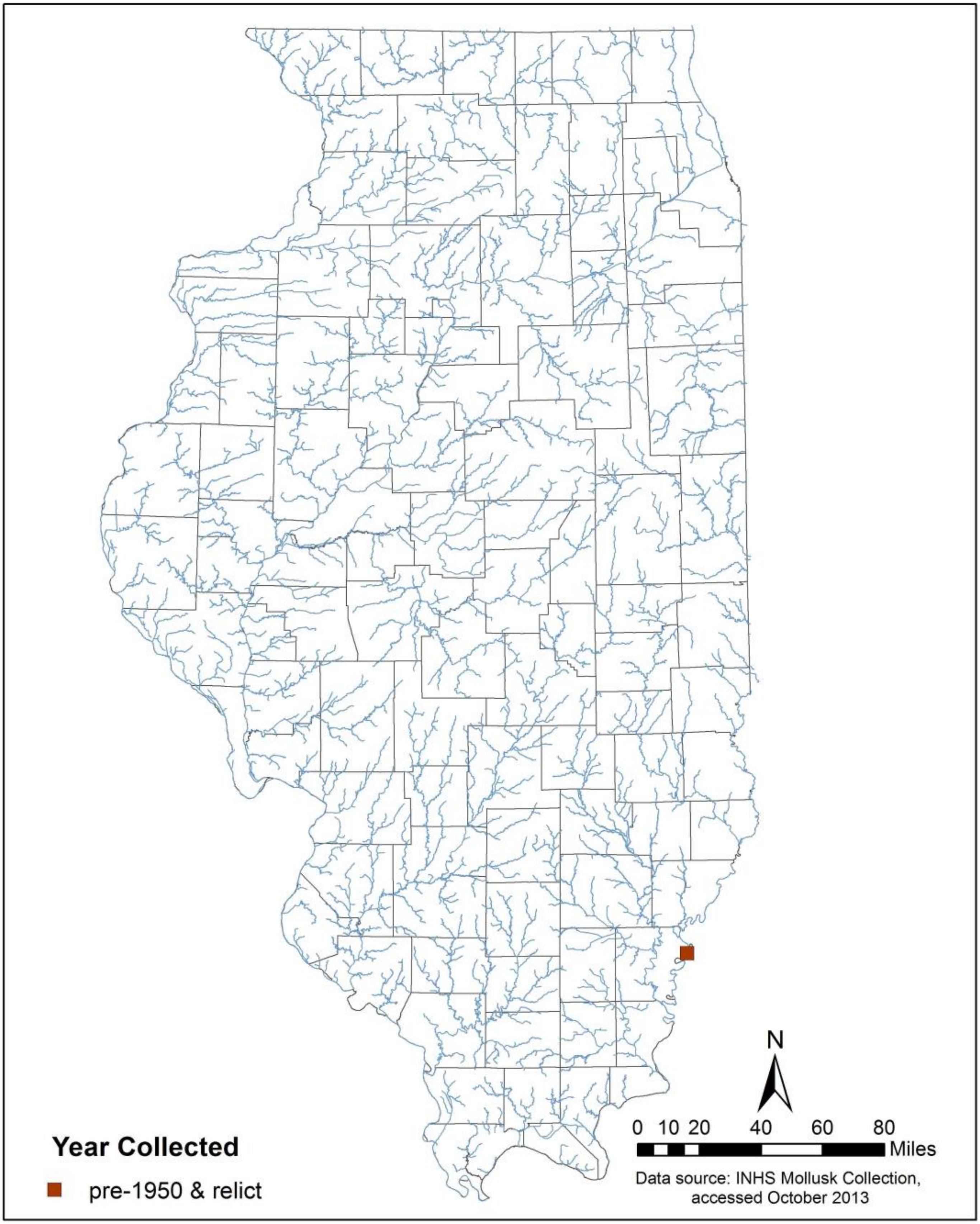
# Elephantear (*Elliptio crassidens*)



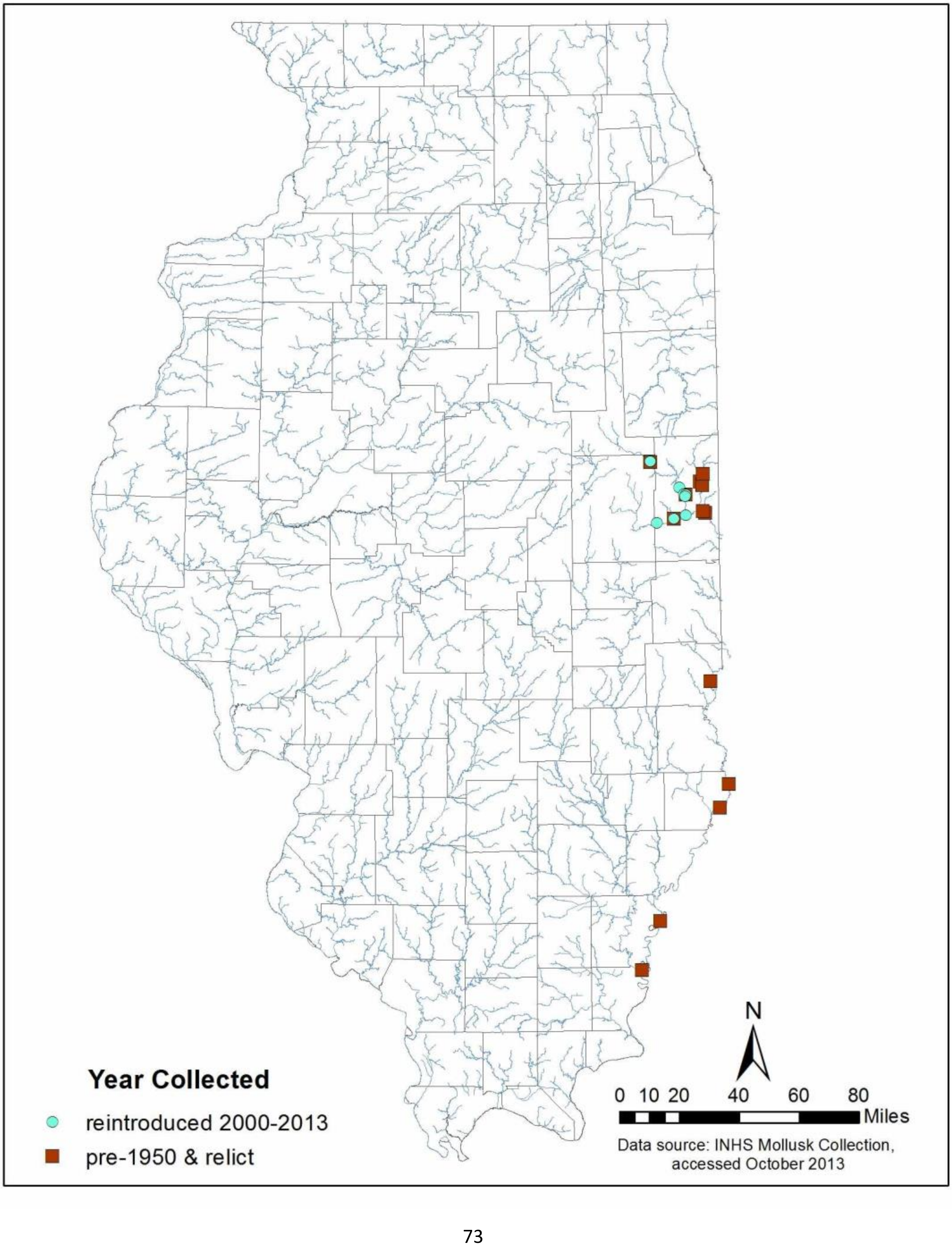
## Spike (*Elliptio dilatata*)



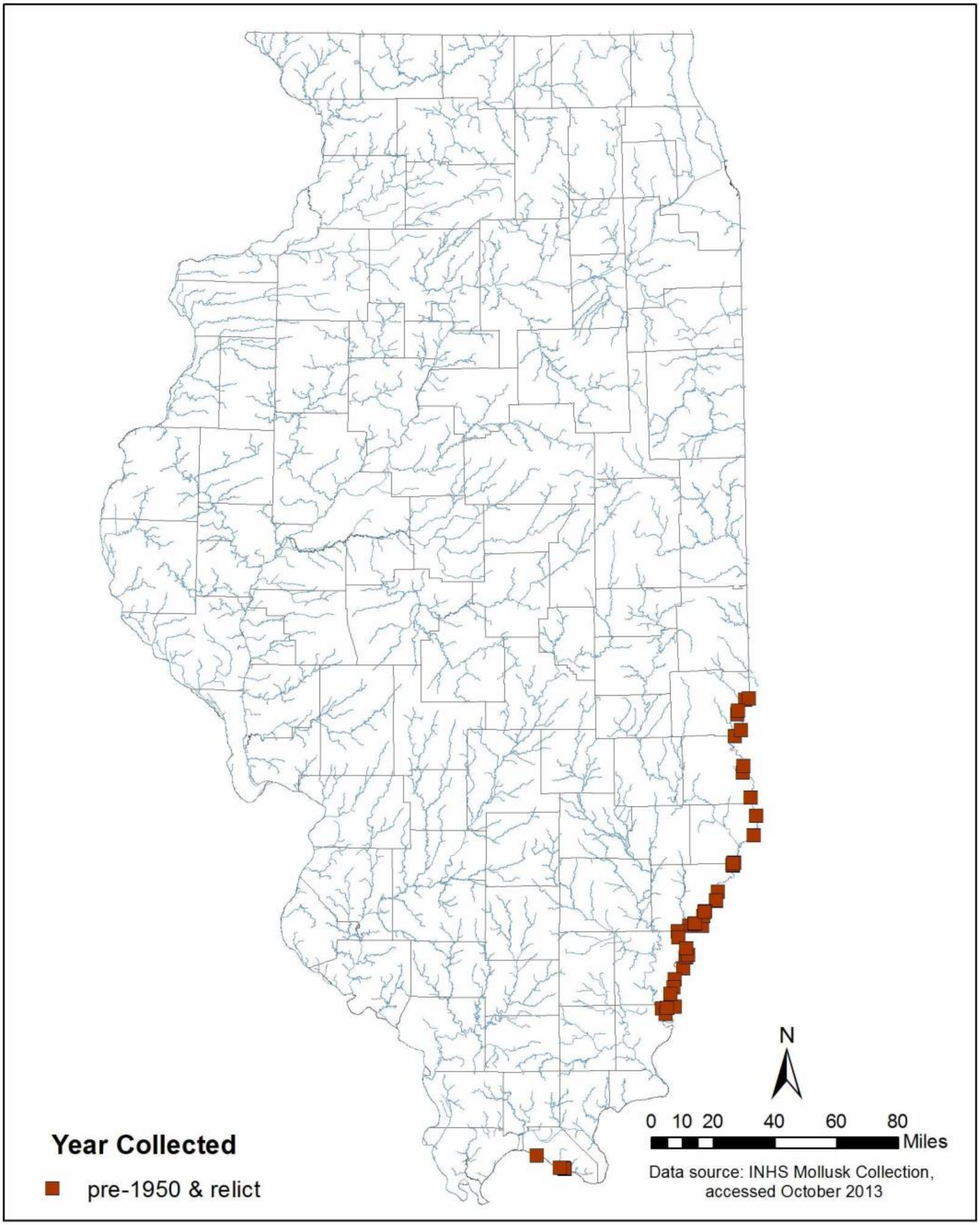
# Catspaw (*Epioblasma obliquata*)



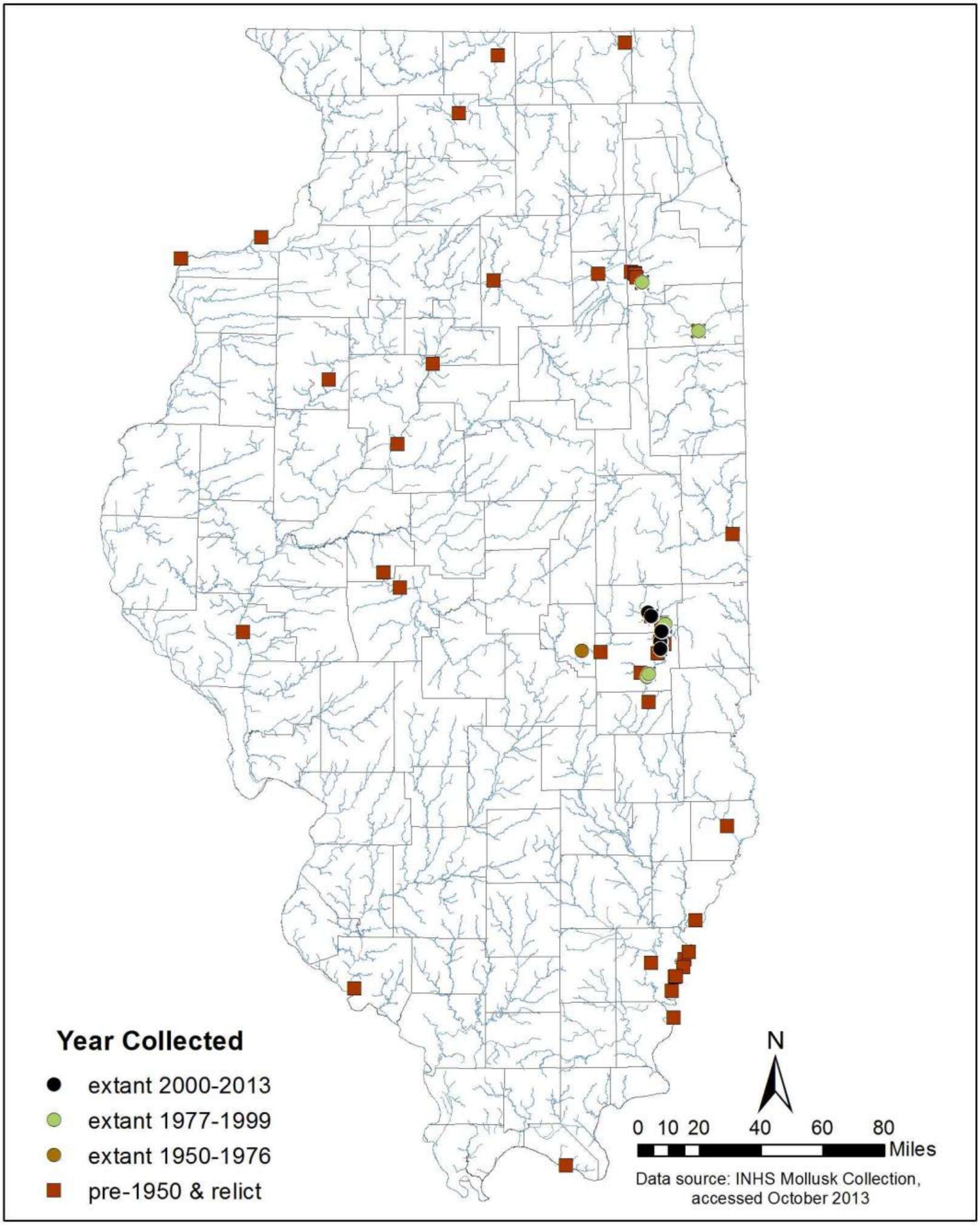
# Northern riffleshell (*Epioblasma rangiana*)



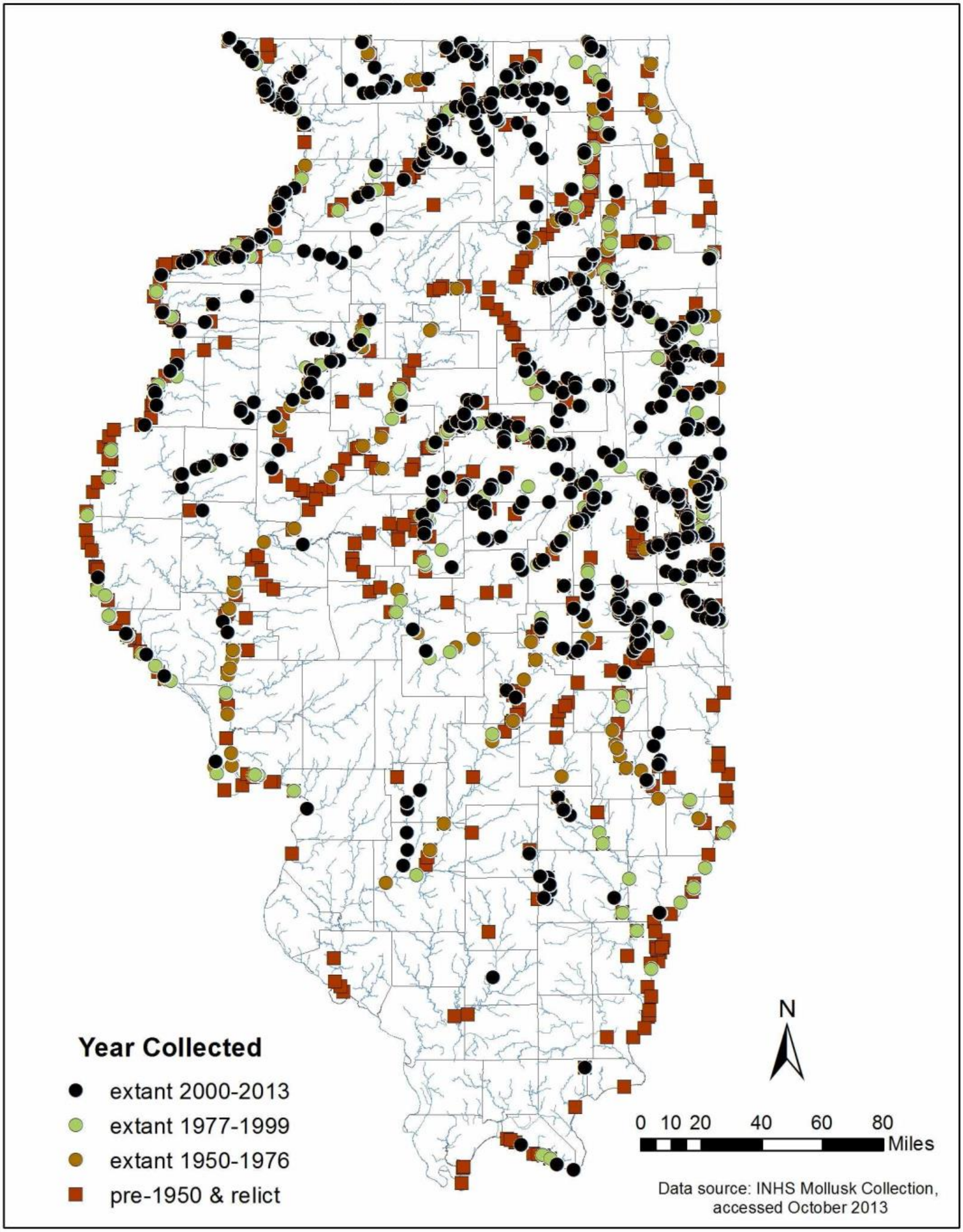
# Tubercled blossom (*Epioblasma torulosa*)



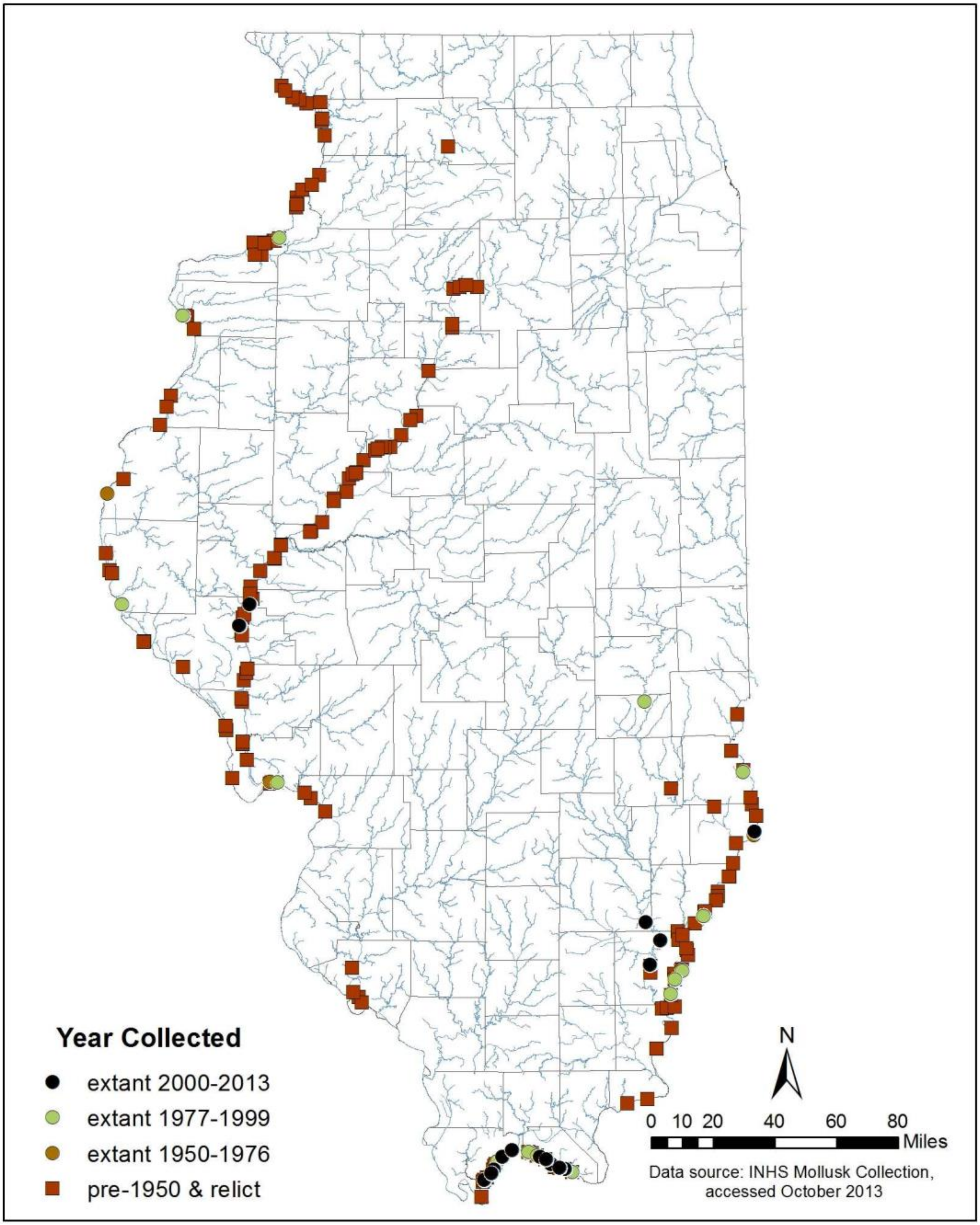
# Snuffbox (*Epioblasma triquetra*)



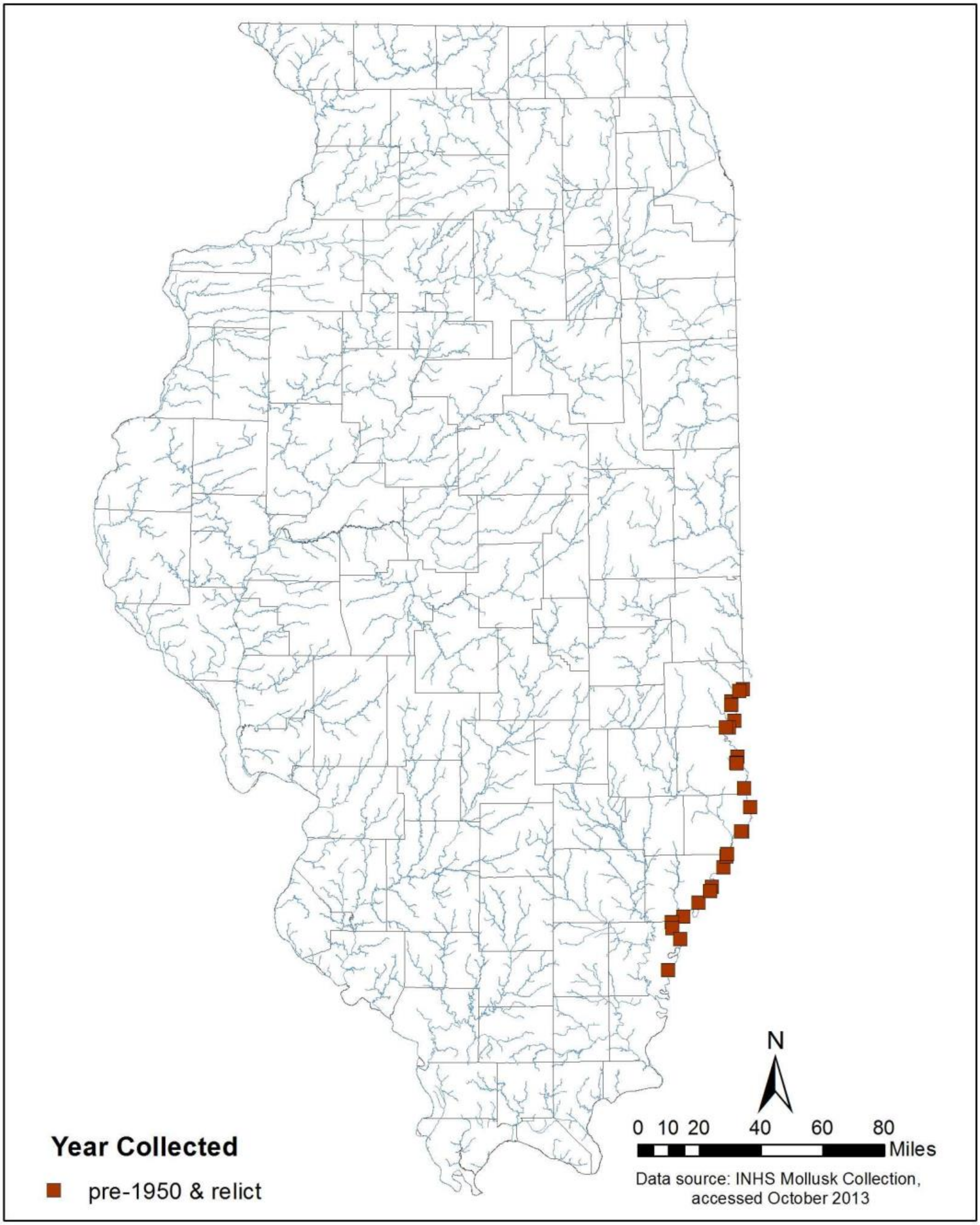
# Wabash pigtoe (*Fusconaia flava*)



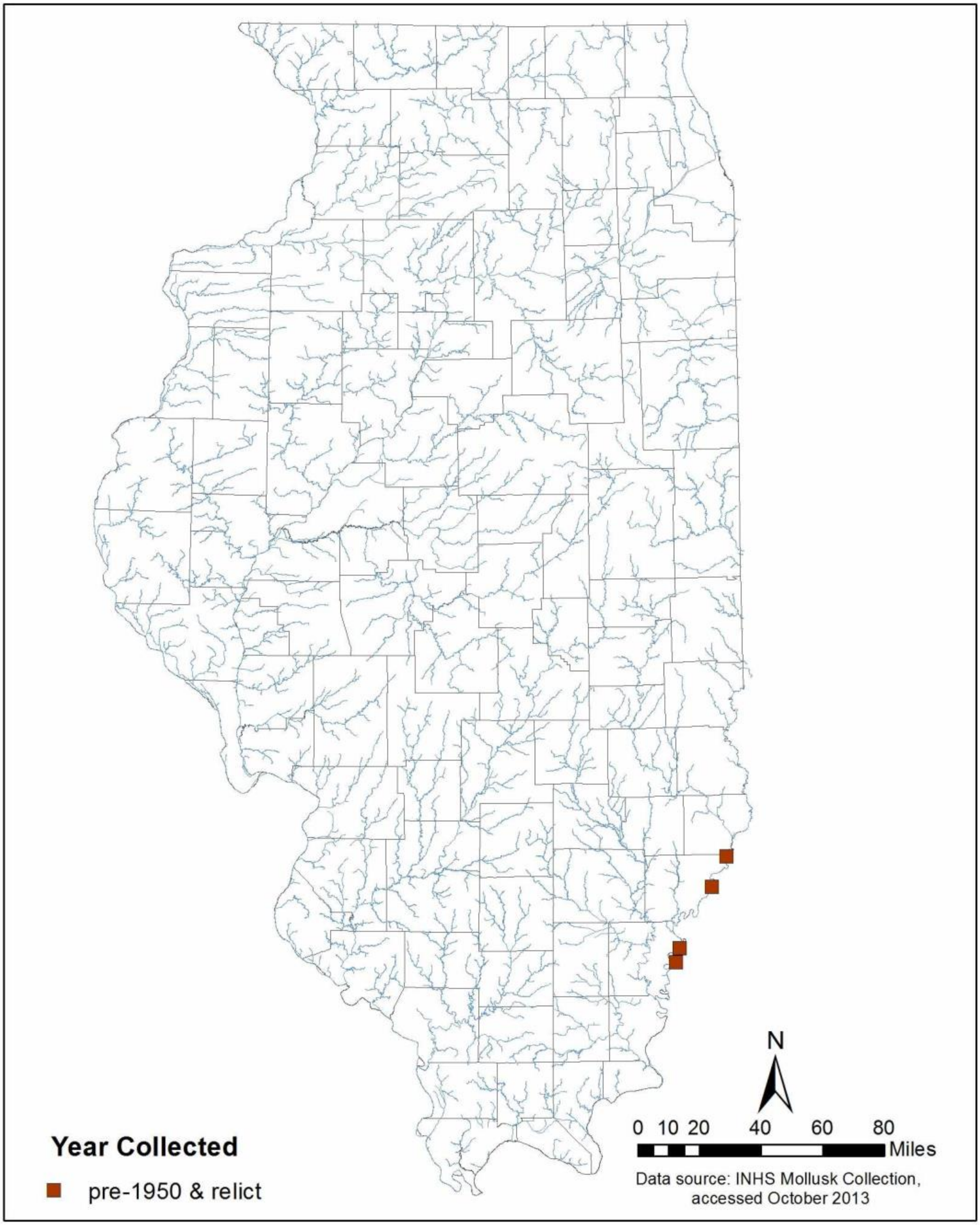
## Ebonyshell (*Fusconaia ebena*)



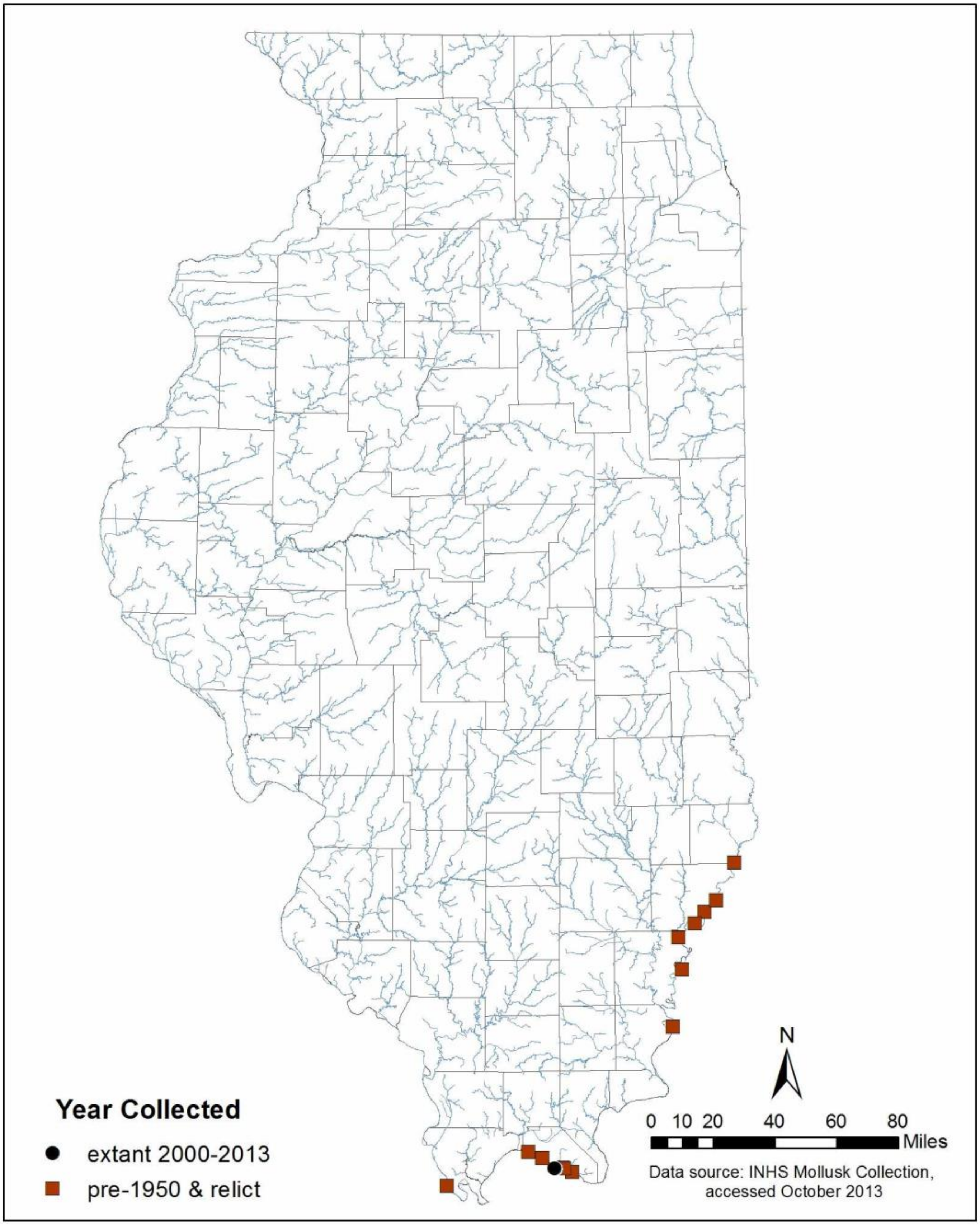
# Longsolid (*Fusconaia subrotunda*)



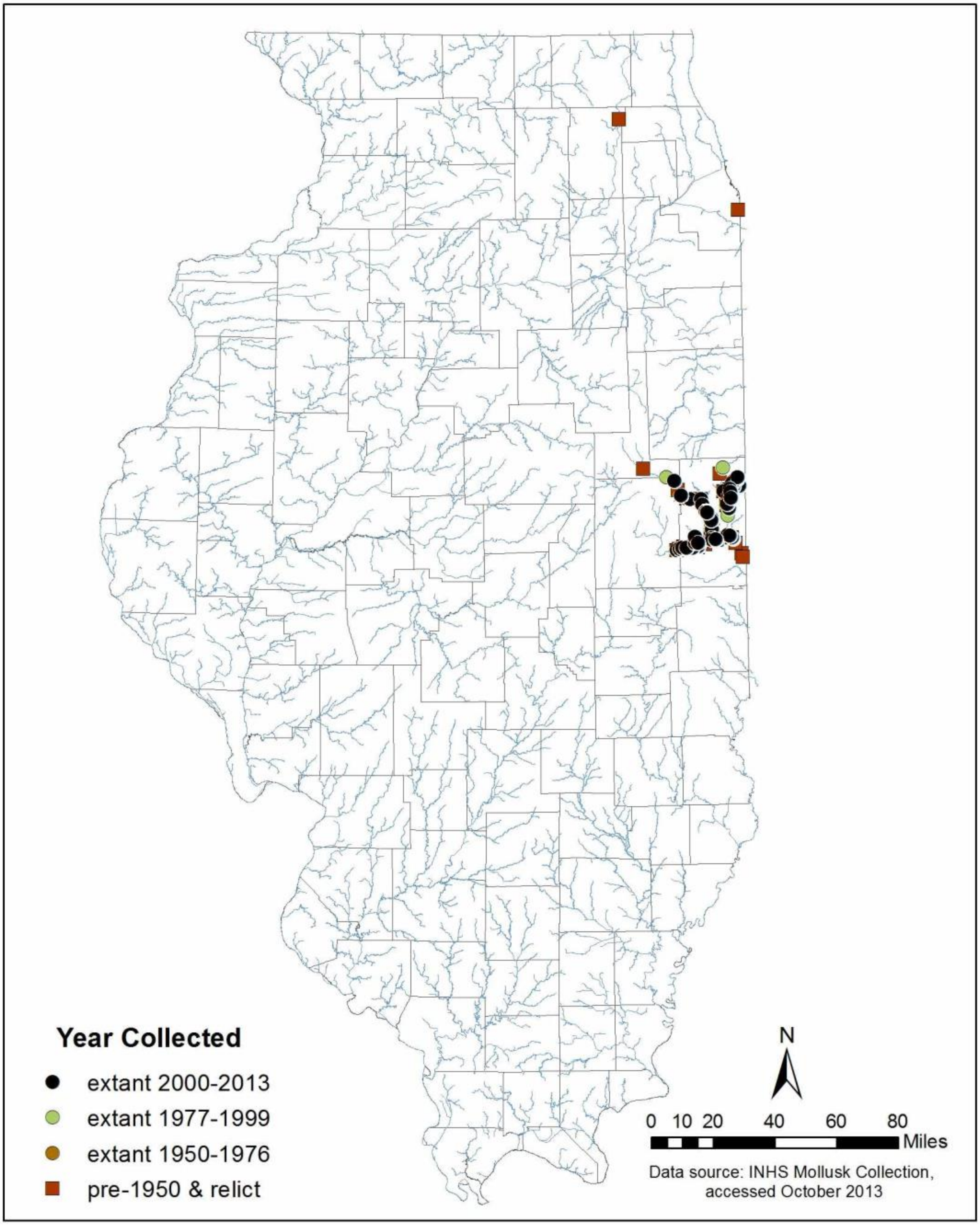
# Cracking pearlymussel (*Hemistena lata*)



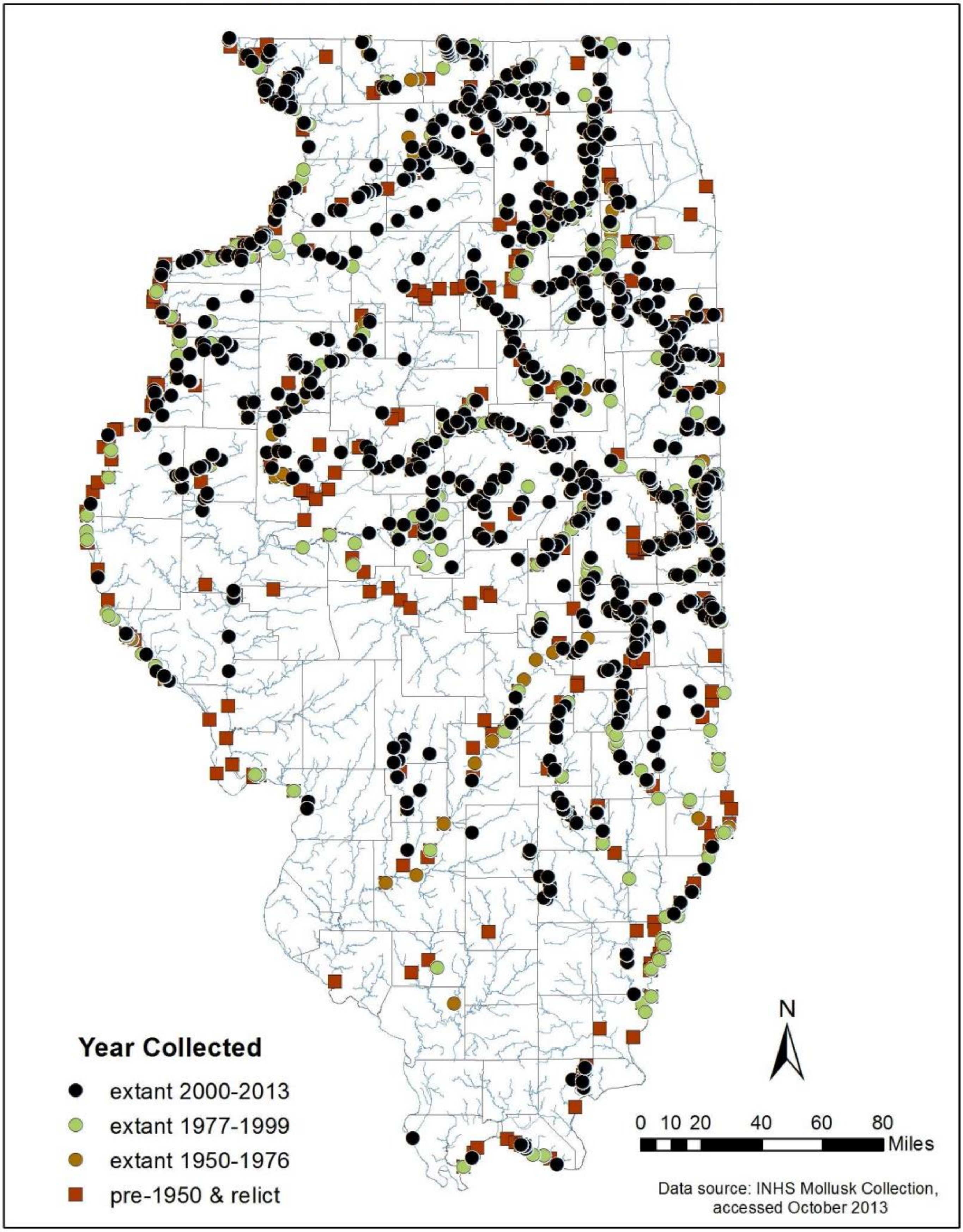
# Pink mucket (*Lampsilis abrupta*)



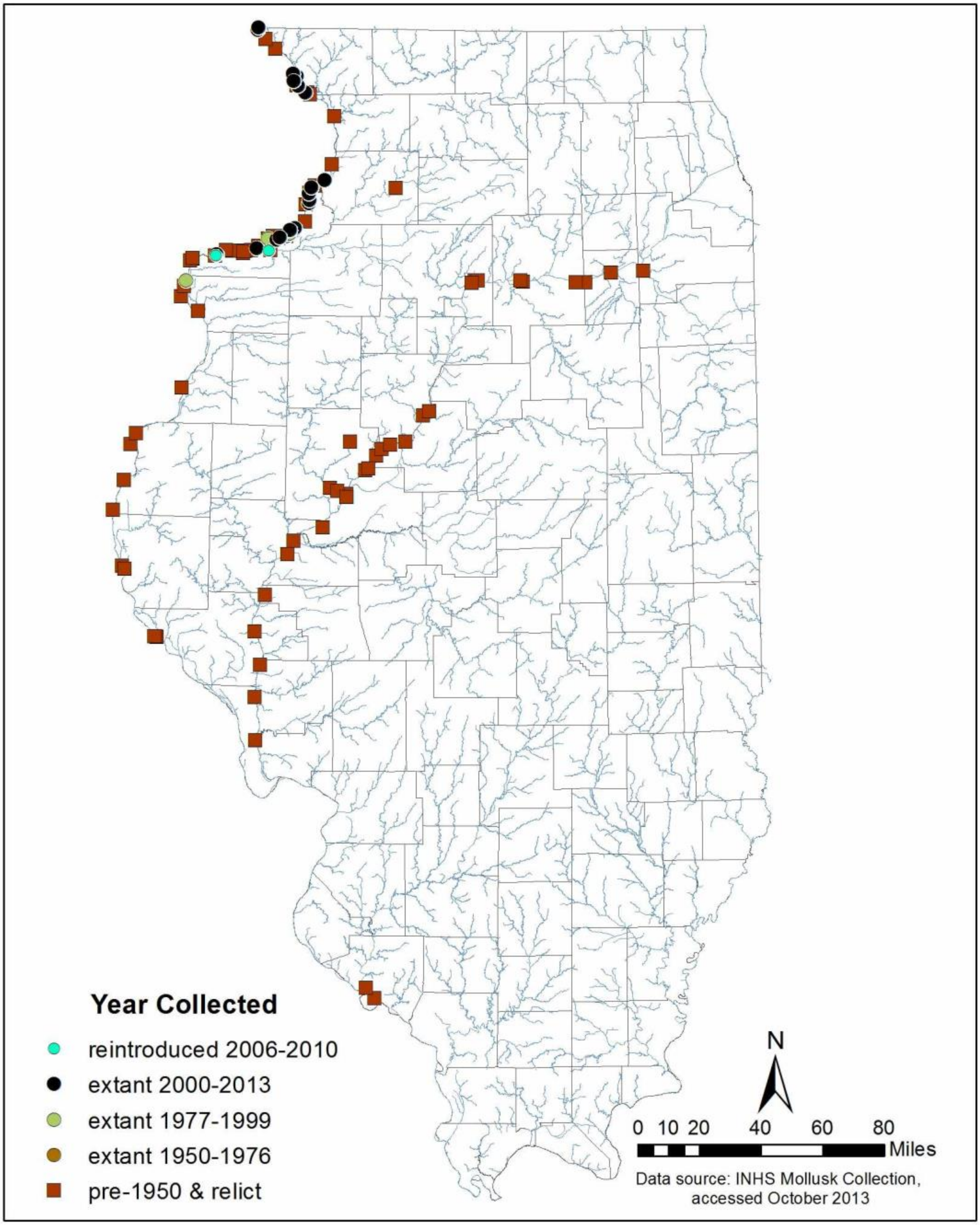
# Wavy-rayed lampmussel (*Lampsilis fasciola*)



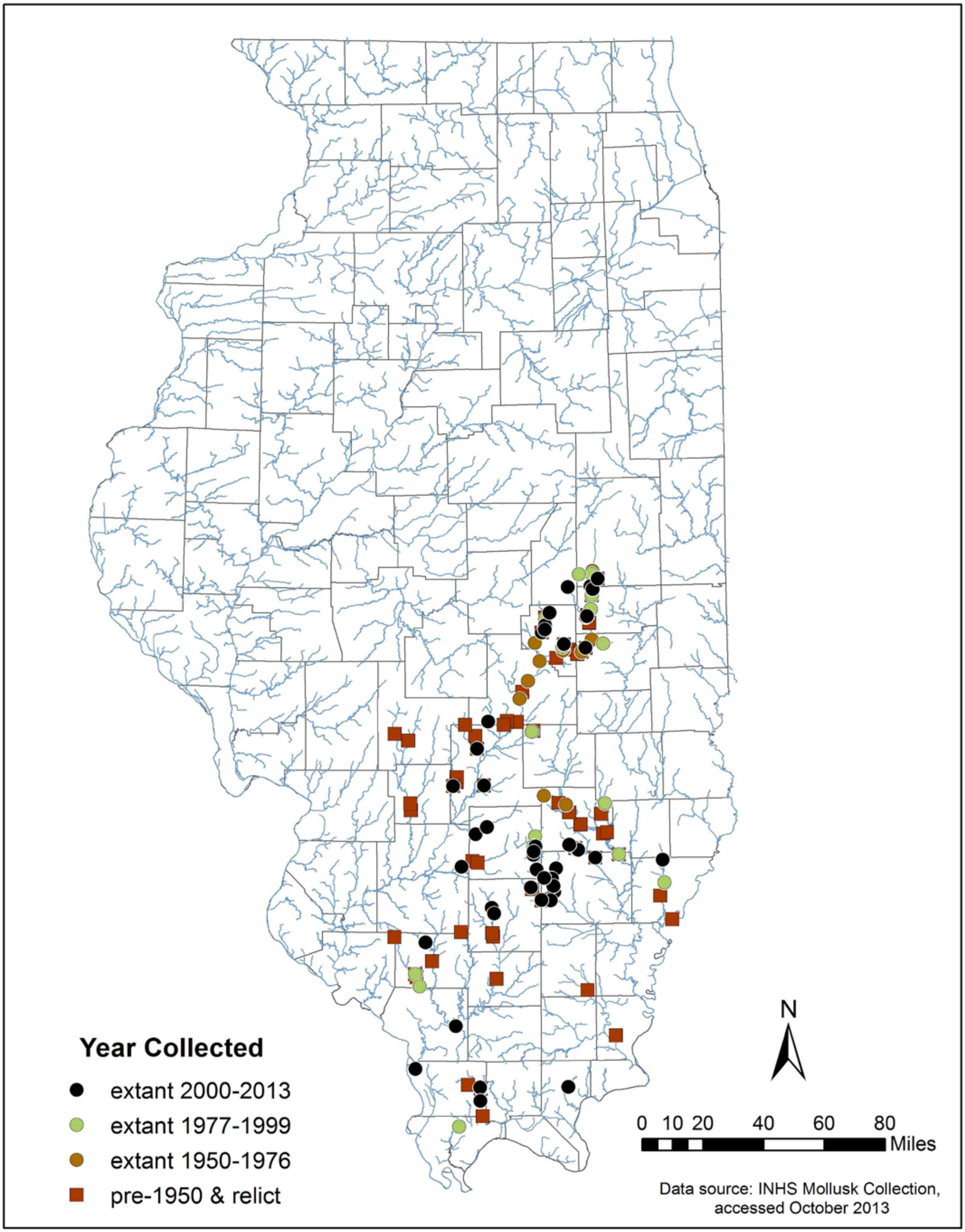
## Plain pocketbook (*Lampsilis cardium*)



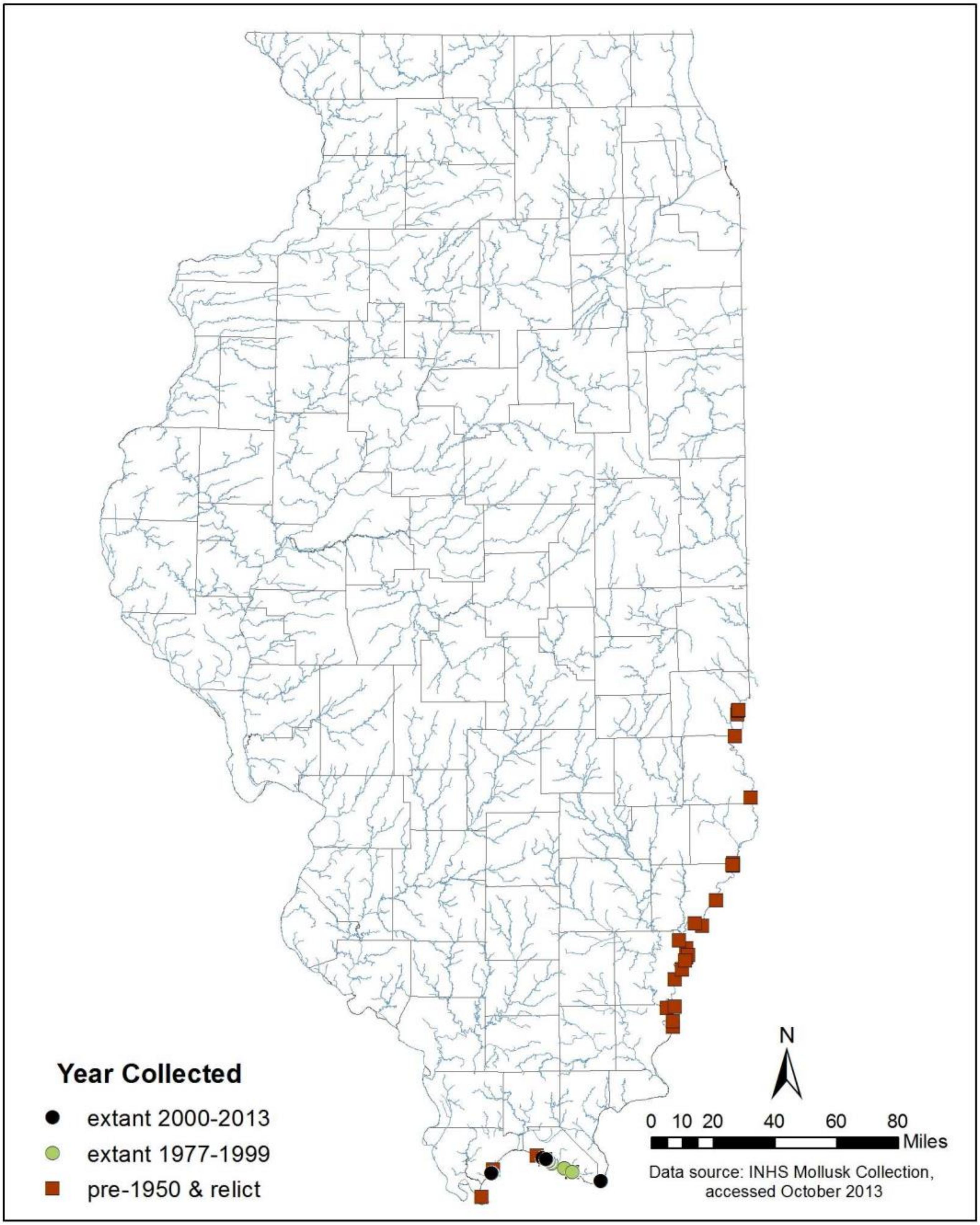
# Higgins eye (*Lampsilis higginsii*)



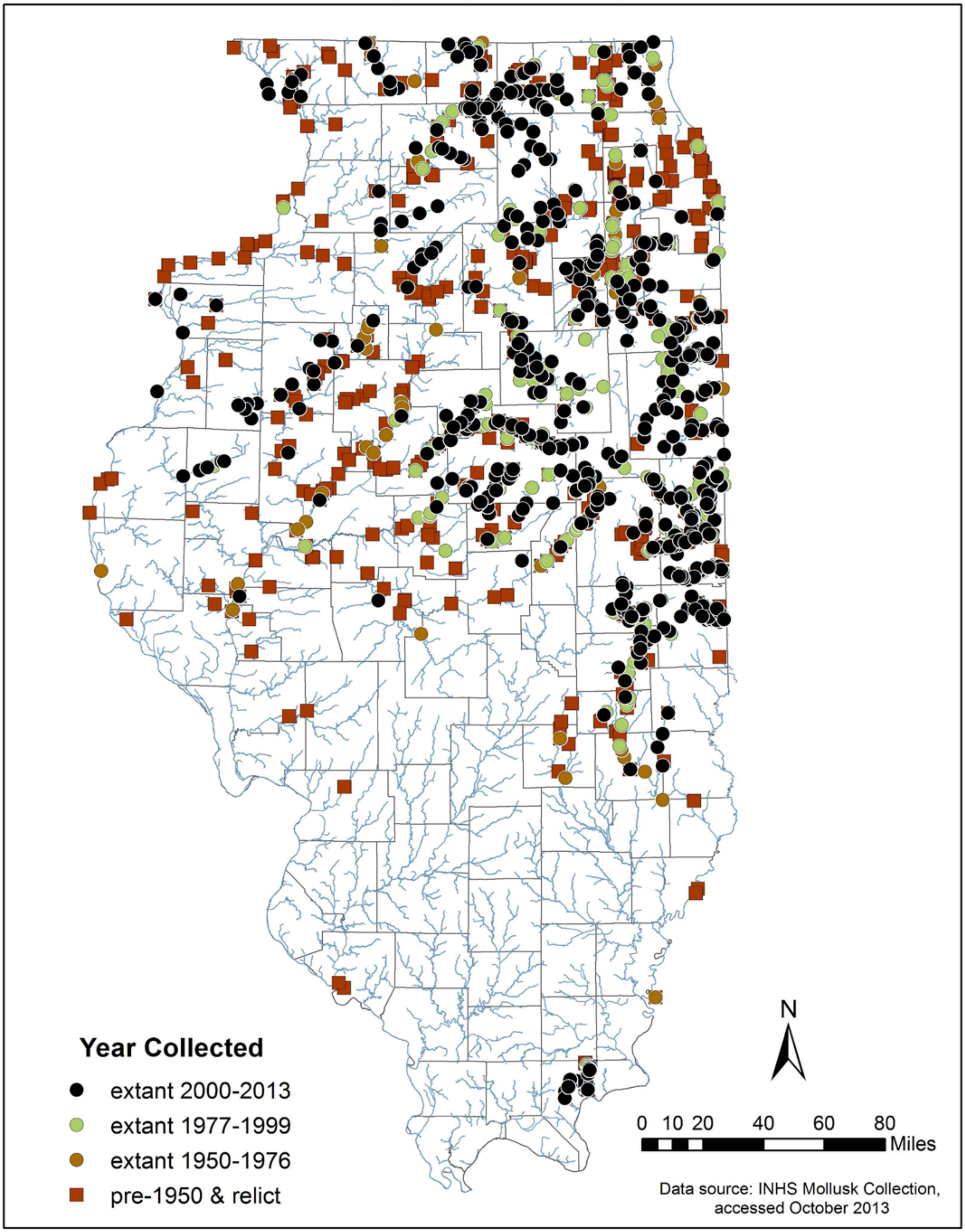
# Louisiana fatmucket (*Lampsilis hydiana*)

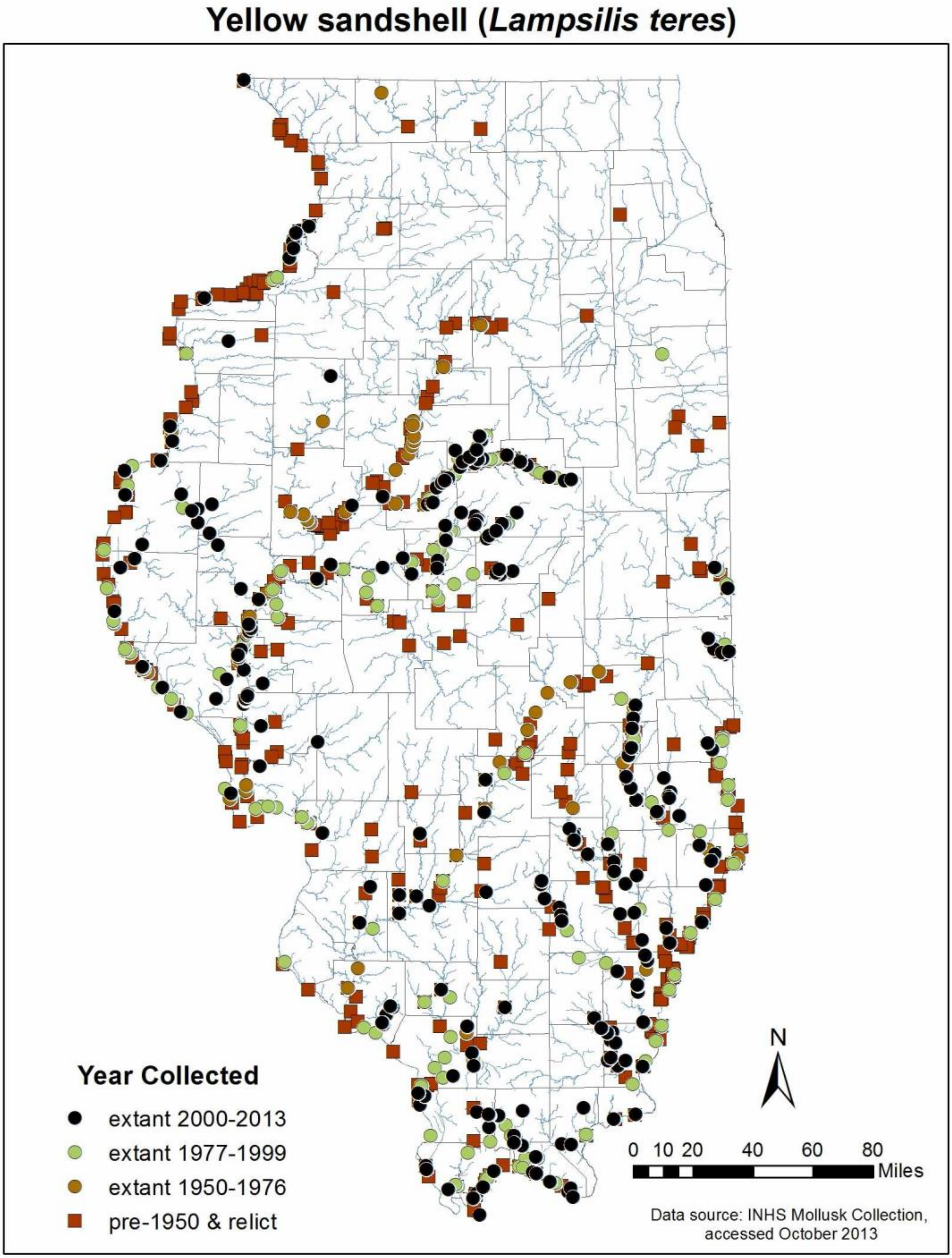


# Pocketbook (*Lampsilis ovata*)



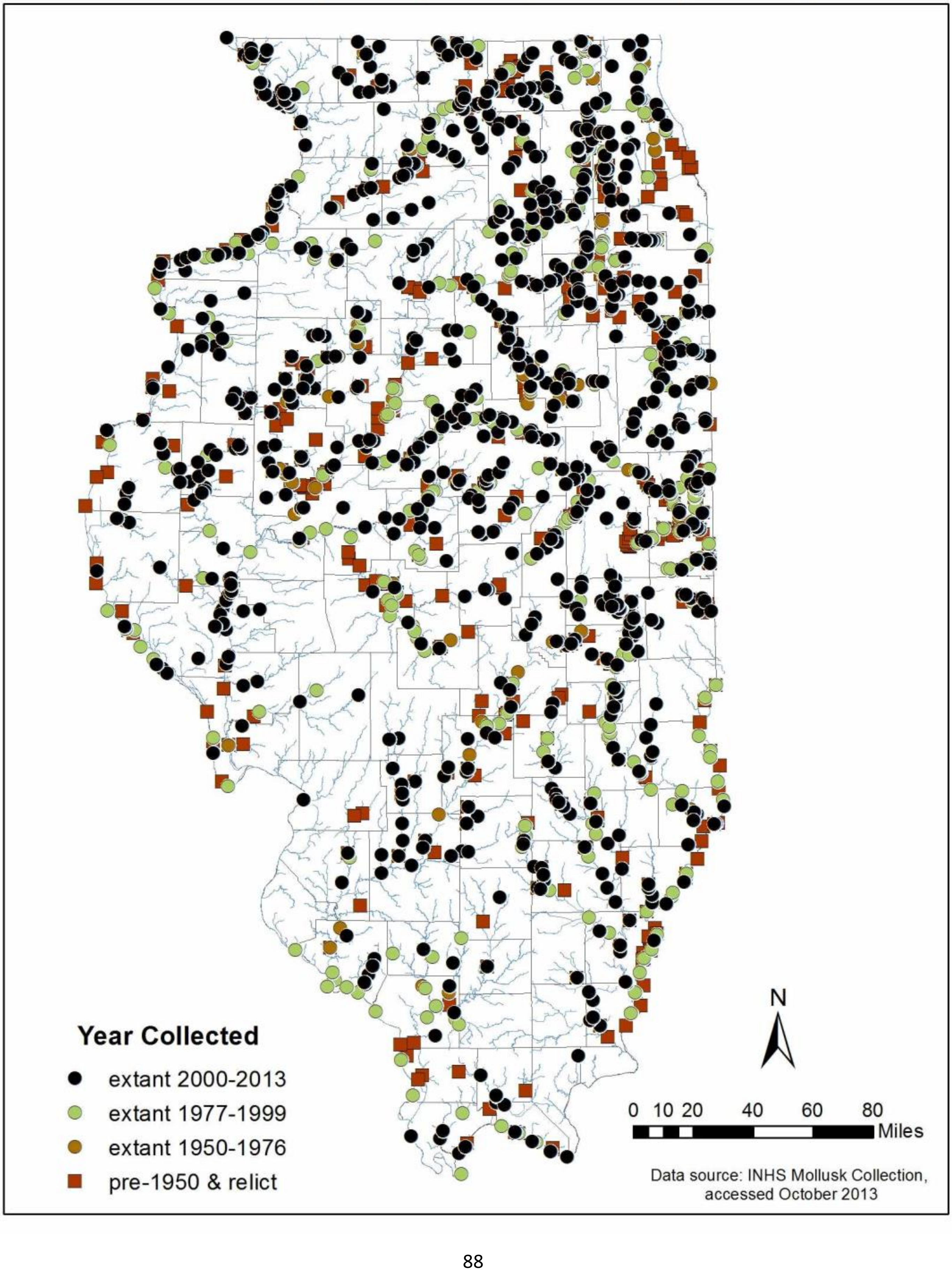
## Fatmucket (*Lampsilis siliquoidea*)



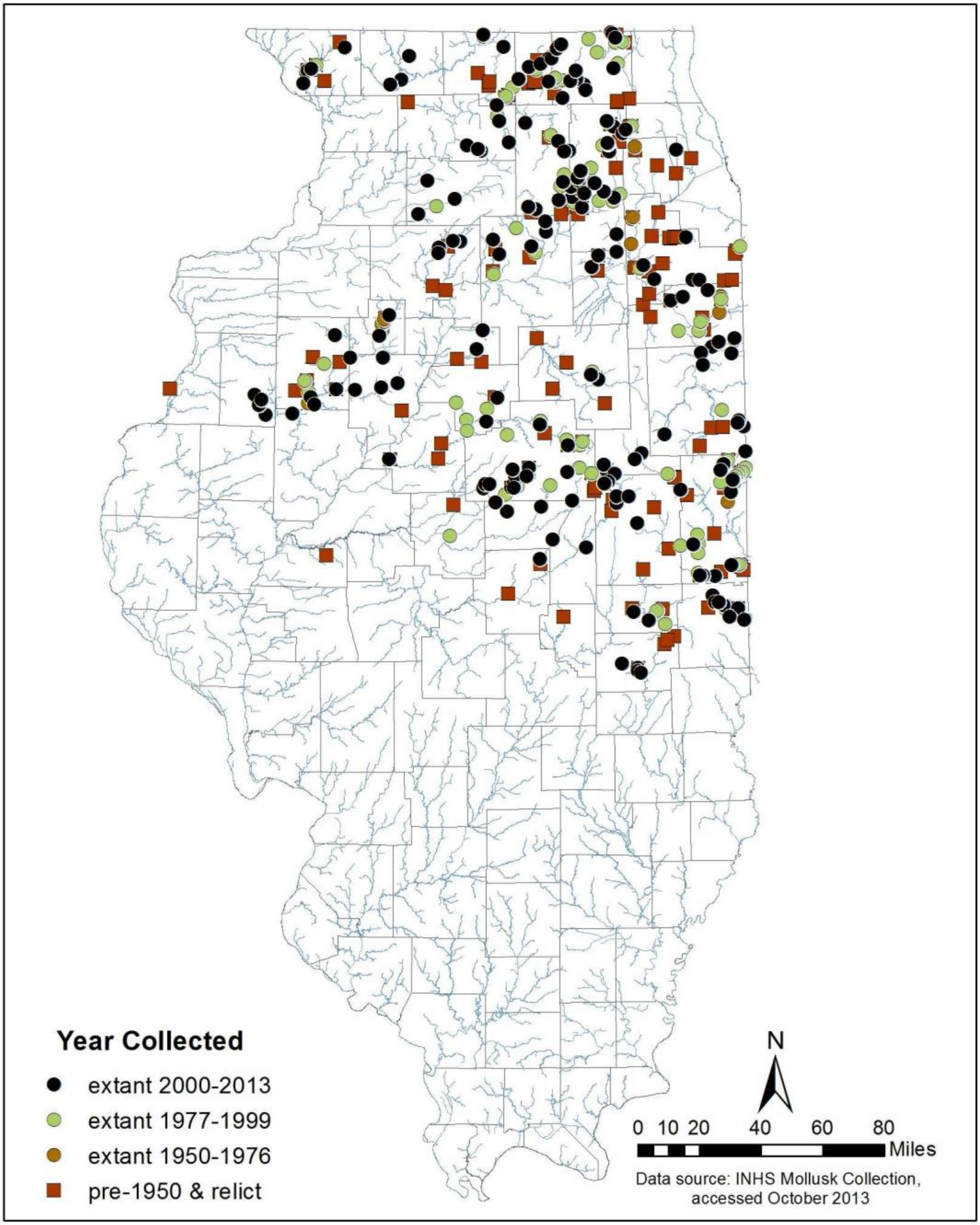


Yellow sandshell (*Lampsilis teres*)
Year Collected
extant 2000-2013
extant 1977-1999
extant 1950-1976
pre-1950 & relict
N
0 10 20 40 60 80
Miles
Data source: INHS Mollusk Collection, accessed October 2013

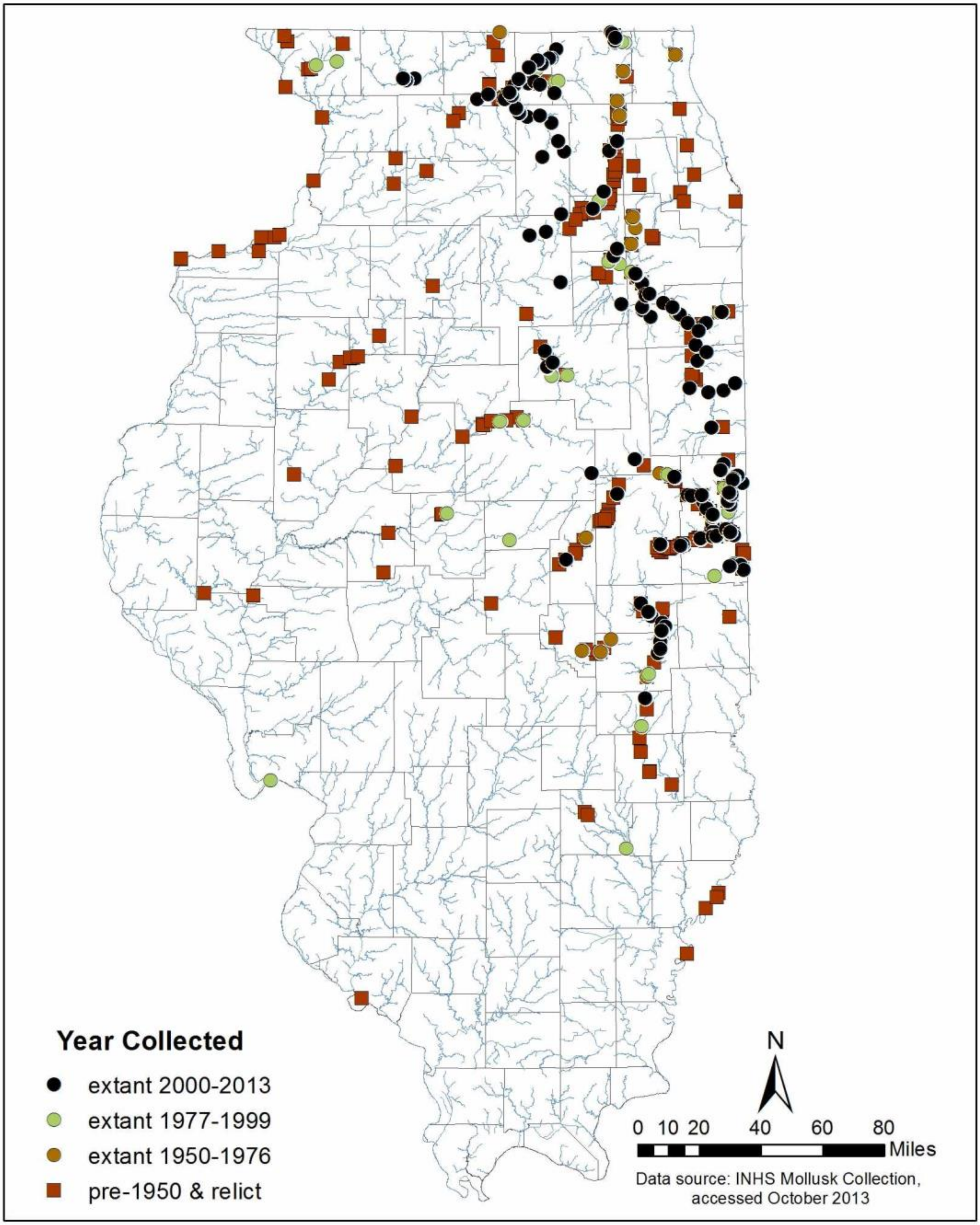
# White heelsplitter (*Lasmigona complanata*)



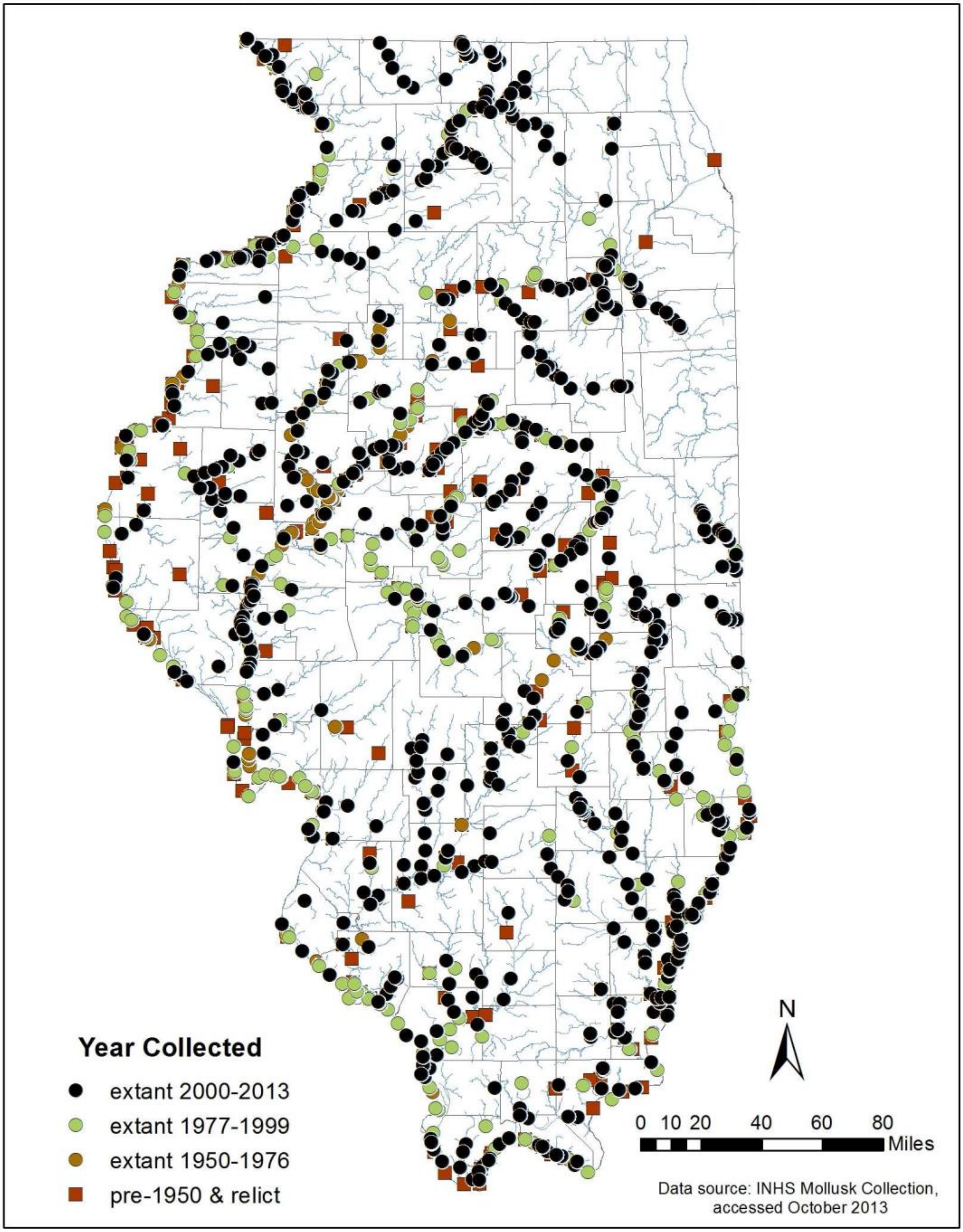
## Creek heelsplitter (*Lasmigona compressa*)



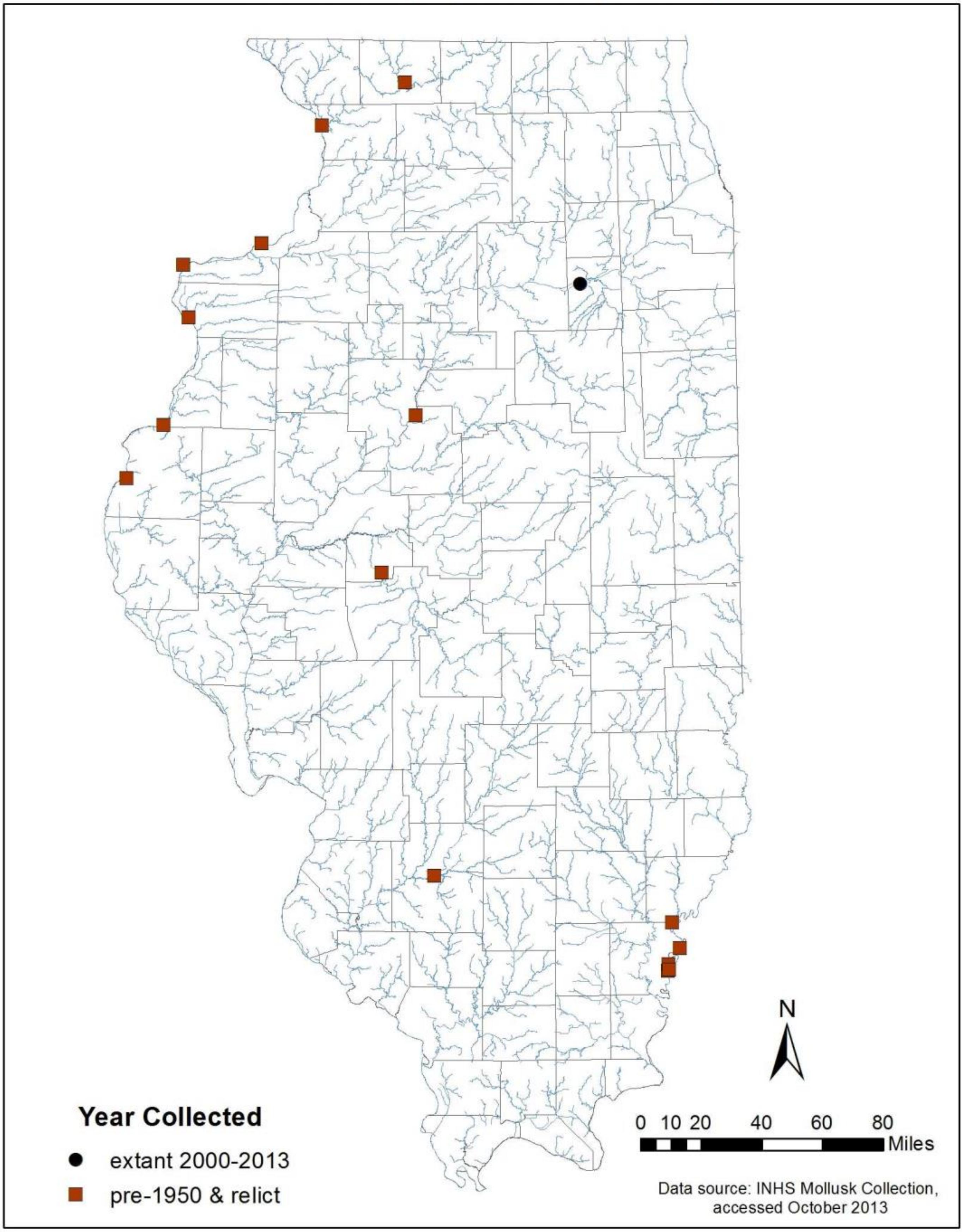
# Flutedshell (*Lasmigona costata*)



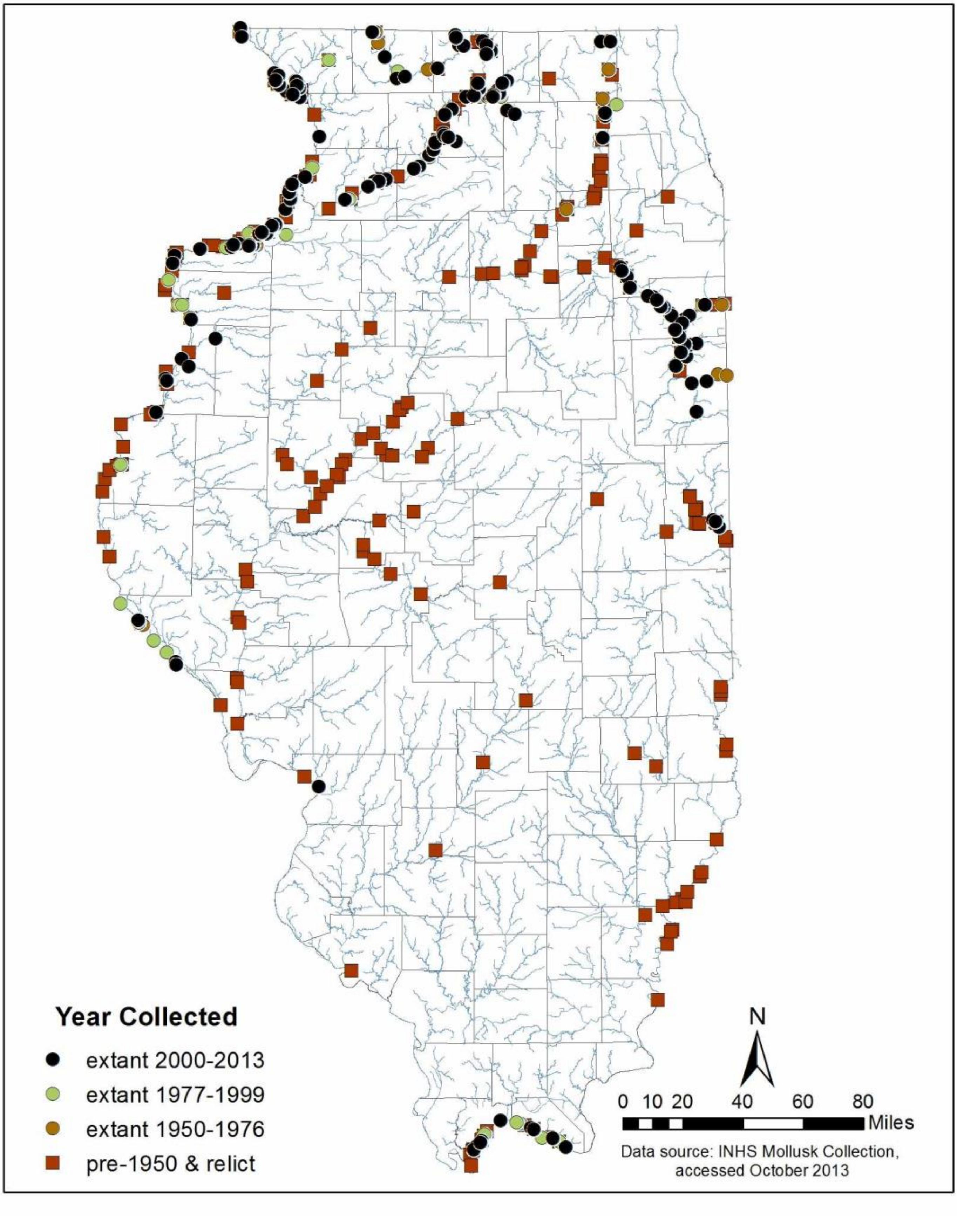
## Fragile papershell (*Leptodea fragilis*)



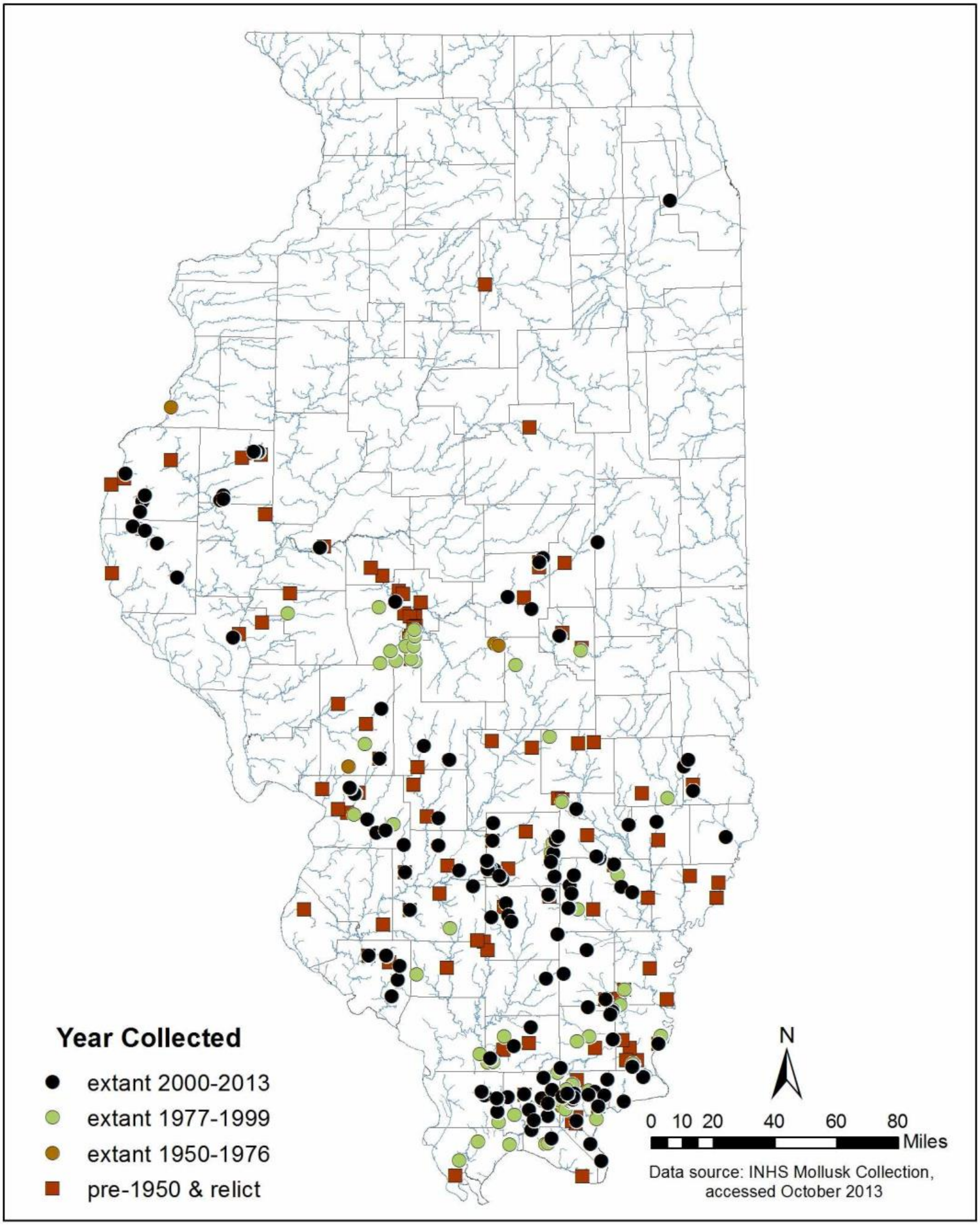
# Scaleshell (*Leptodea leptodon*)



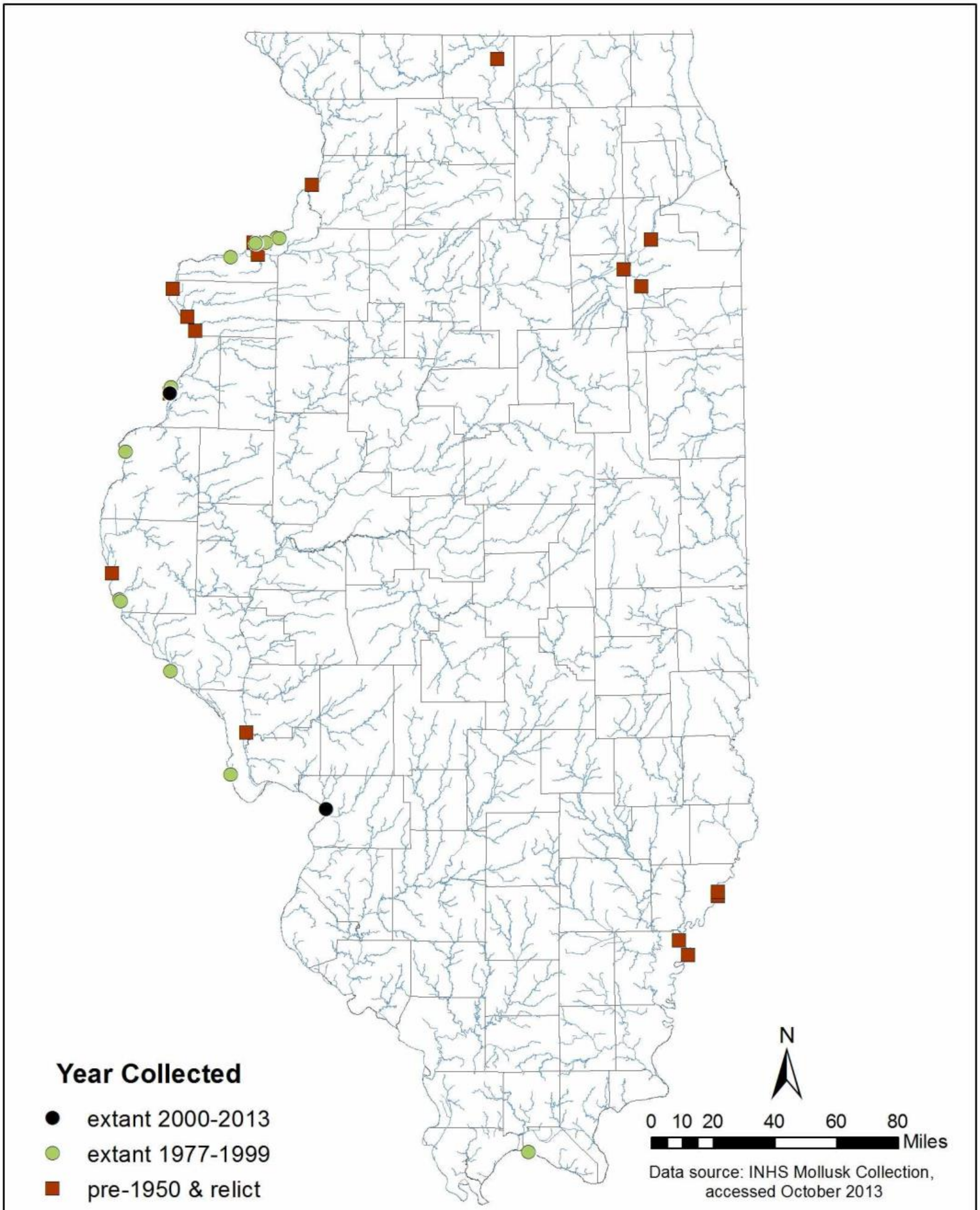
# Black sandshell (*Ligumia recta*)



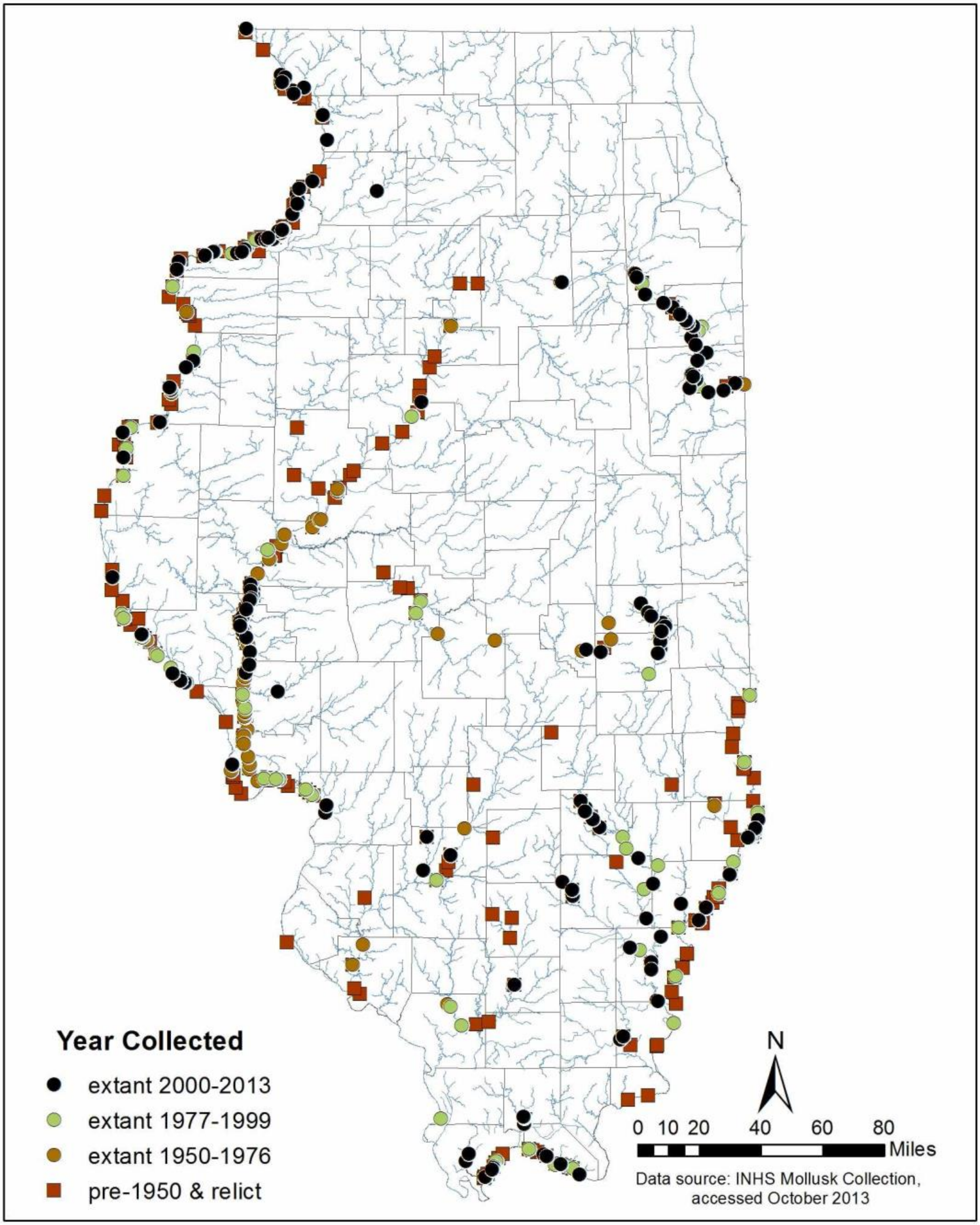
# Pondmussel (*Ligumia subrostrata*)



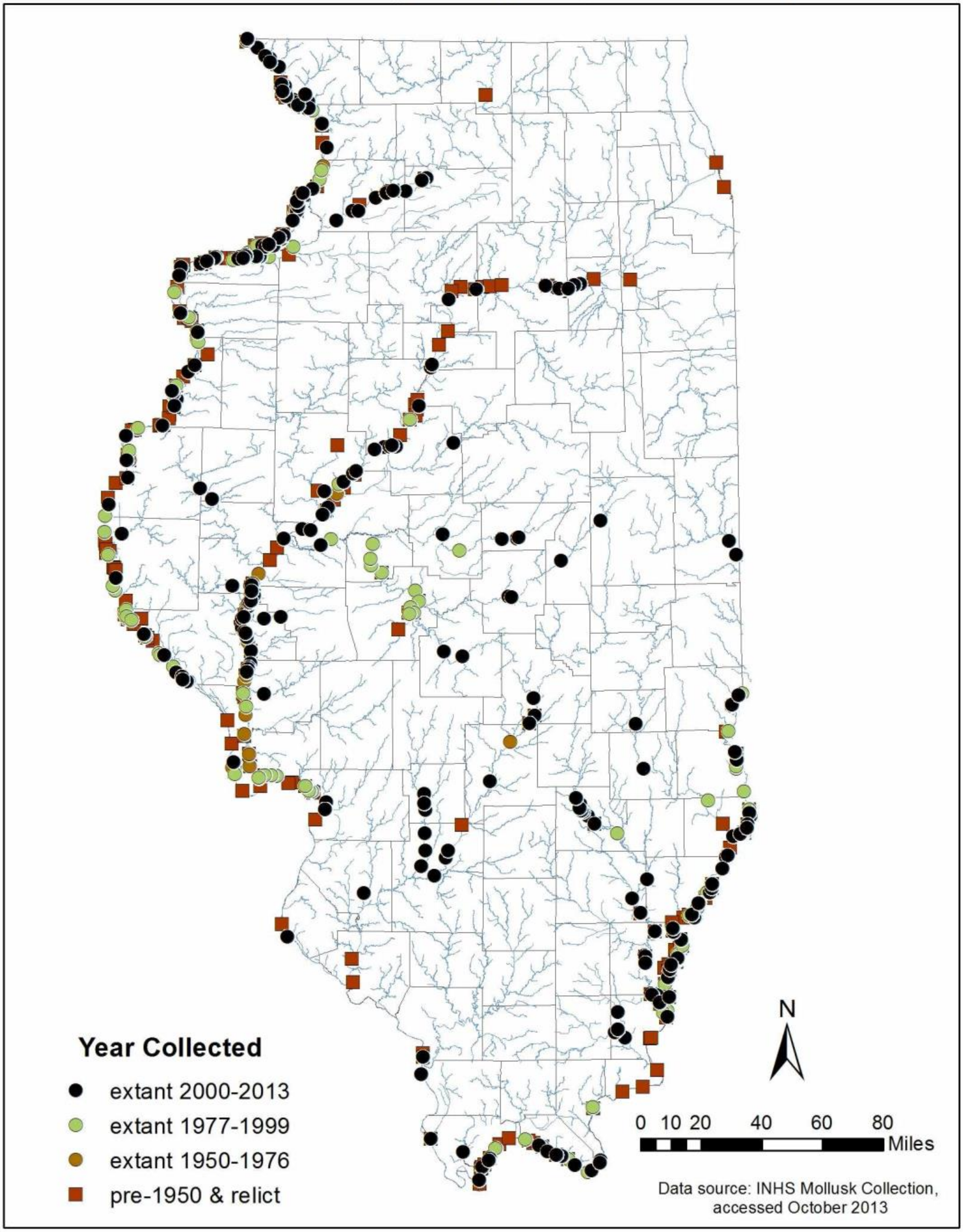
# Spectaclecase (*Margaritifera monodonta*)



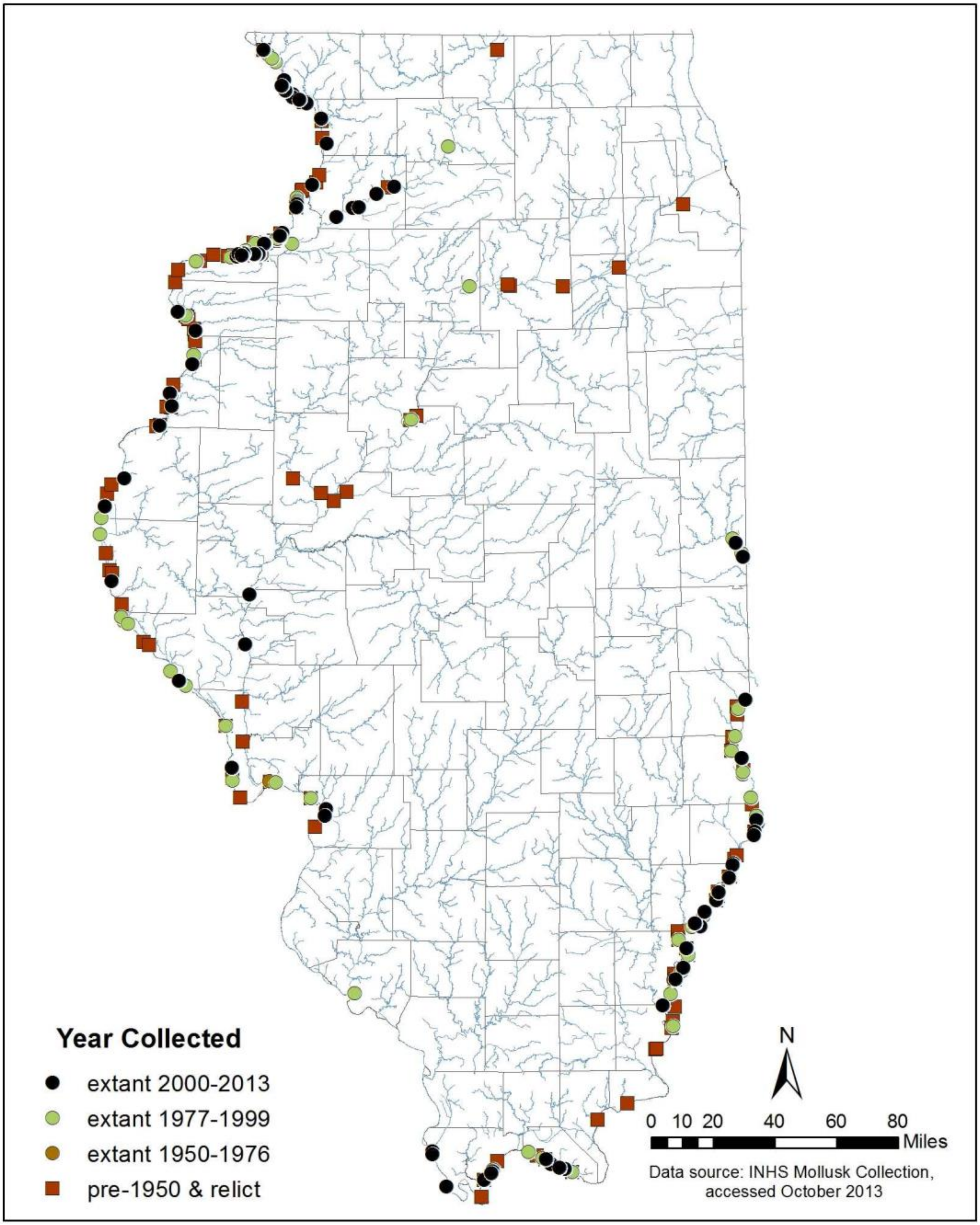
## Washboard (*Megalonaias nervosa*)



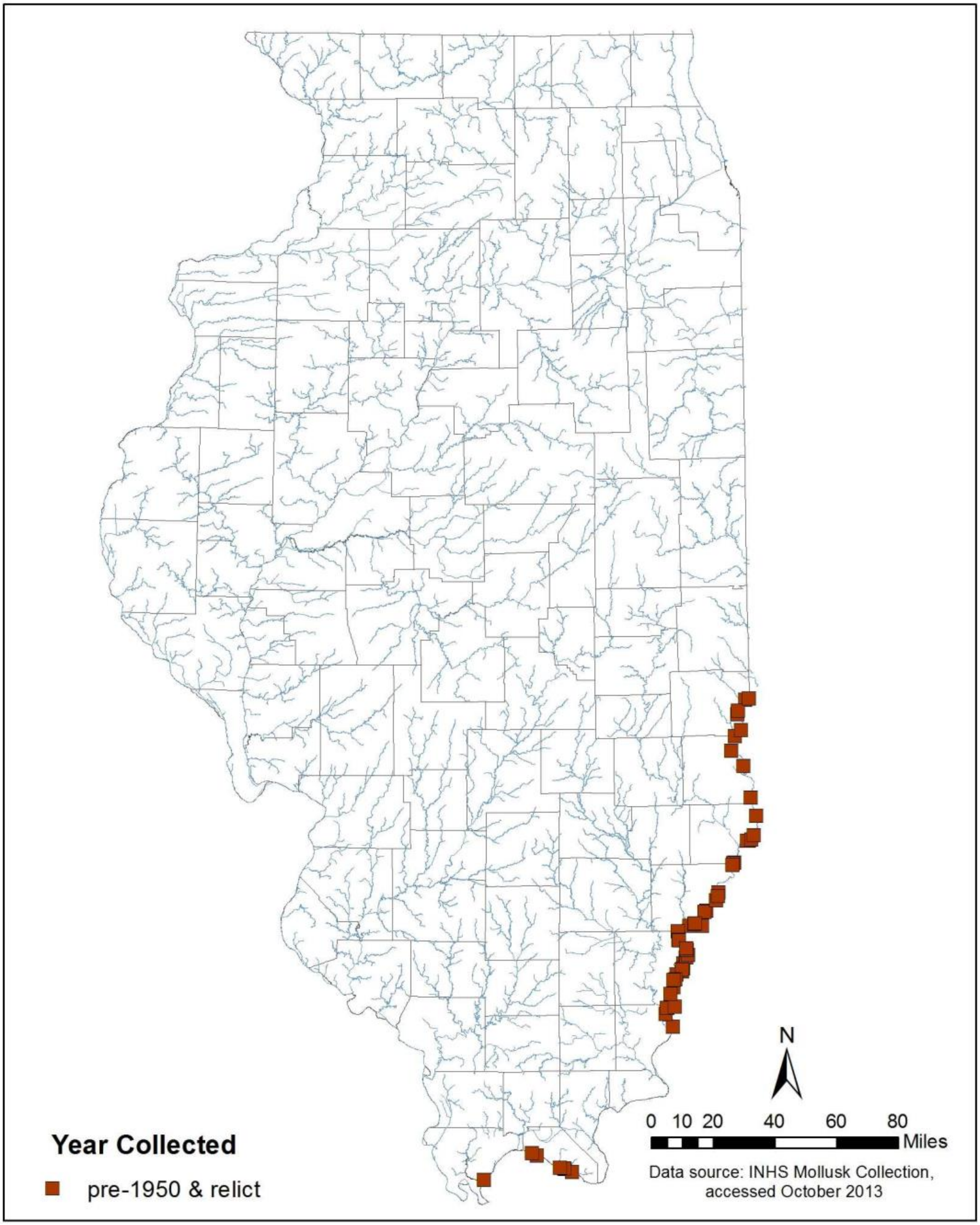
# Threehorn wartyback (*Obliquaria reflexa*)



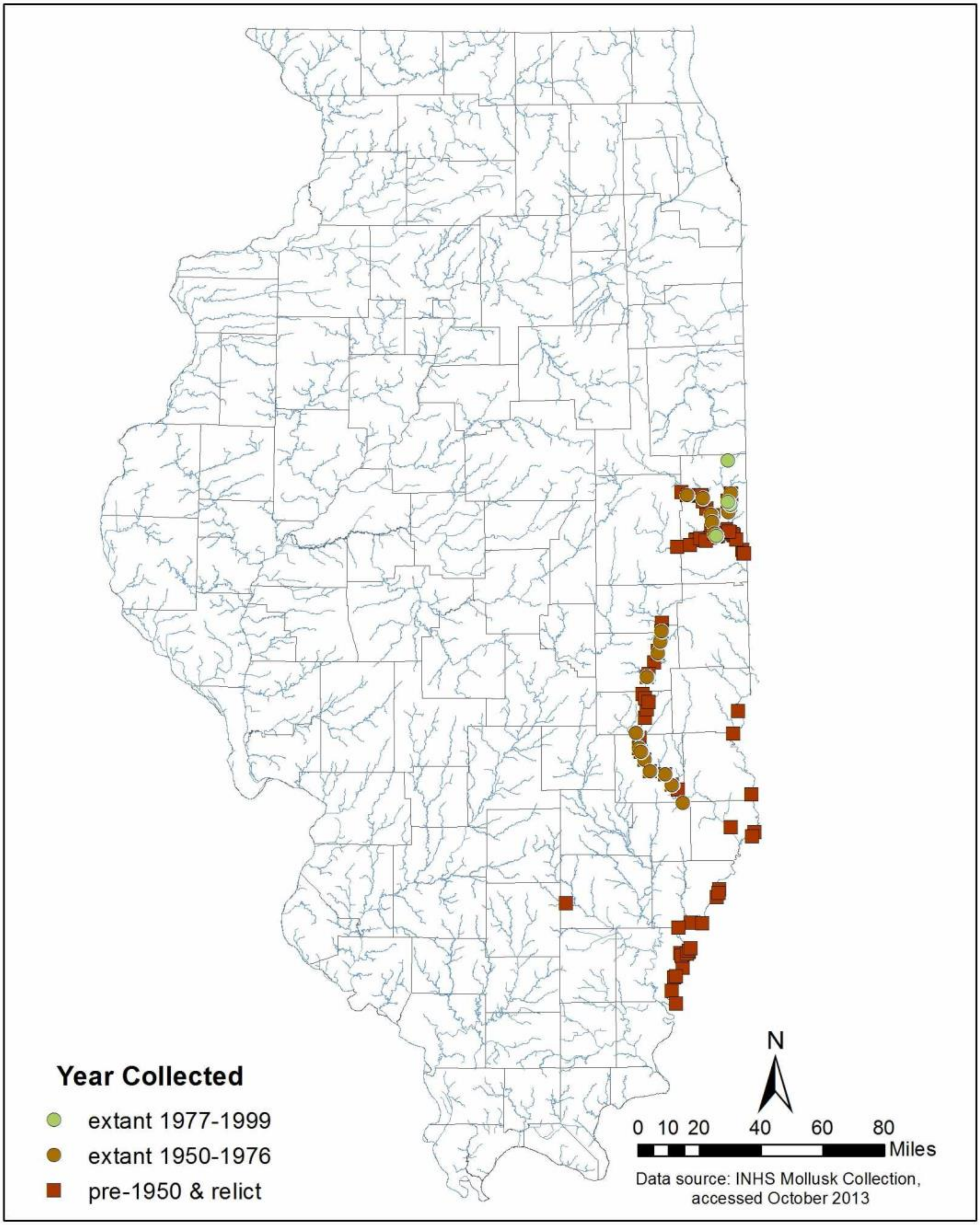
# Hickorynut (*Obovaria olivaria*)



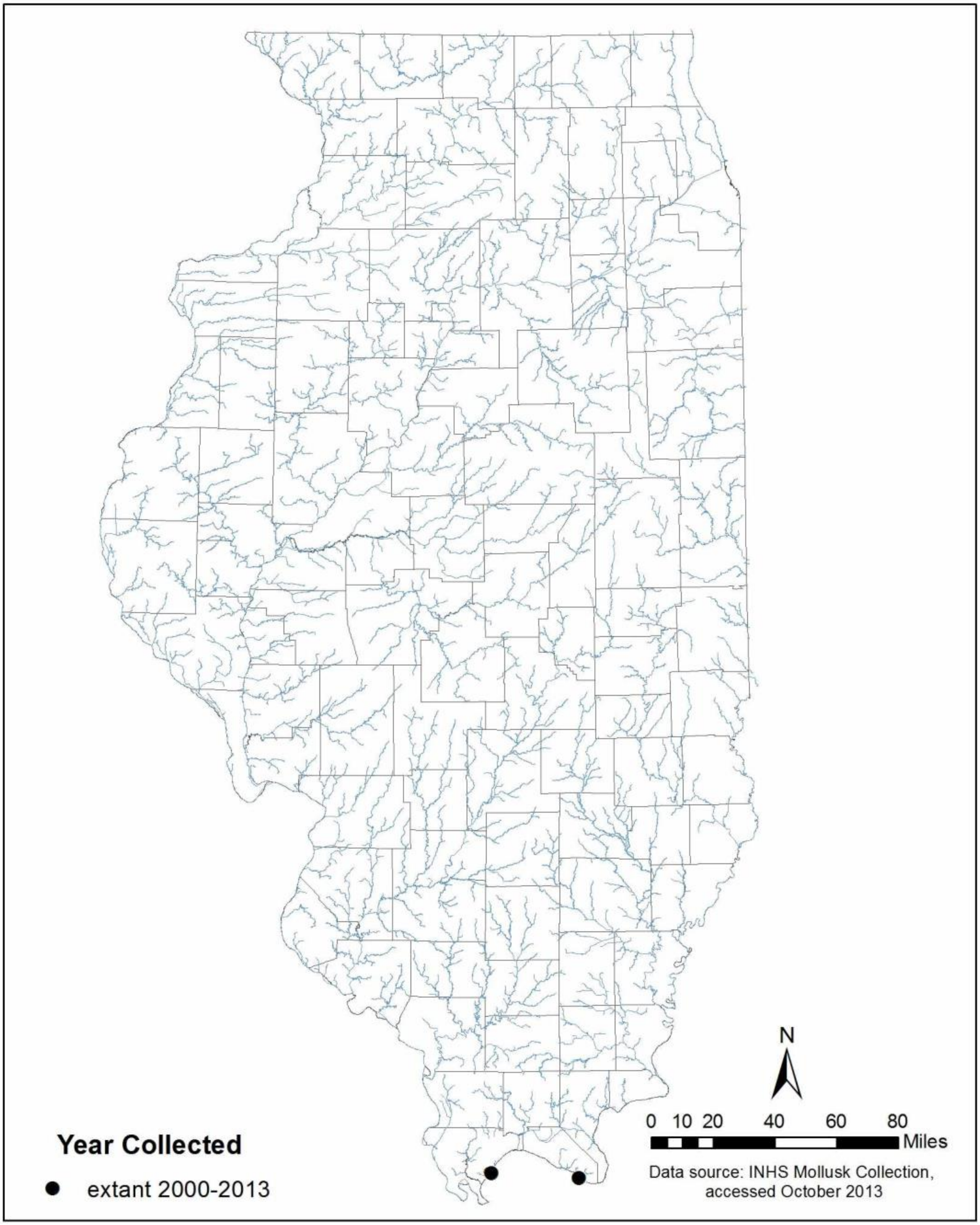
# Ring pink (*Obovaria retusa*)



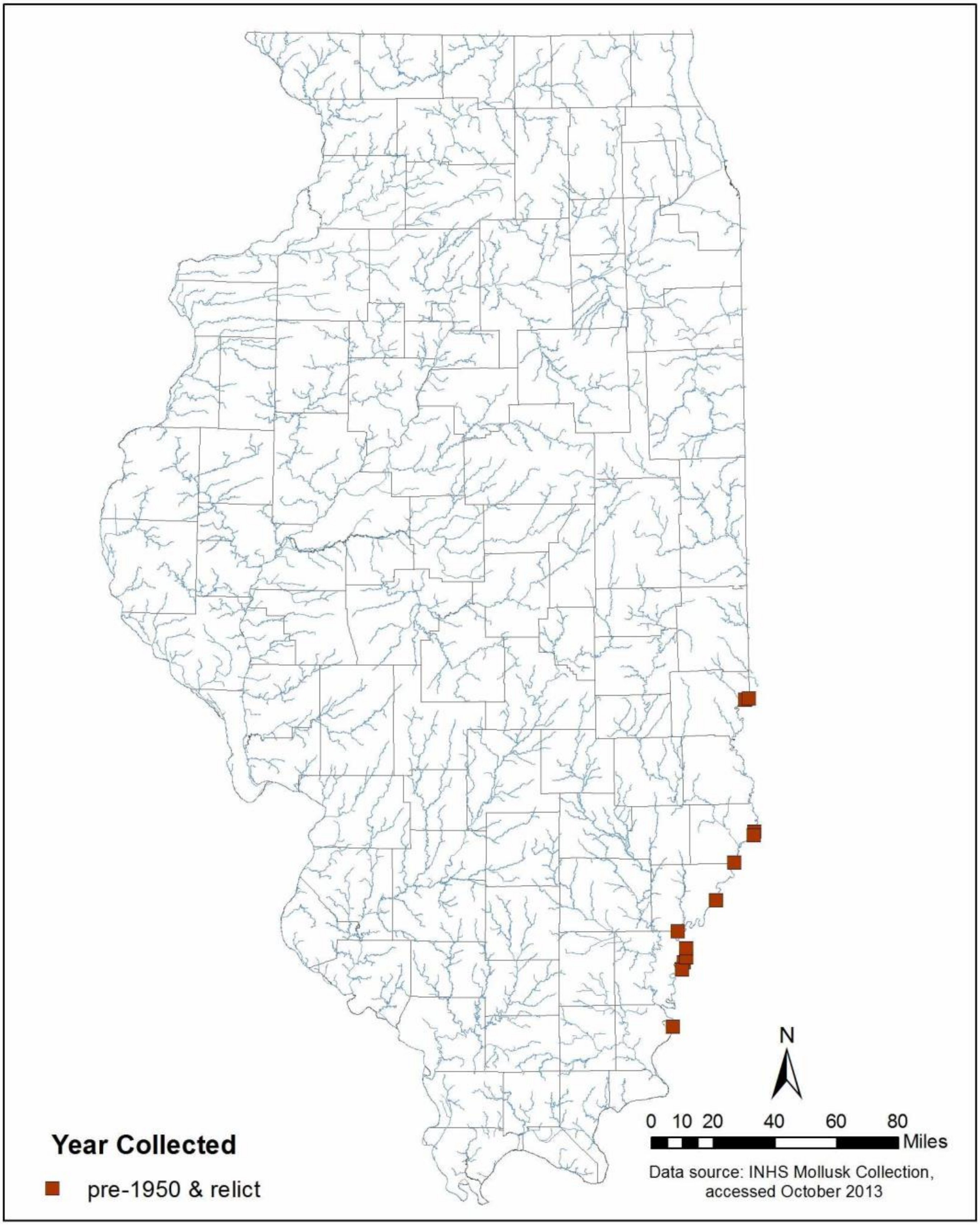
# Round hickorynut (*Obovaria subrotunda*)



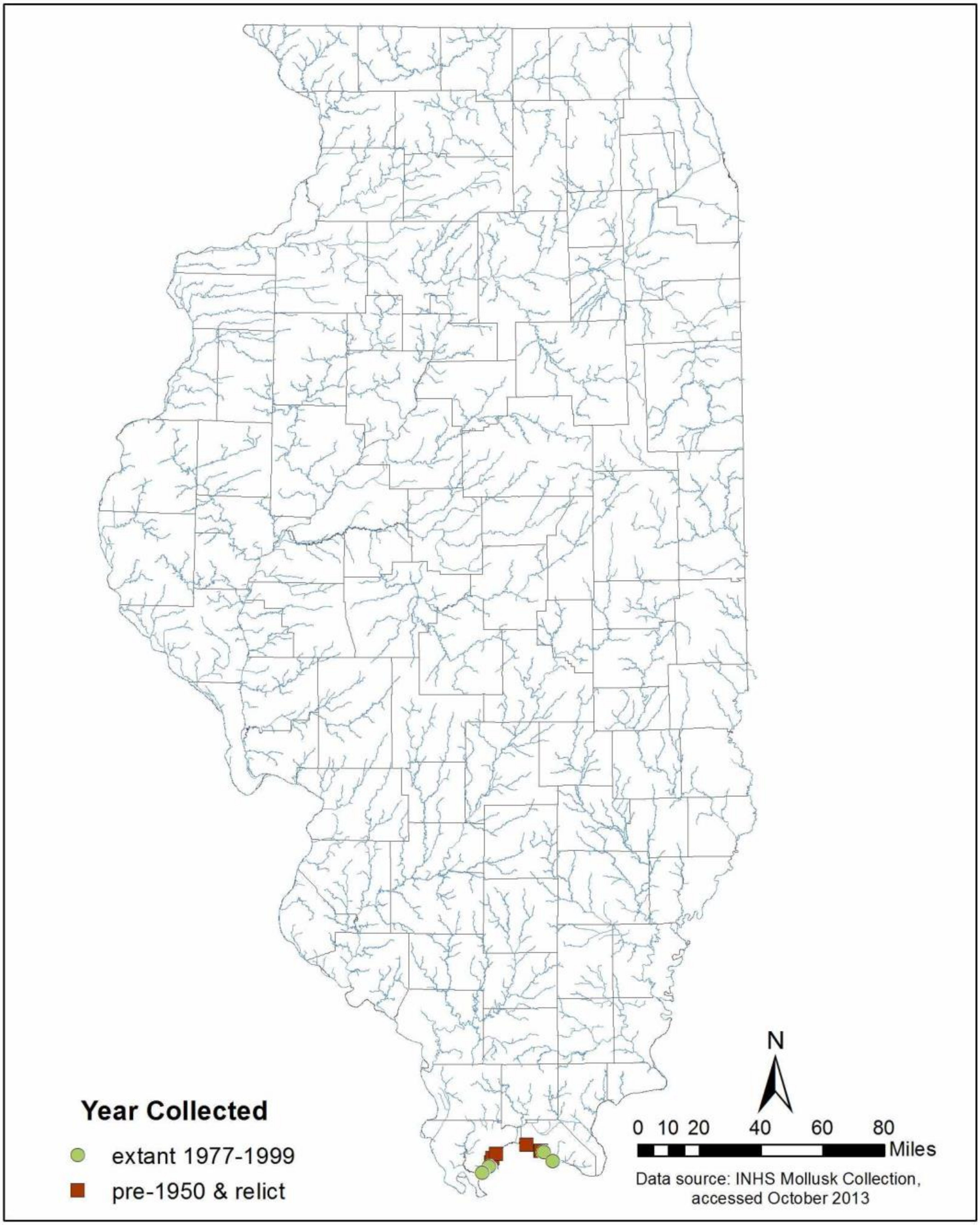
# Bankclimber (*Plectomerus dombeyanus*)



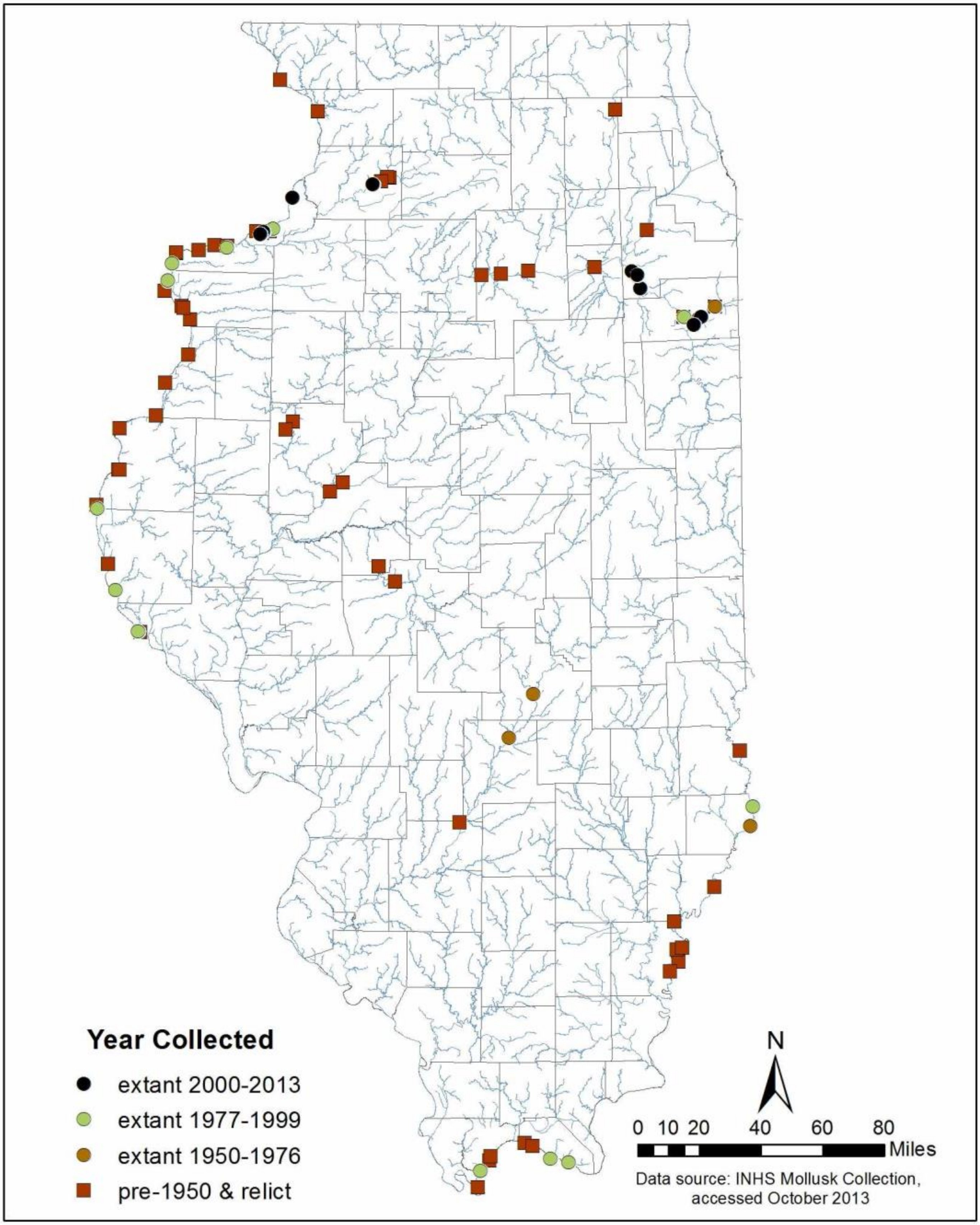
## White wartyback (*Plethobasus cicatricosus*)



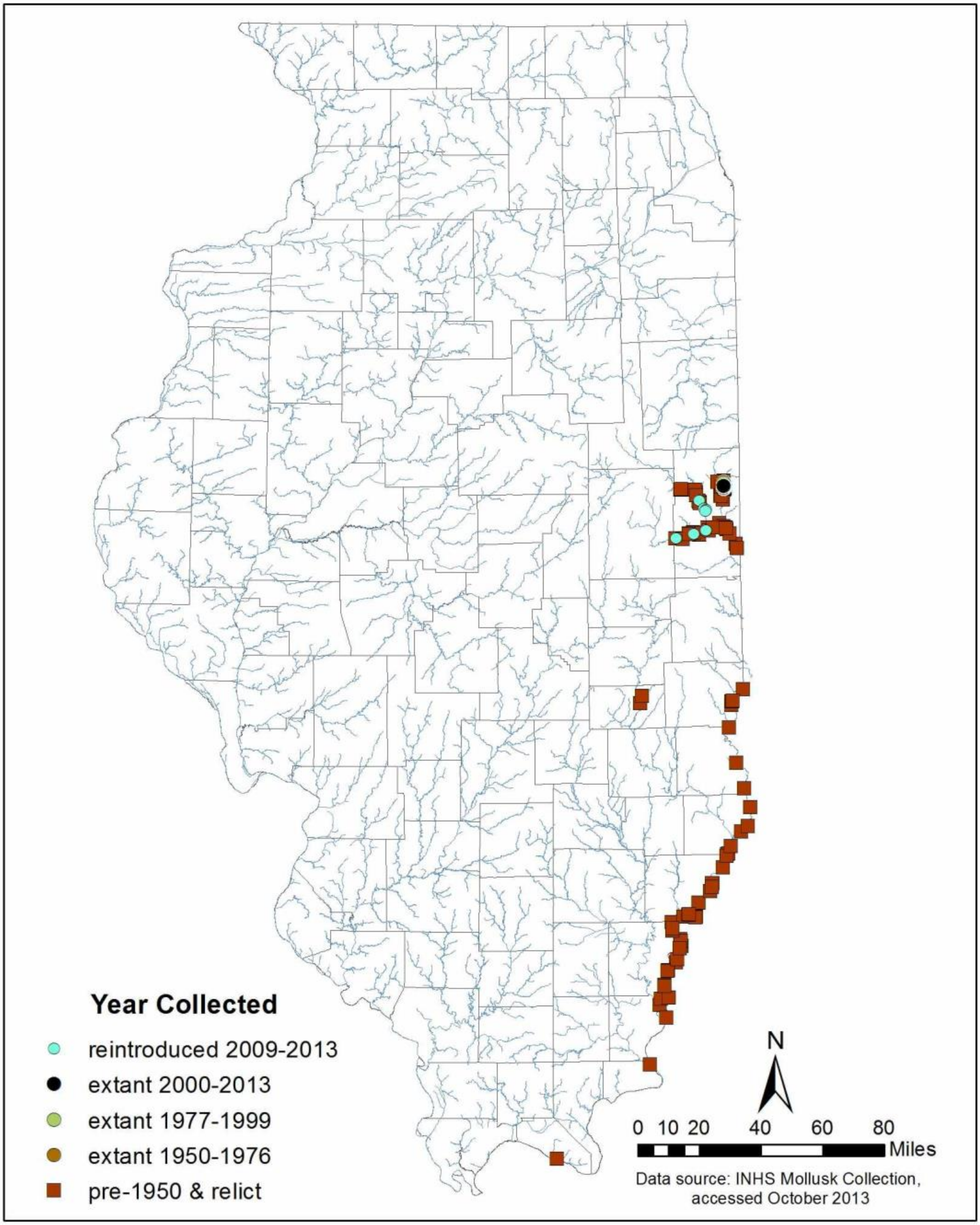
# Orangefoot pimpleback (*Plethobasus cooperianus*)



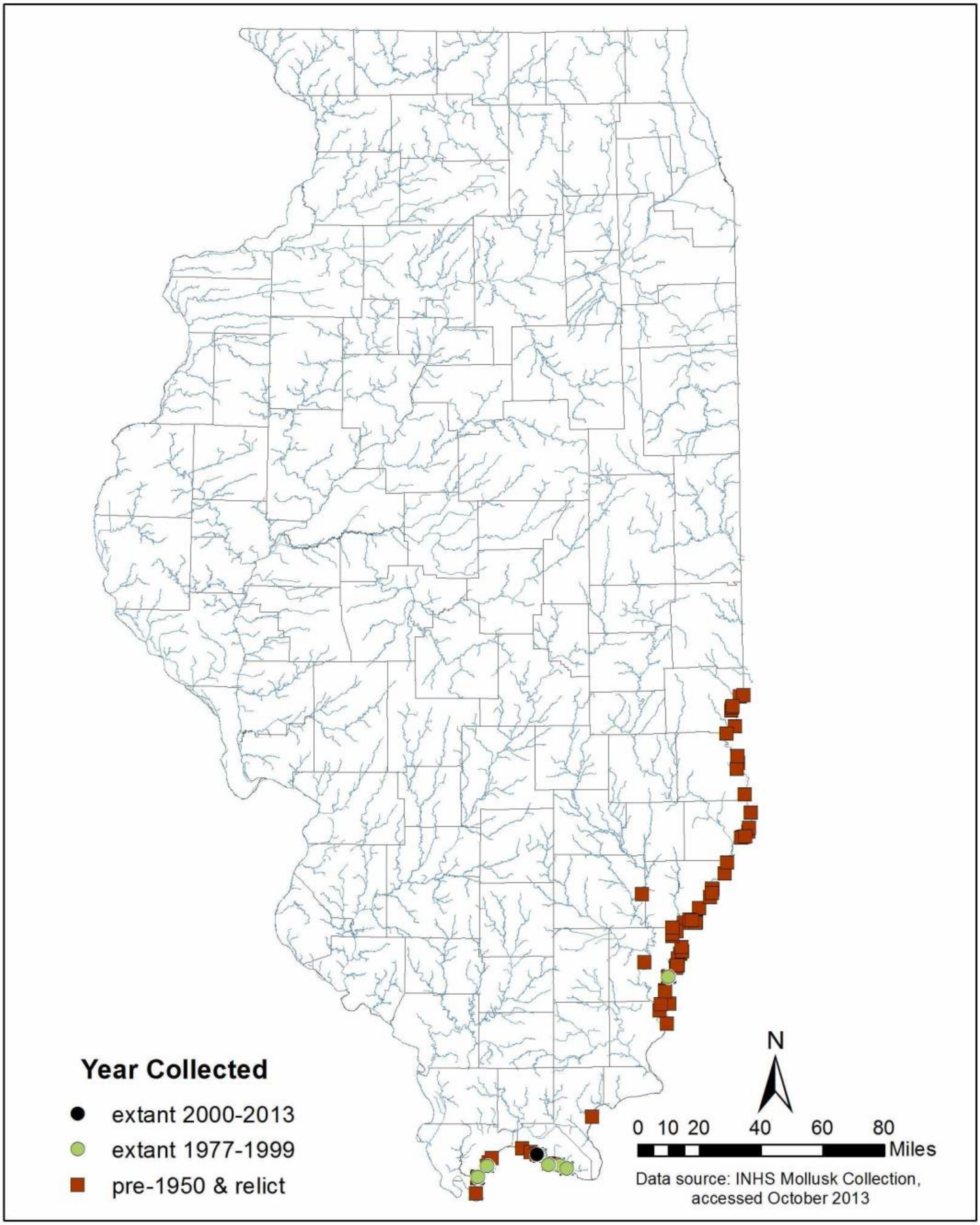
# Sheepnose (*Plethobasus cyphyus*)



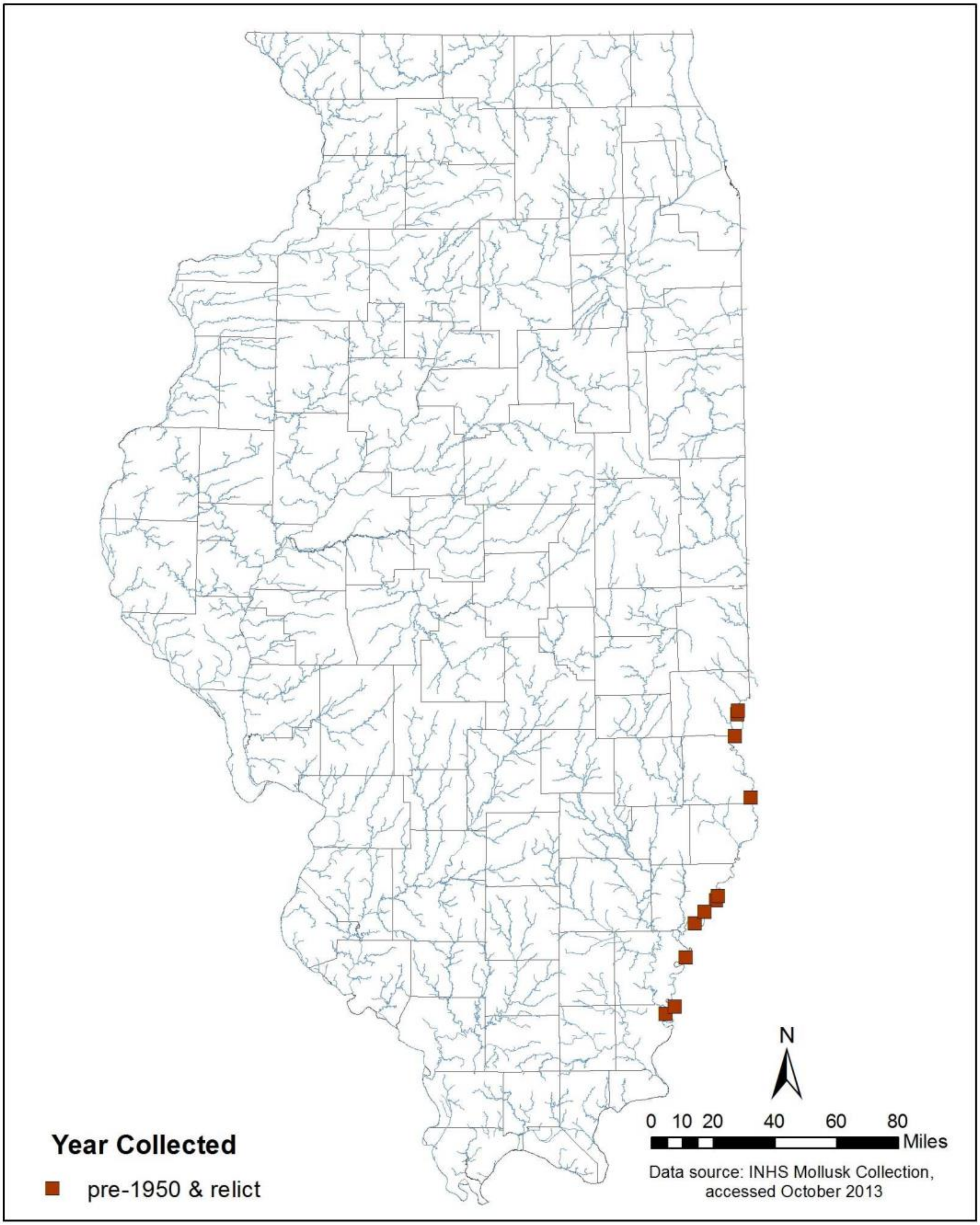
# Clubshell (*Pleurobema clava*)



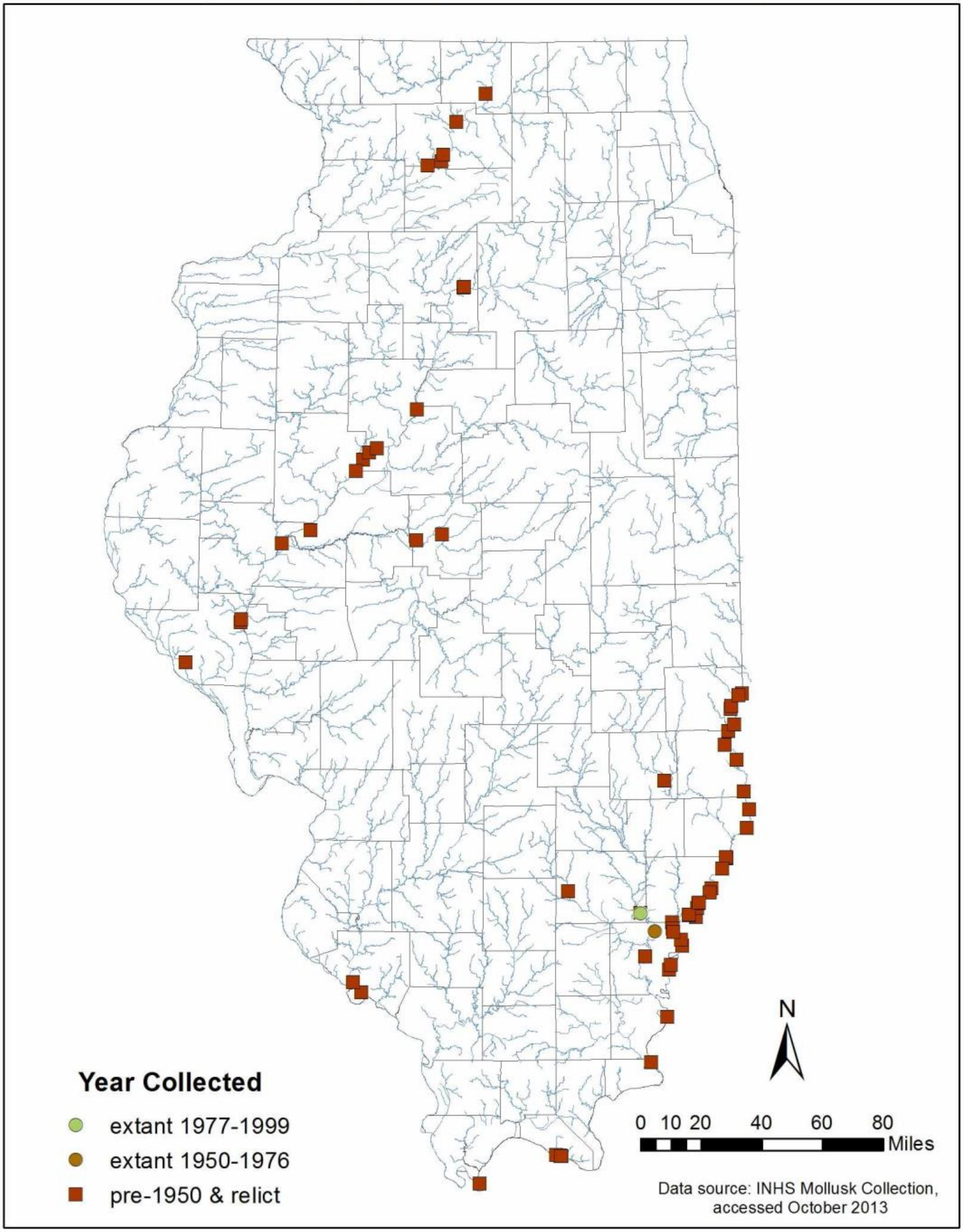
## Ohio pigtoe (*Pleurobema cordatum*)

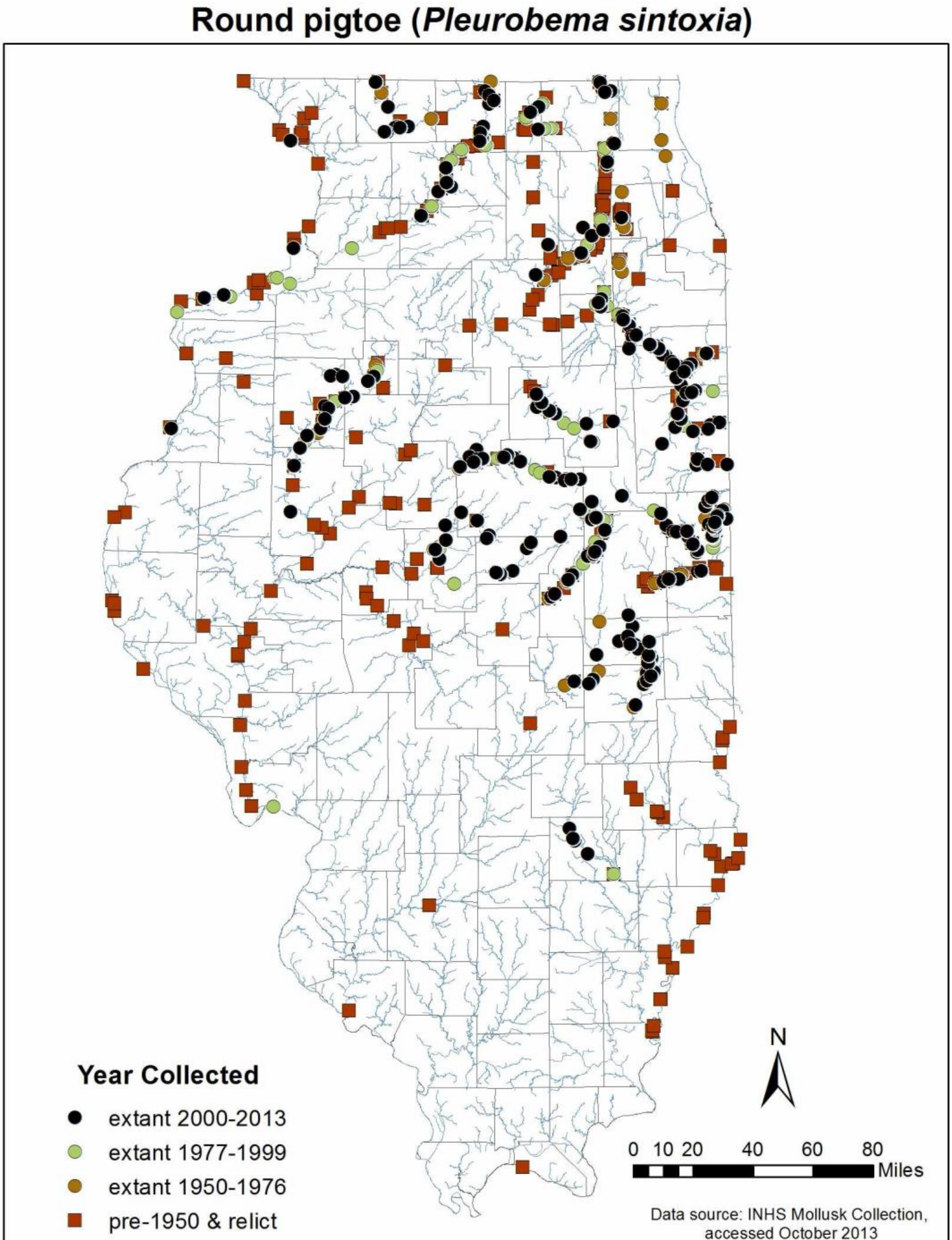


# Rough pigtoe (*Pleurobema plenum*)

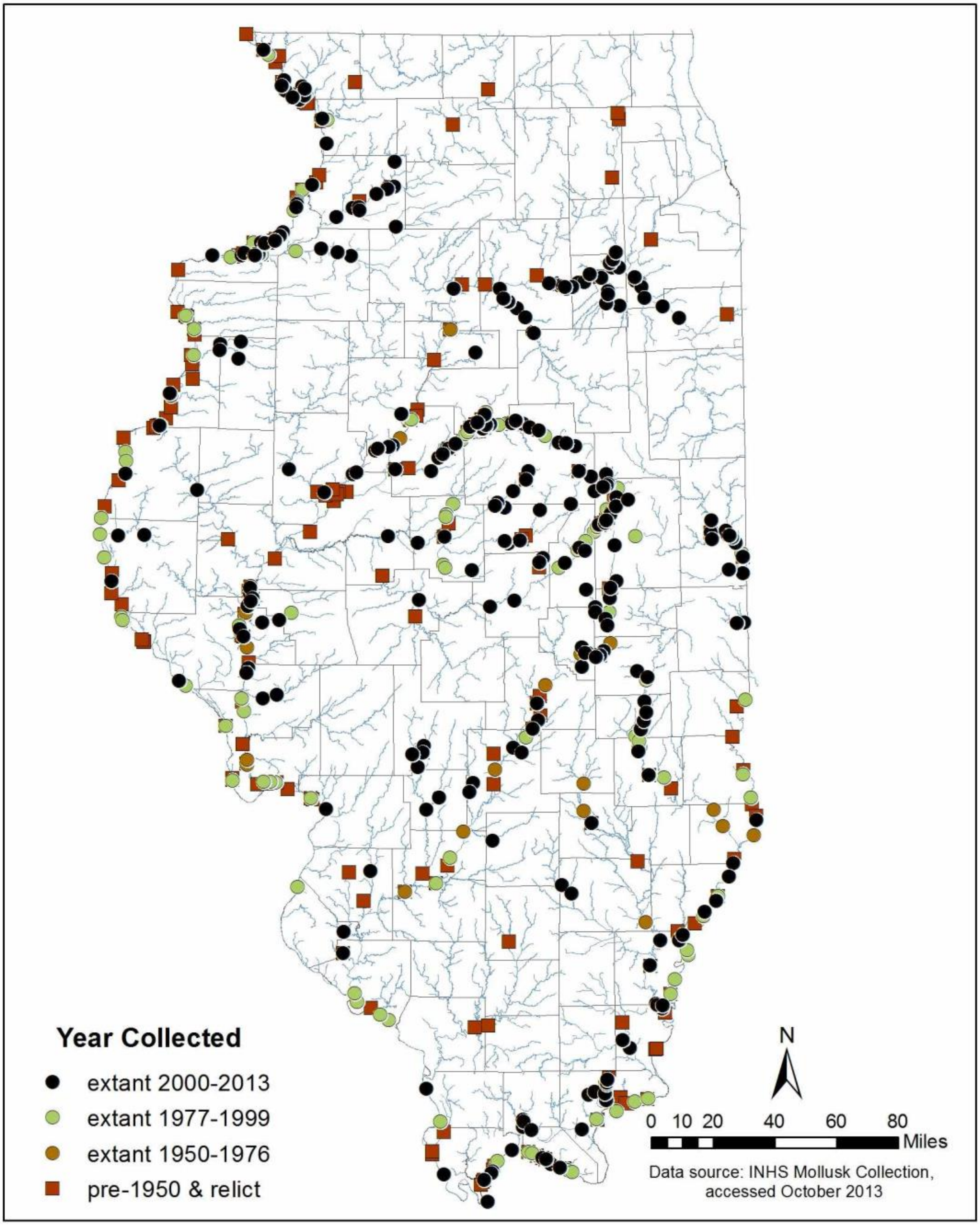


## Pyramid pigtoe (*Pleurobema rubrum*)

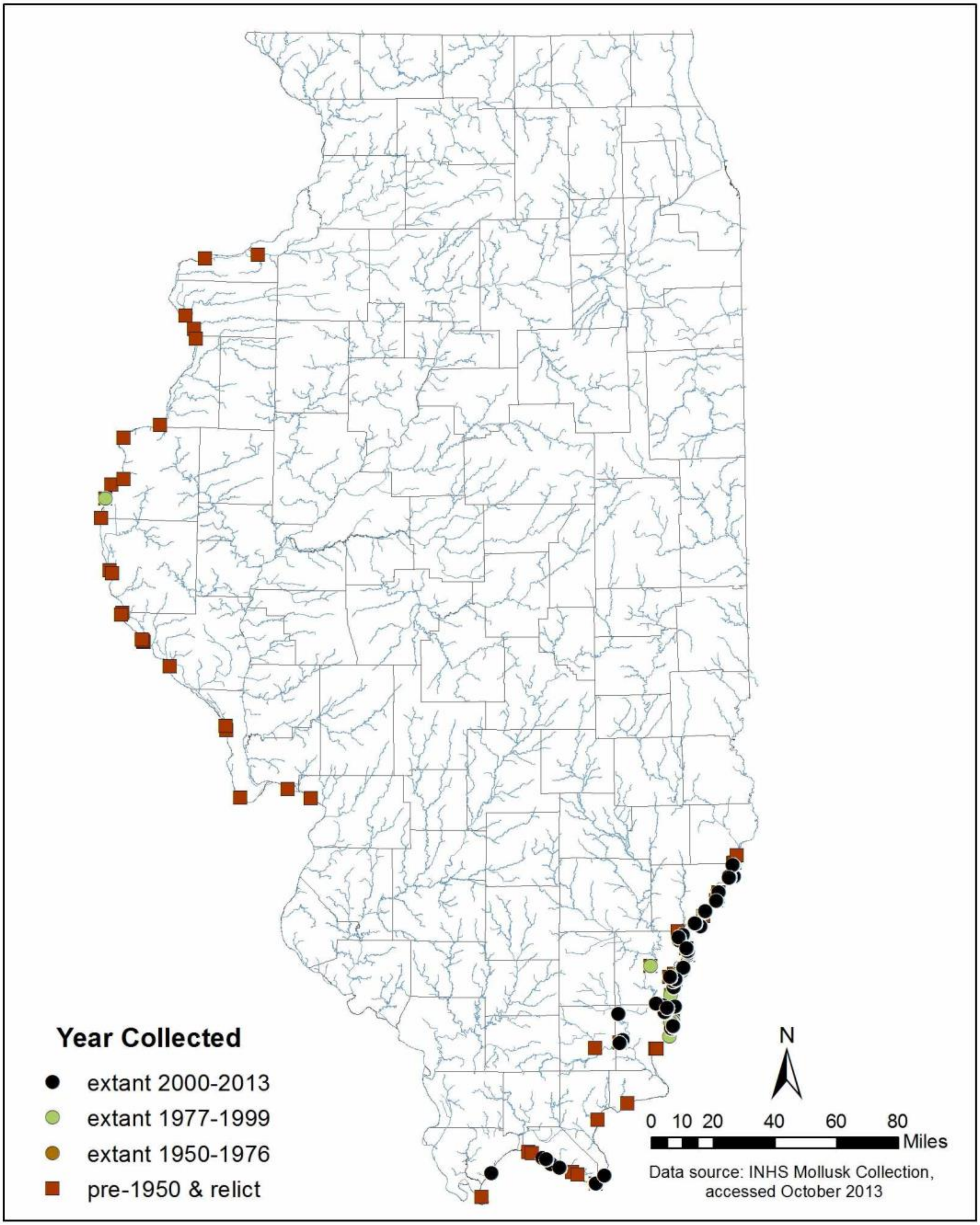



Round pigtoe (*Pleurobema sintoxia*)
Year Collected
extant 2000-2013
extant 1977-1999
extant 1950-1976
pre-1950 & relict
N
0 10 20 40 60 80
Miles
Data source: INHS Mollusk Collection, accessed October 2013

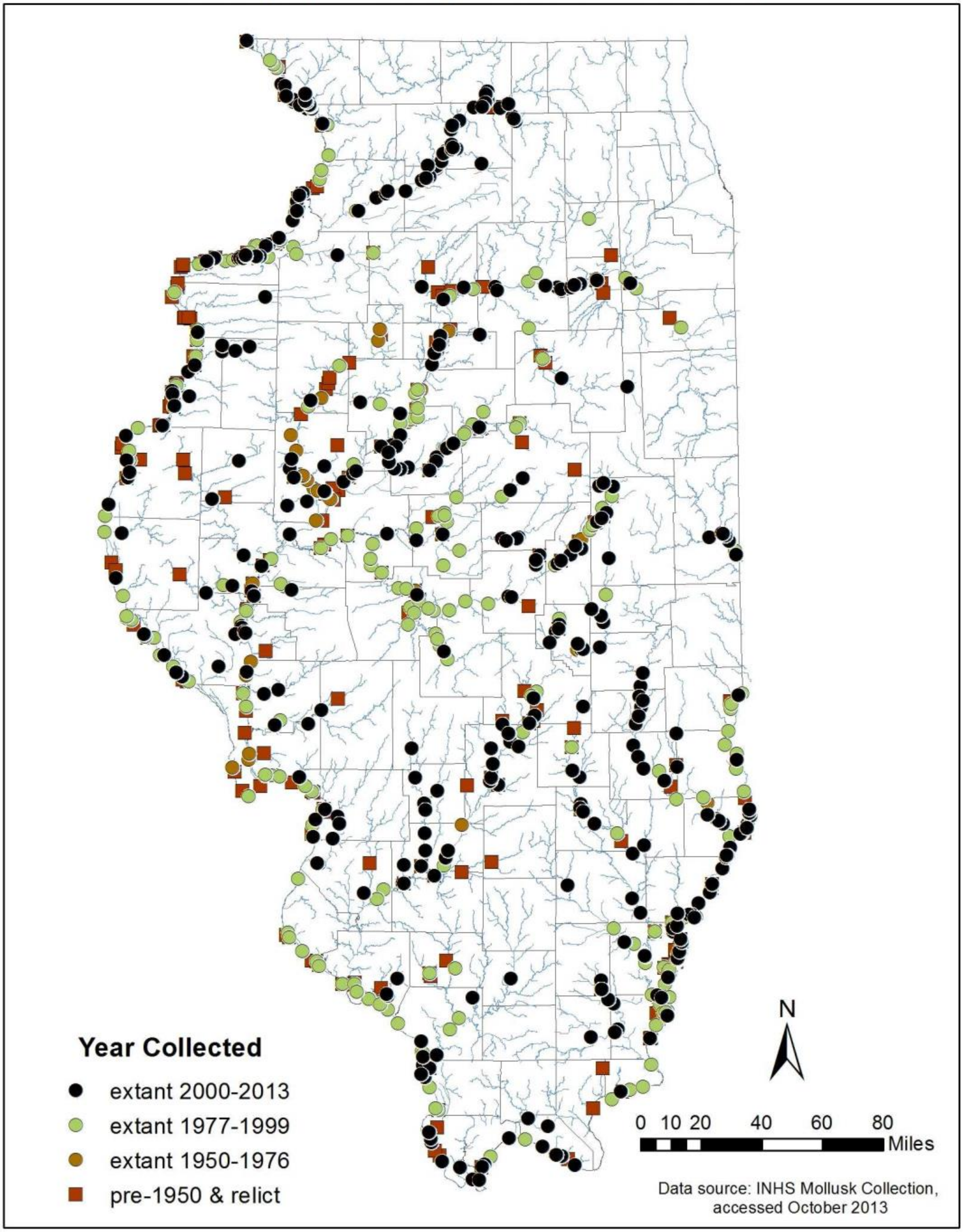
# Pink heelsplitter (*Potamilus alatus*)



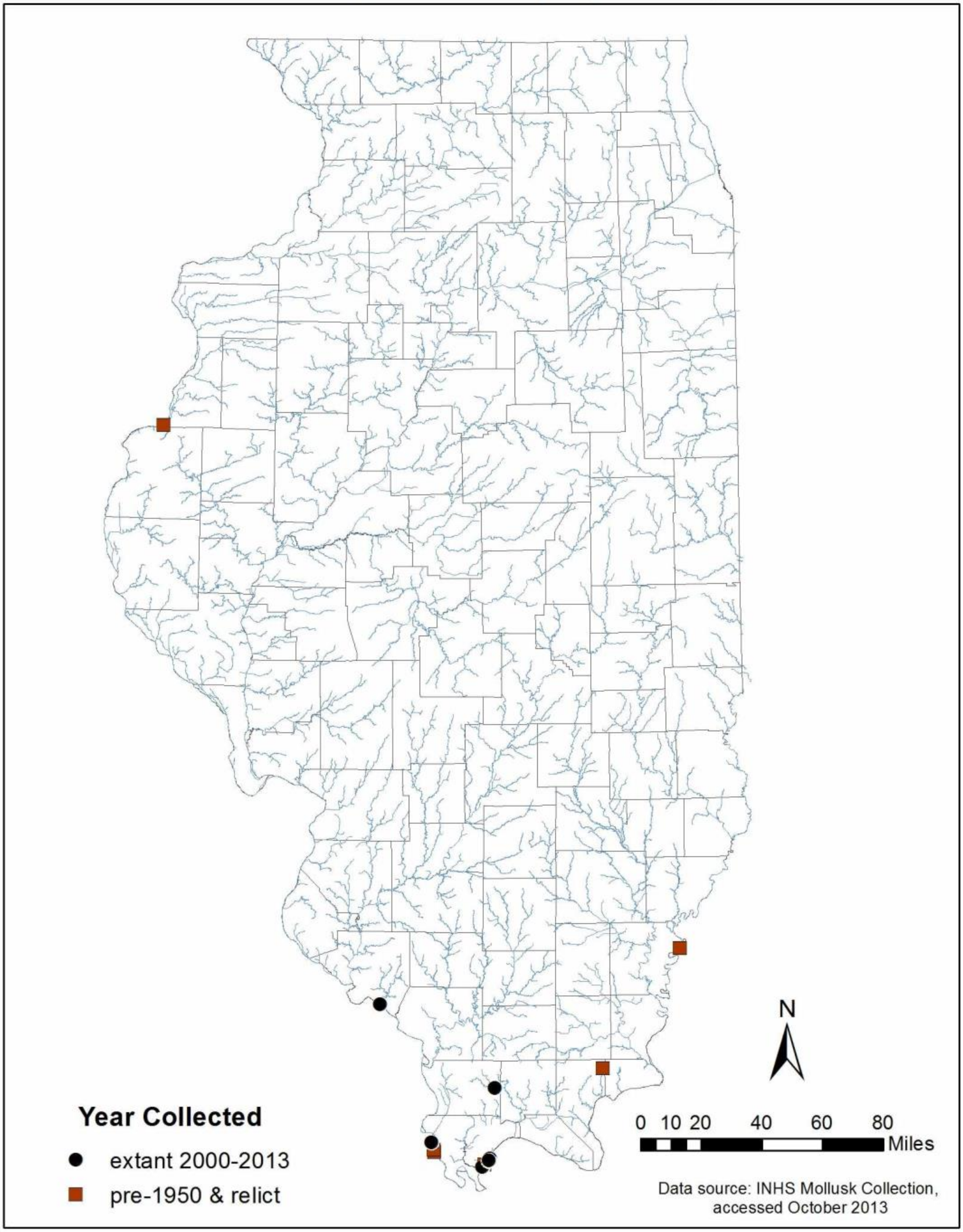
# Fat pocketbook (*Potamilus capax*)

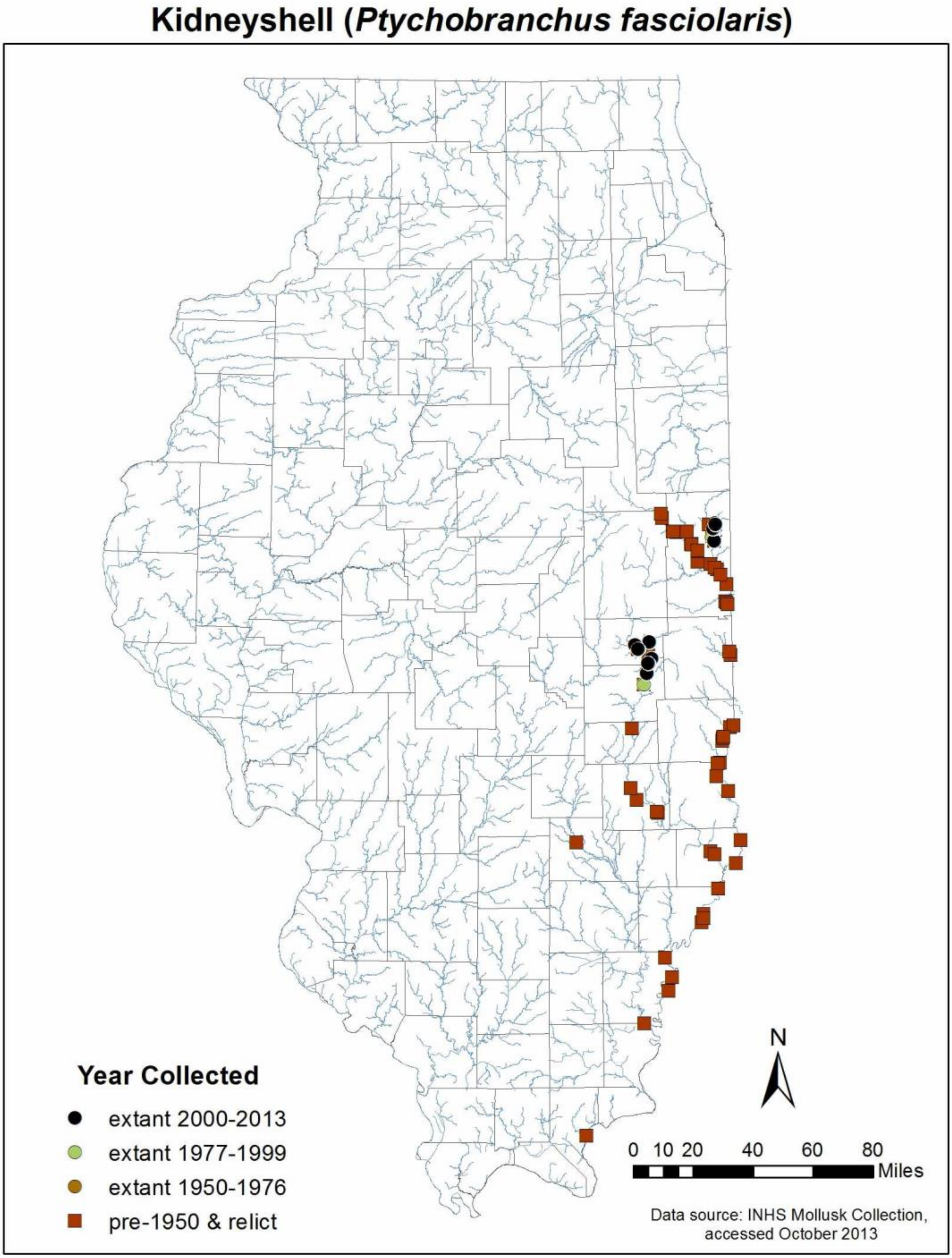


# Pink papershell (*Potamilus ohiensis*)

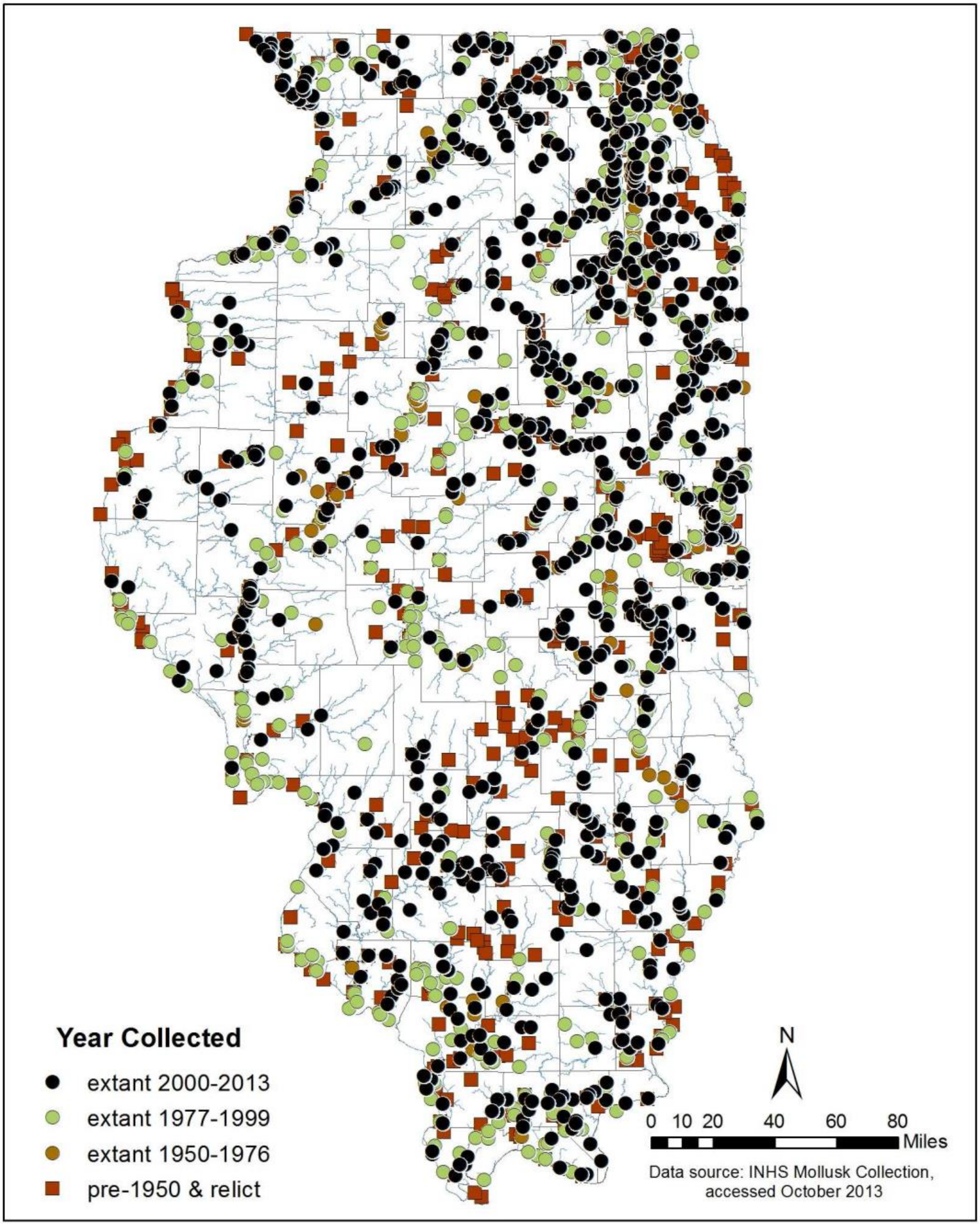


## Bleufer (*Potamilus purpuratus*)

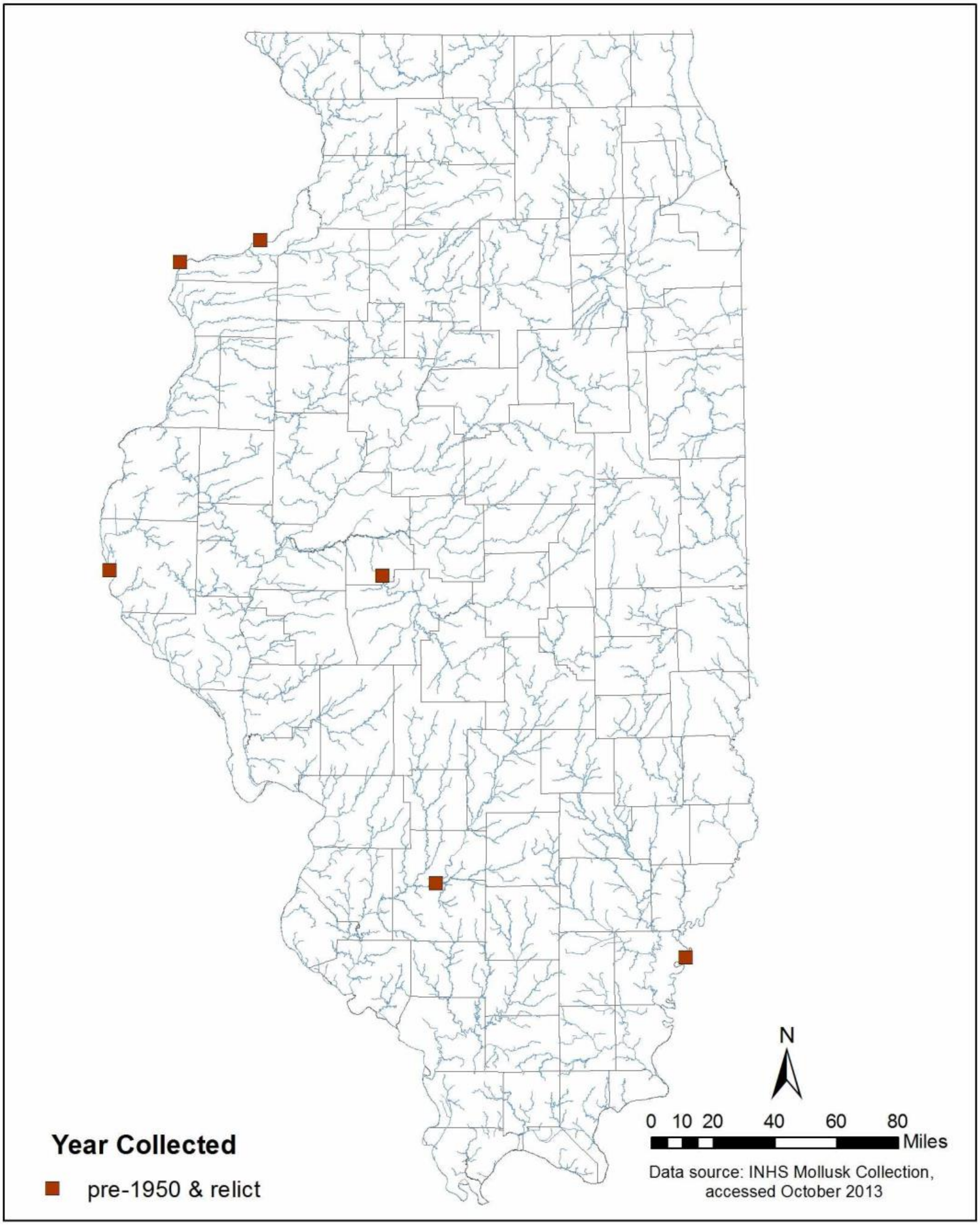



Kidneyshell (*Ptychobranchus fasciolaris*)
Year Collected
extant 2000-2013
extant 1977-1999
extant 1950-1976
pre-1950 & relict
N
0 10 20 40 60 80
Miles
Data source: INHS Mollusk Collection, accessed October 2013

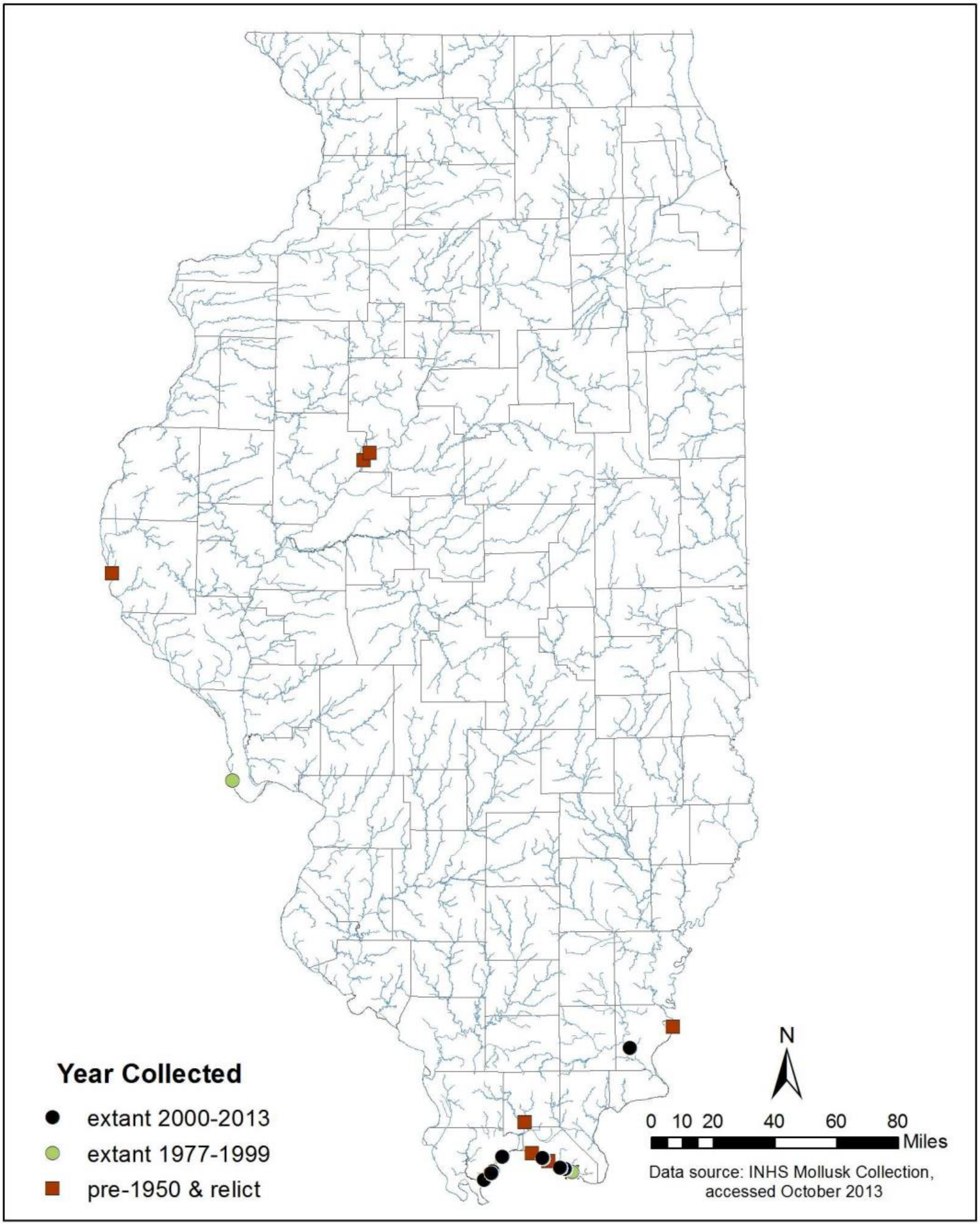
# Giant floater (*Pyganodon grandis*)



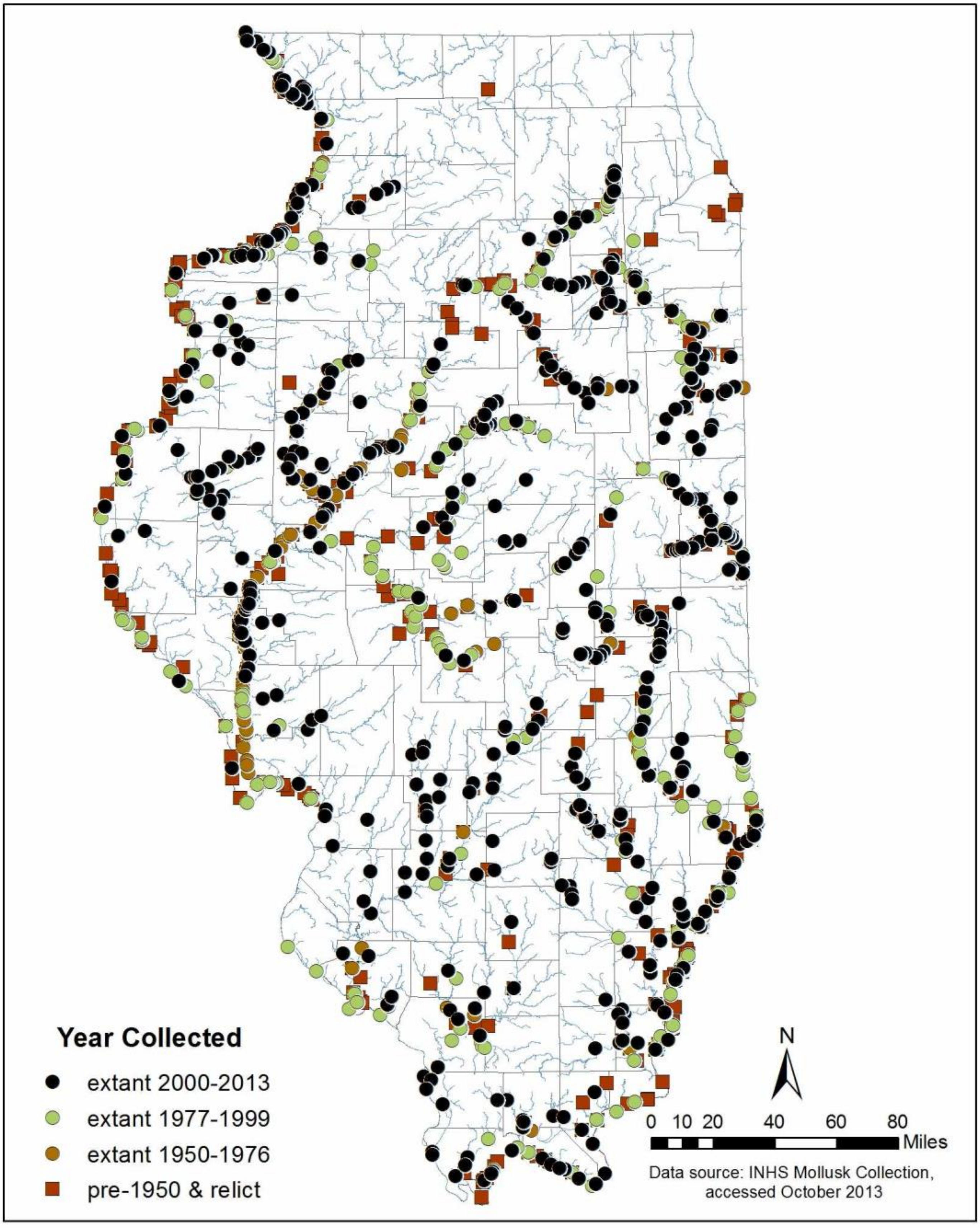
# Winged mapleleaf (*Quadrula fragosa*)



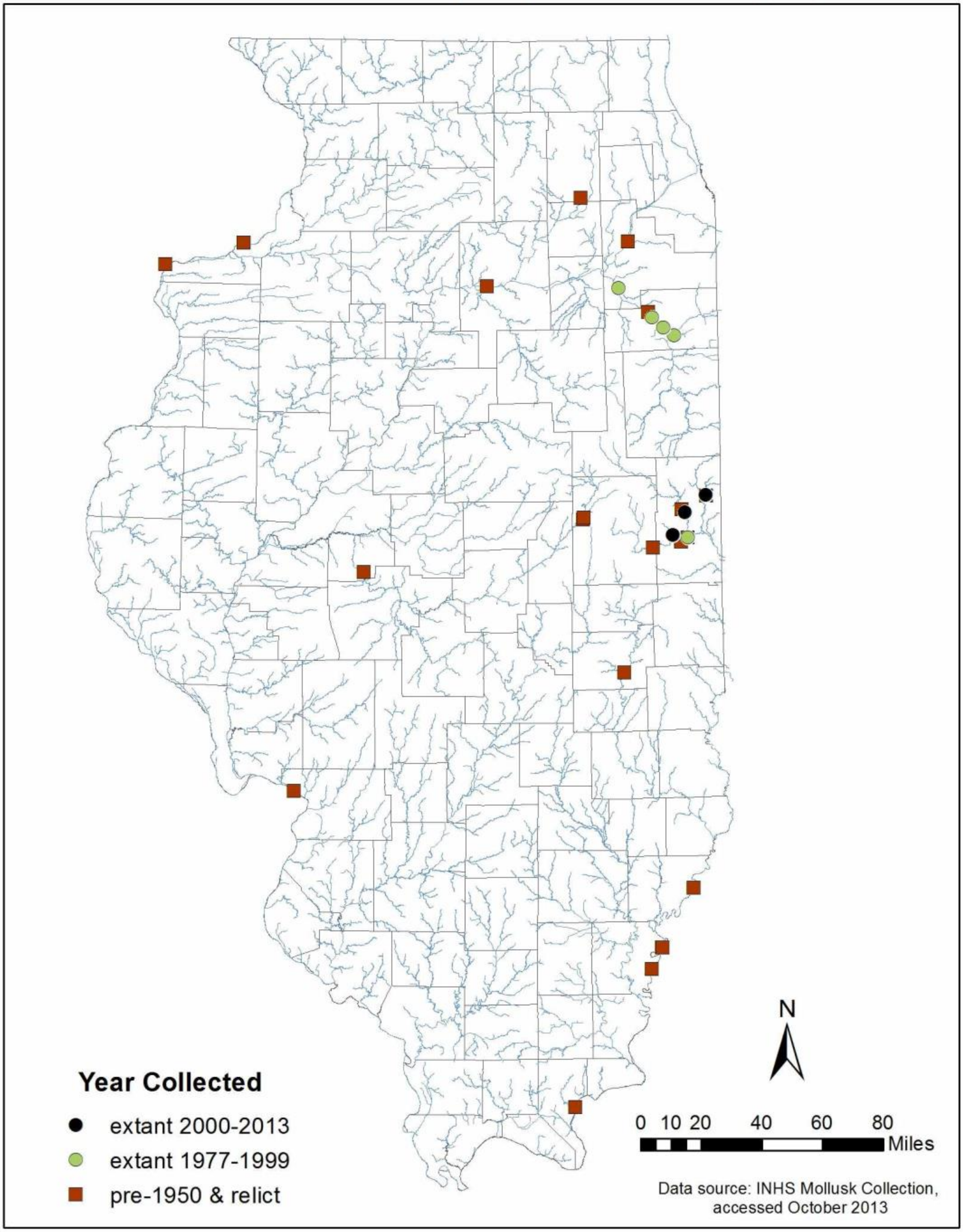
# Gulf mapleleaf (*Quadrula nobilis*)



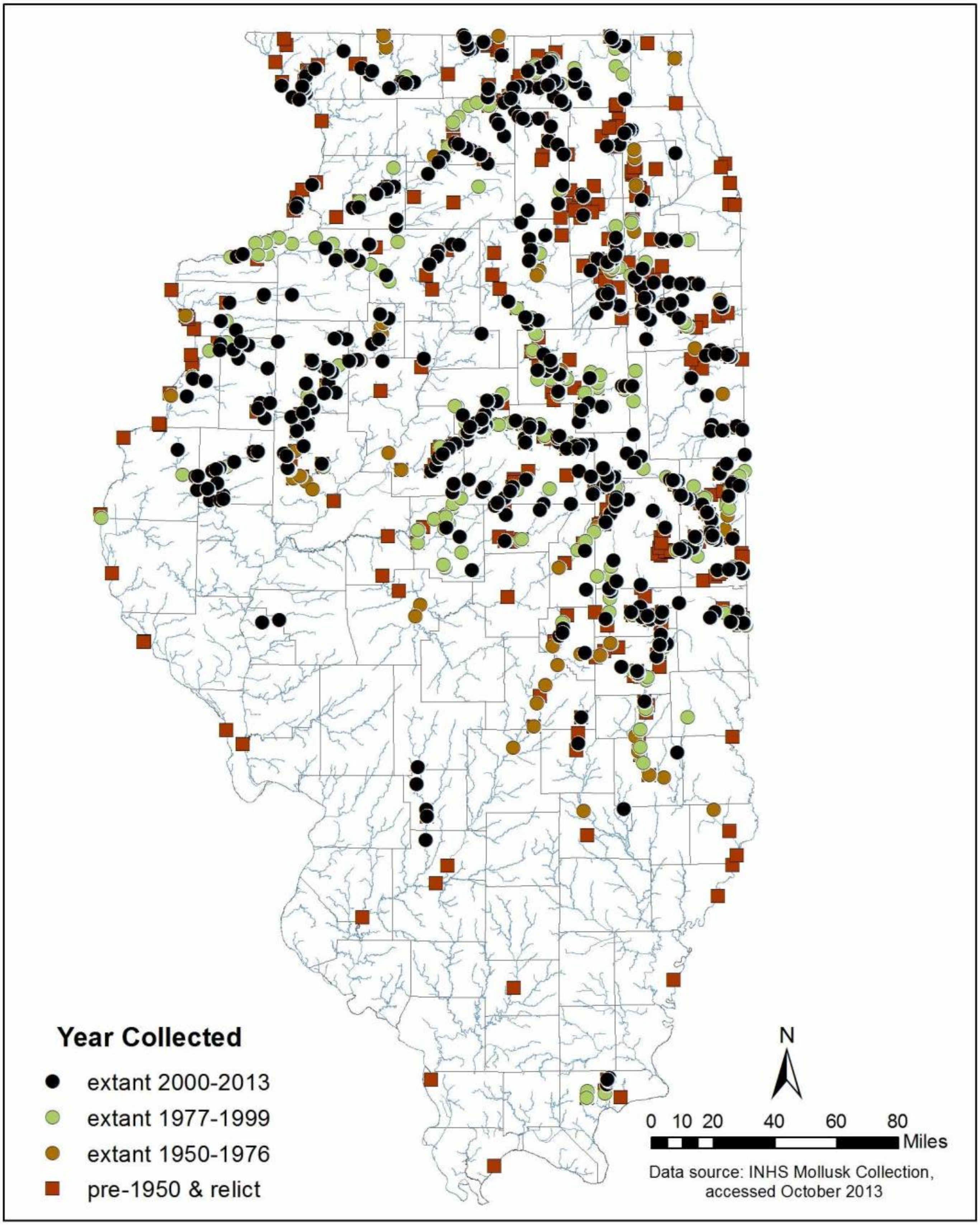
# Mapleleaf (*Quadrula quadrula*)



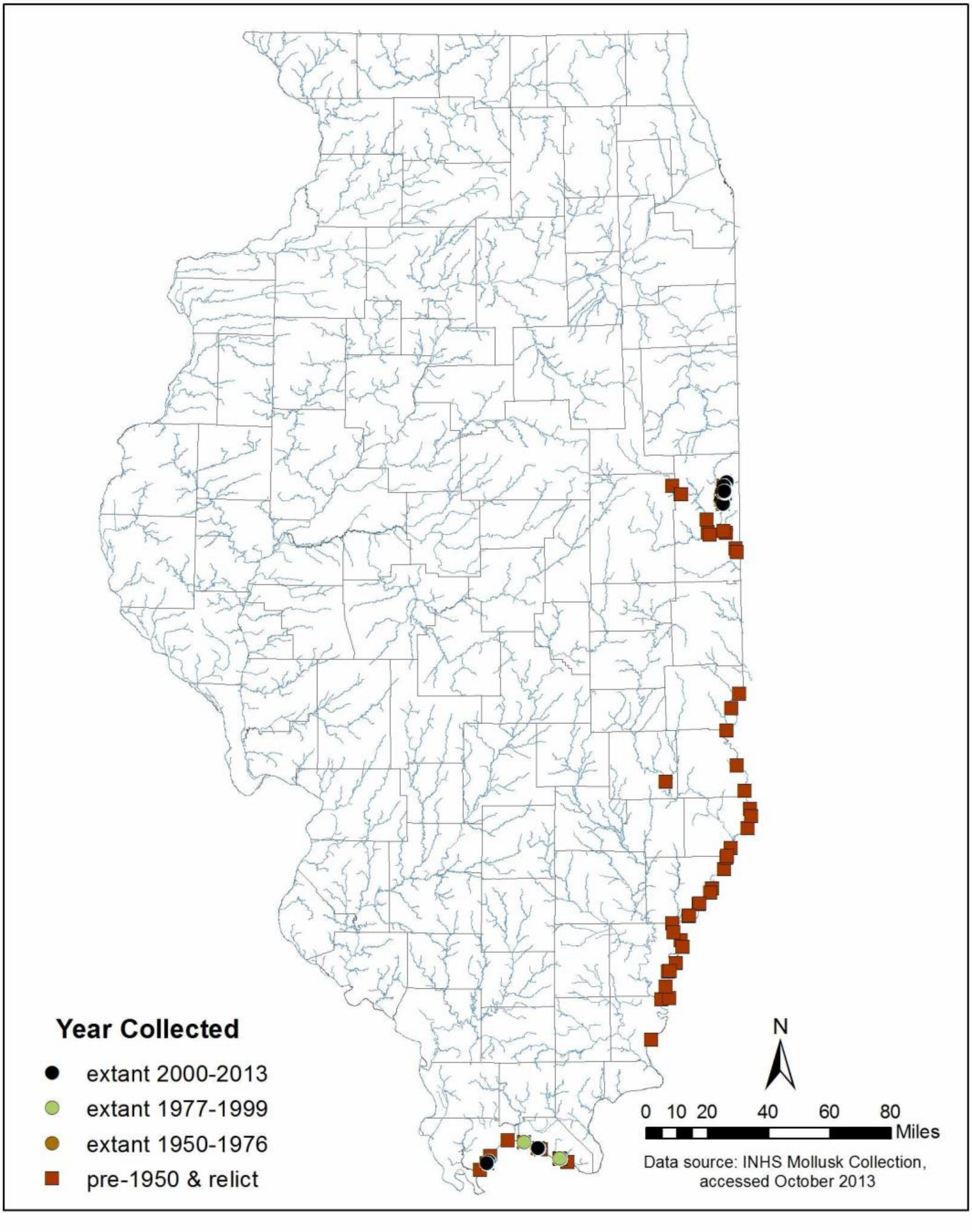
# Salamander mussel (*Simpsonaias ambigua*)



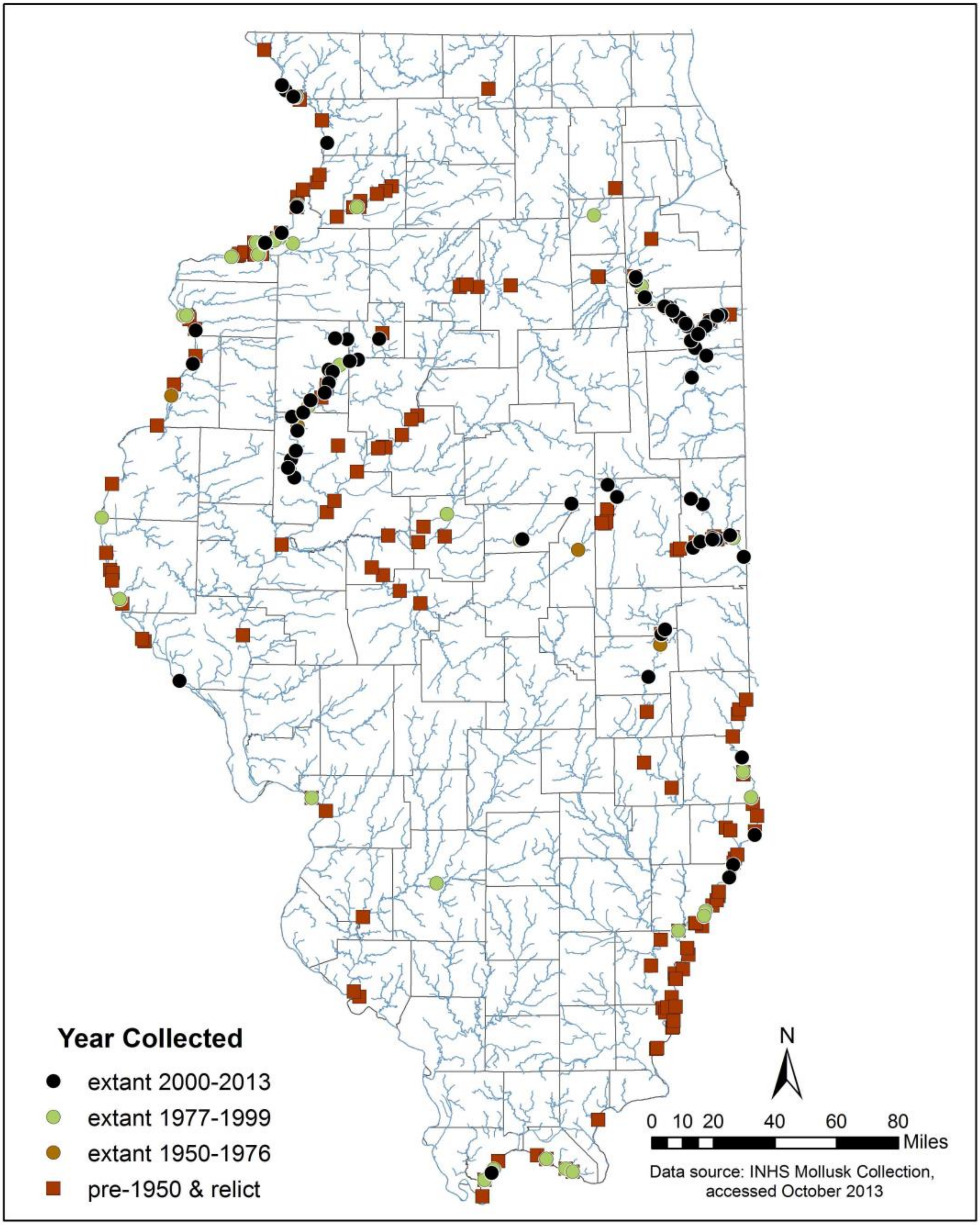
## Creeper (*Strophitus undulatus*)



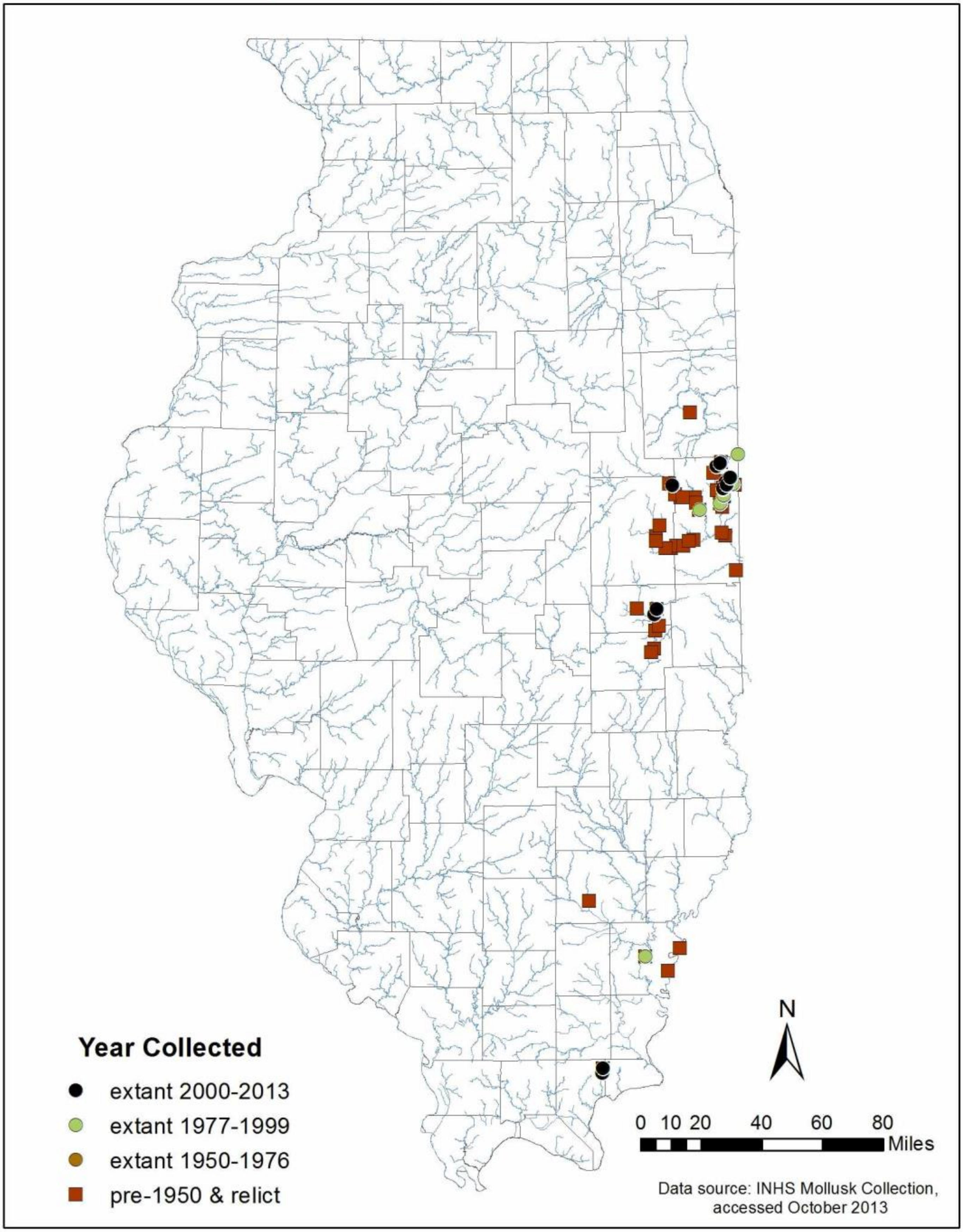
## Rabbitsfoot (*Theliderma cylindrica*)



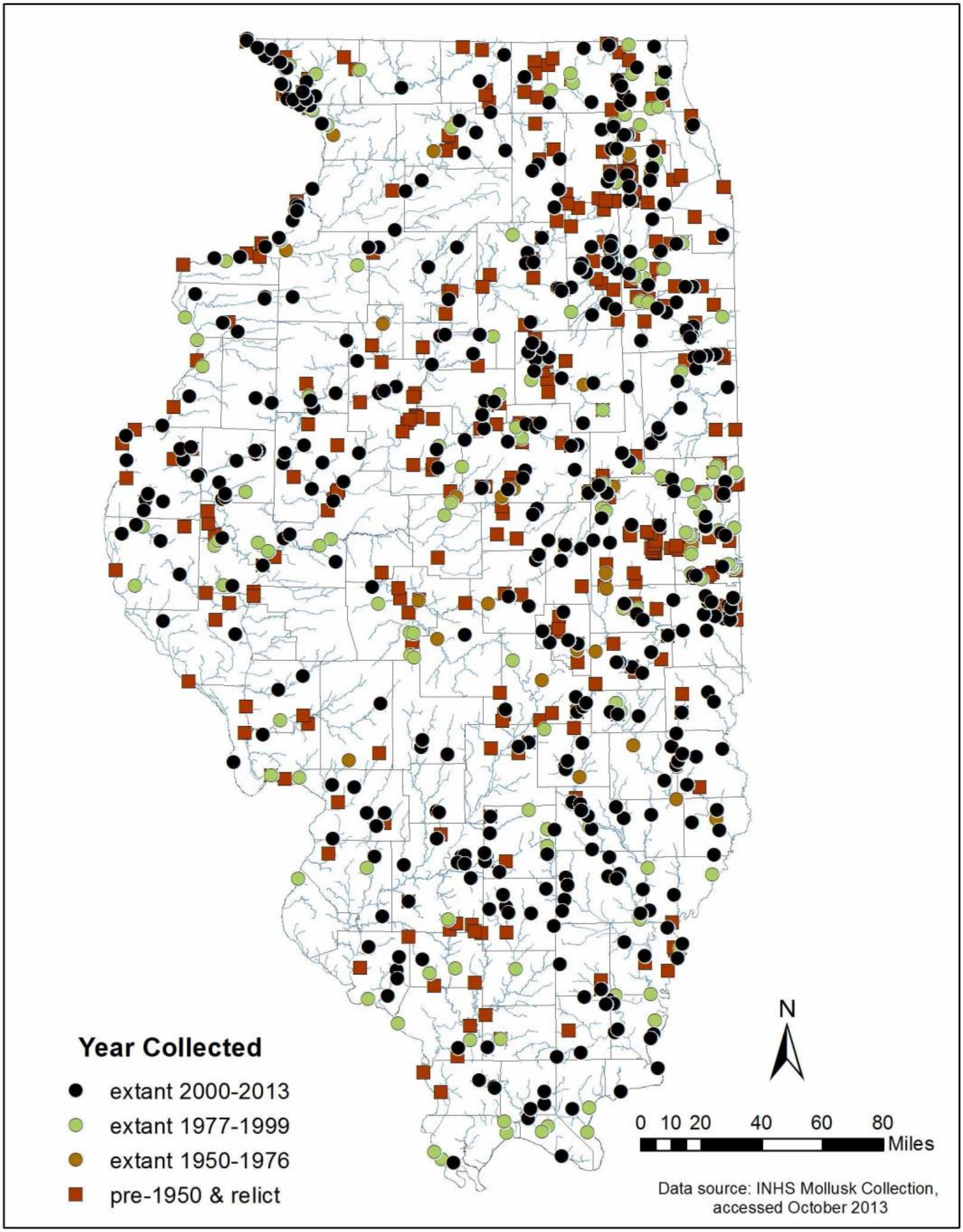
# Monkeyface (*Theliderma metanevra*)



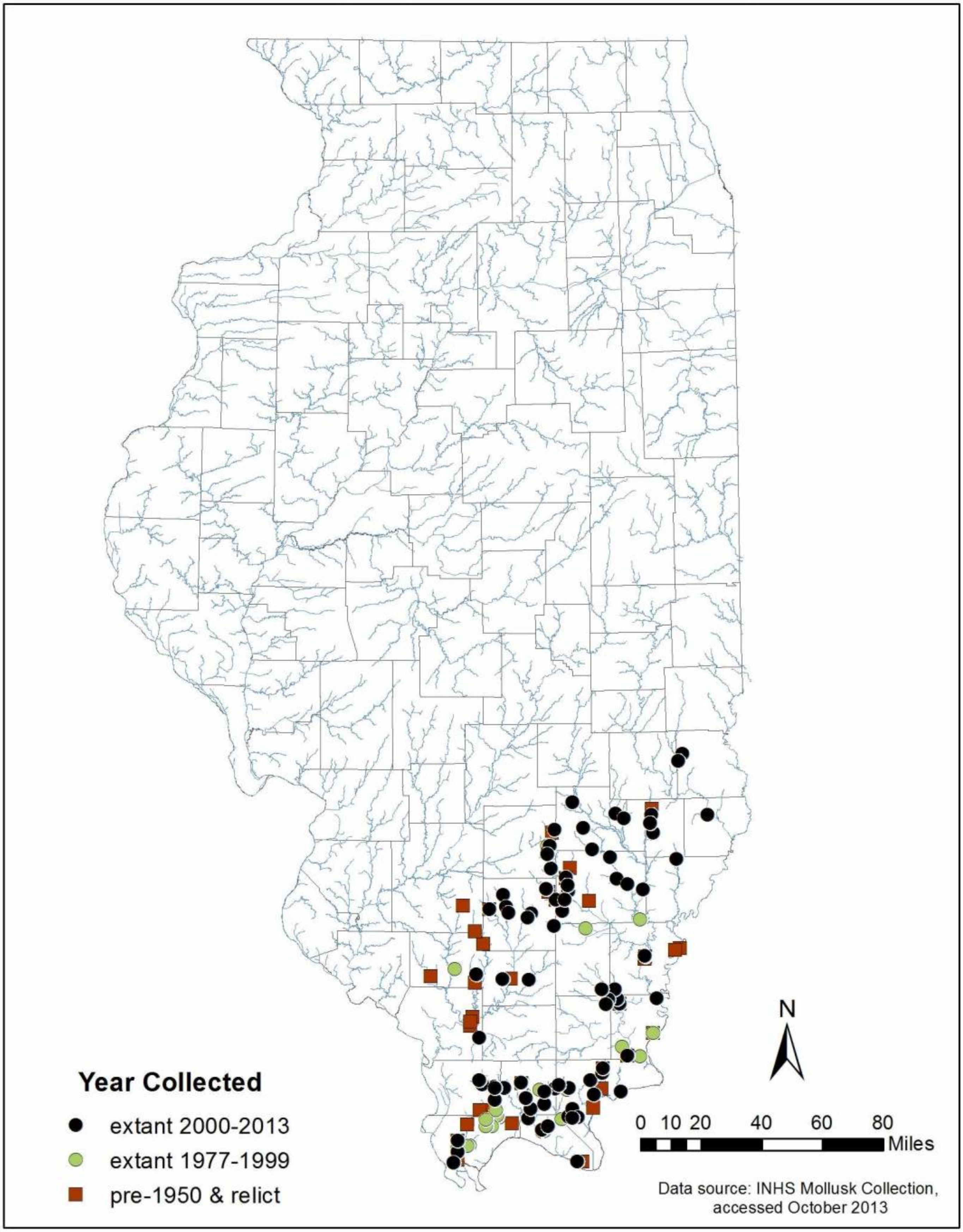
## Purple lilliput (*Toxolasma lividum*)



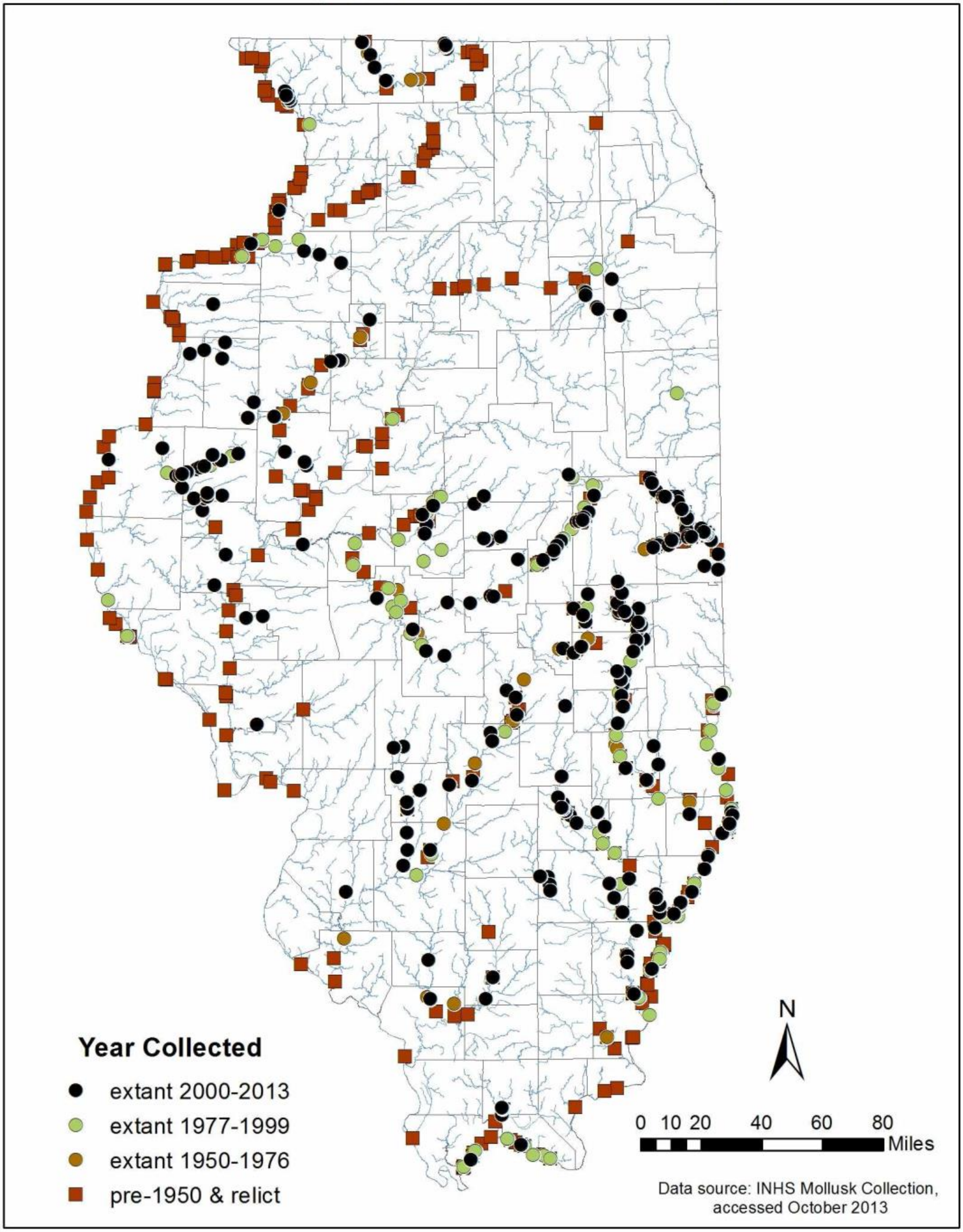
# Lilliput (*Toxolasma parvum*)



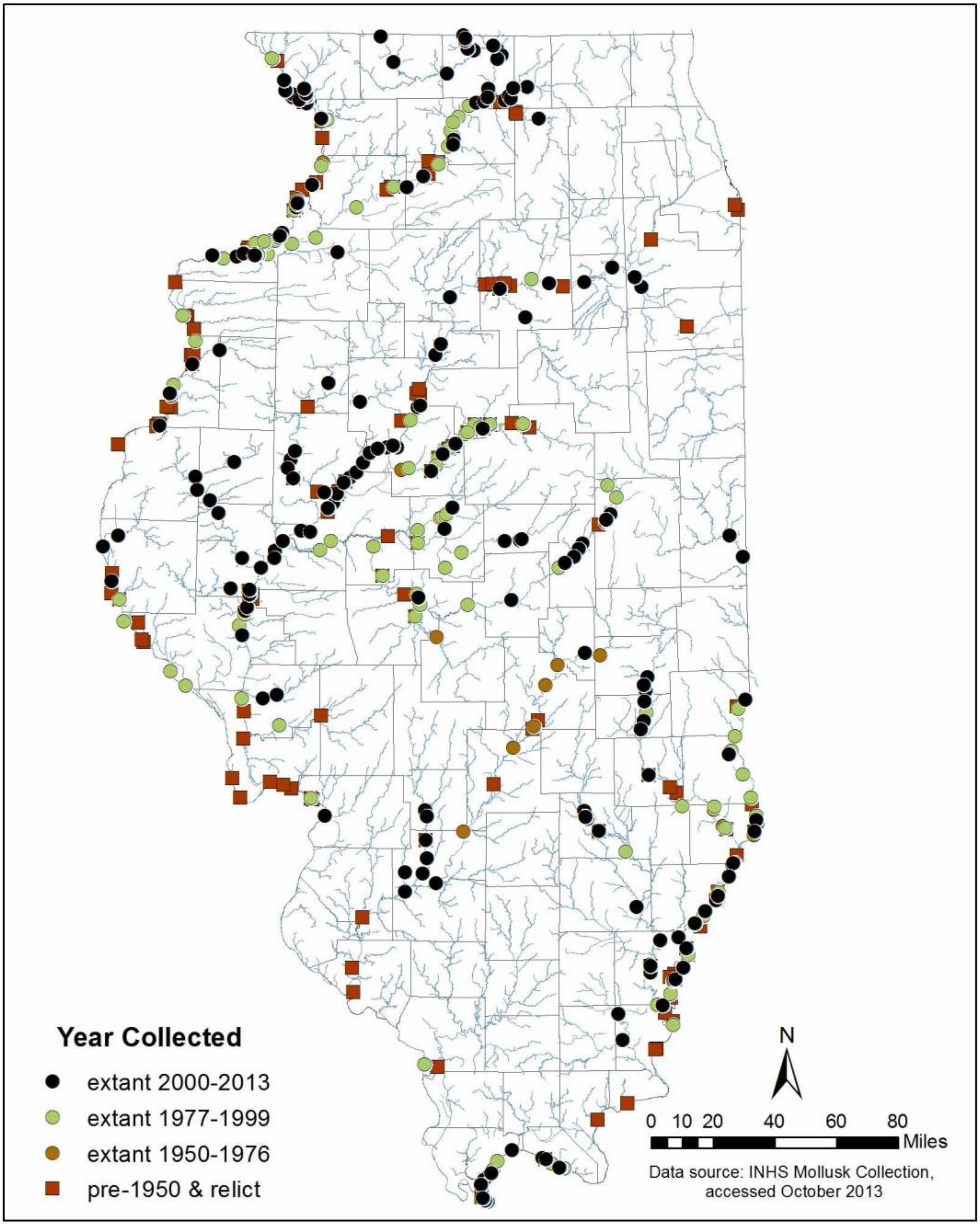
## Texas lilliput (*Toxolasma texasense*)

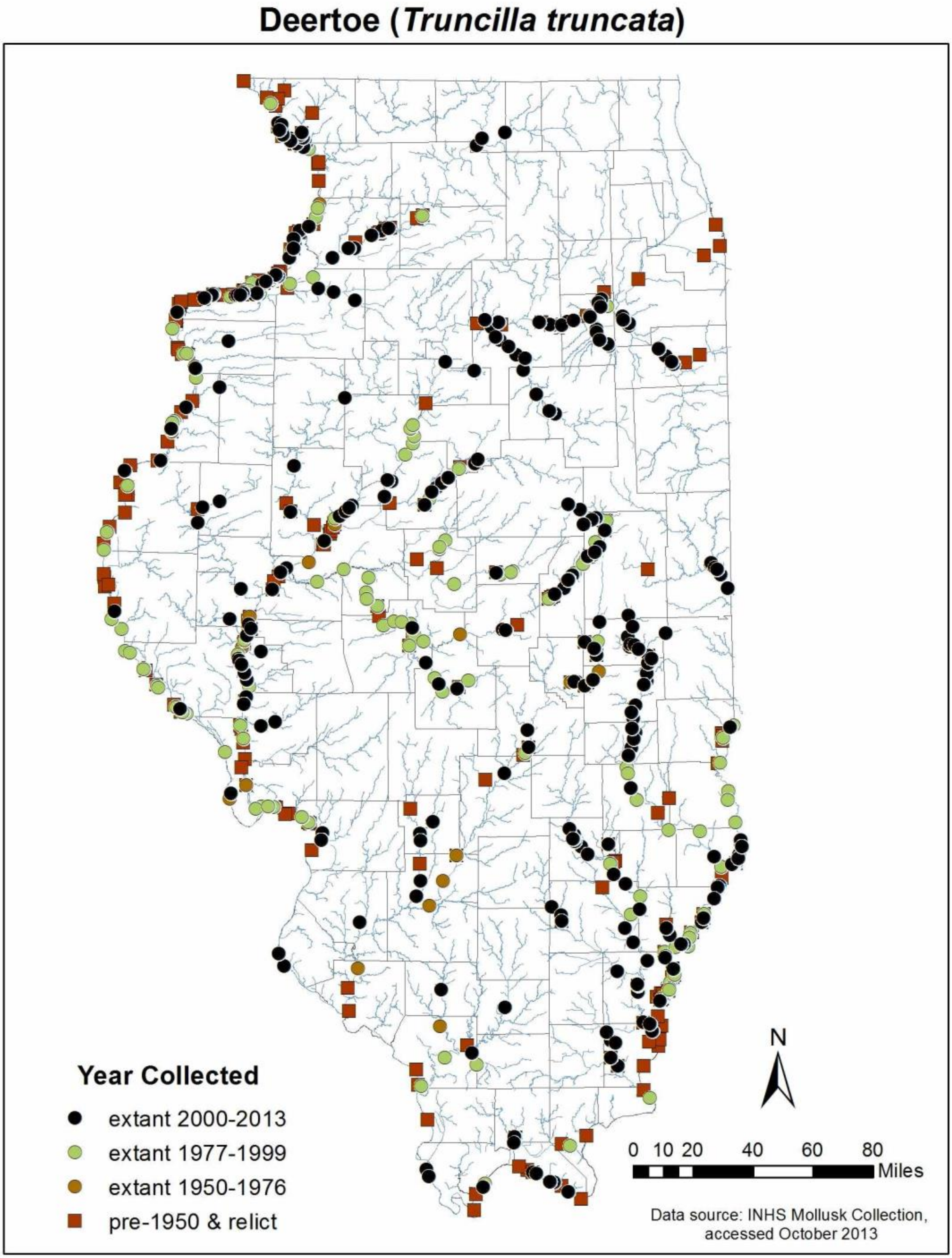


# Pistolgrip (*Tritogonia verrucosa*)

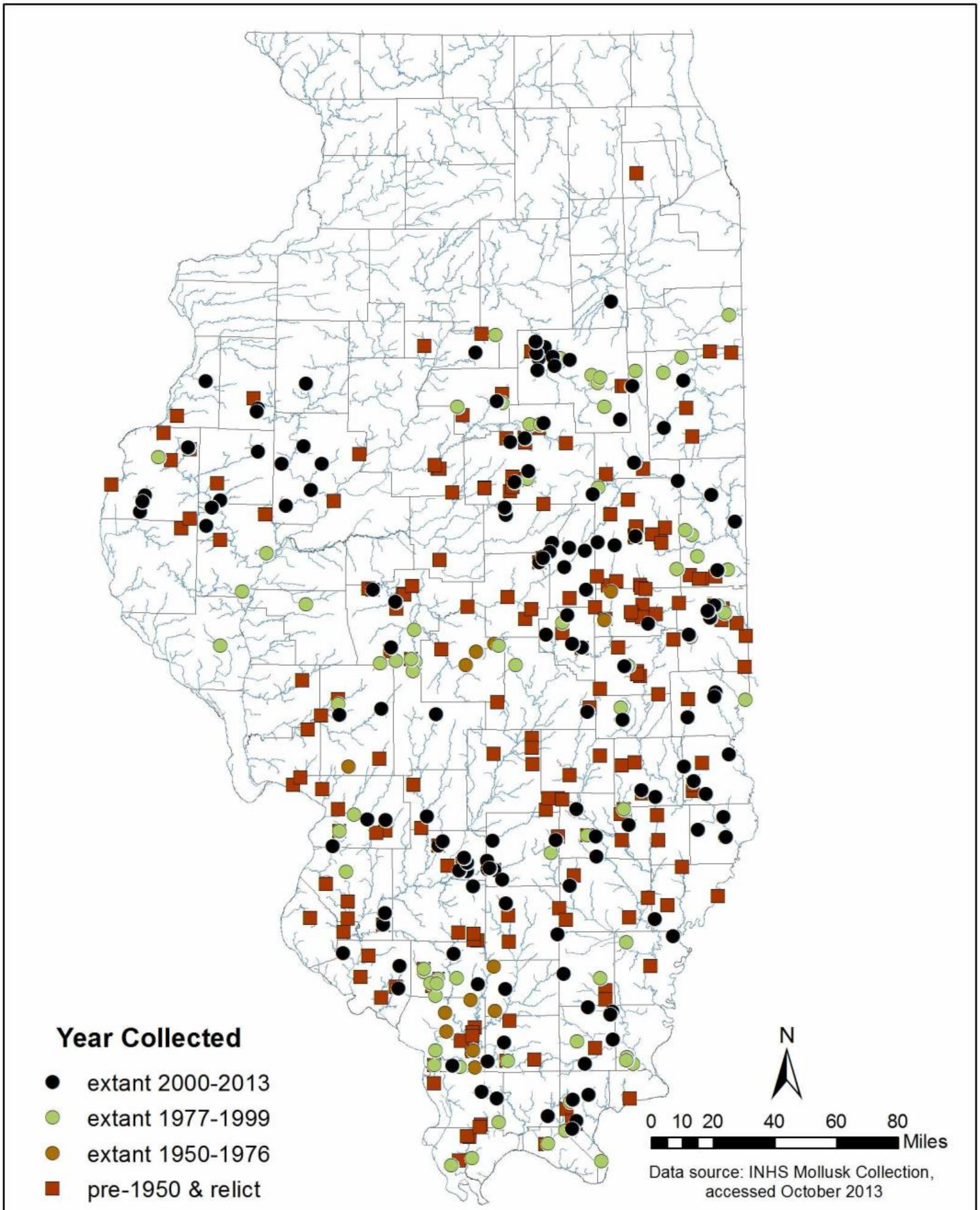


# Fawnsfoot (*Truncilla donaciformis*)

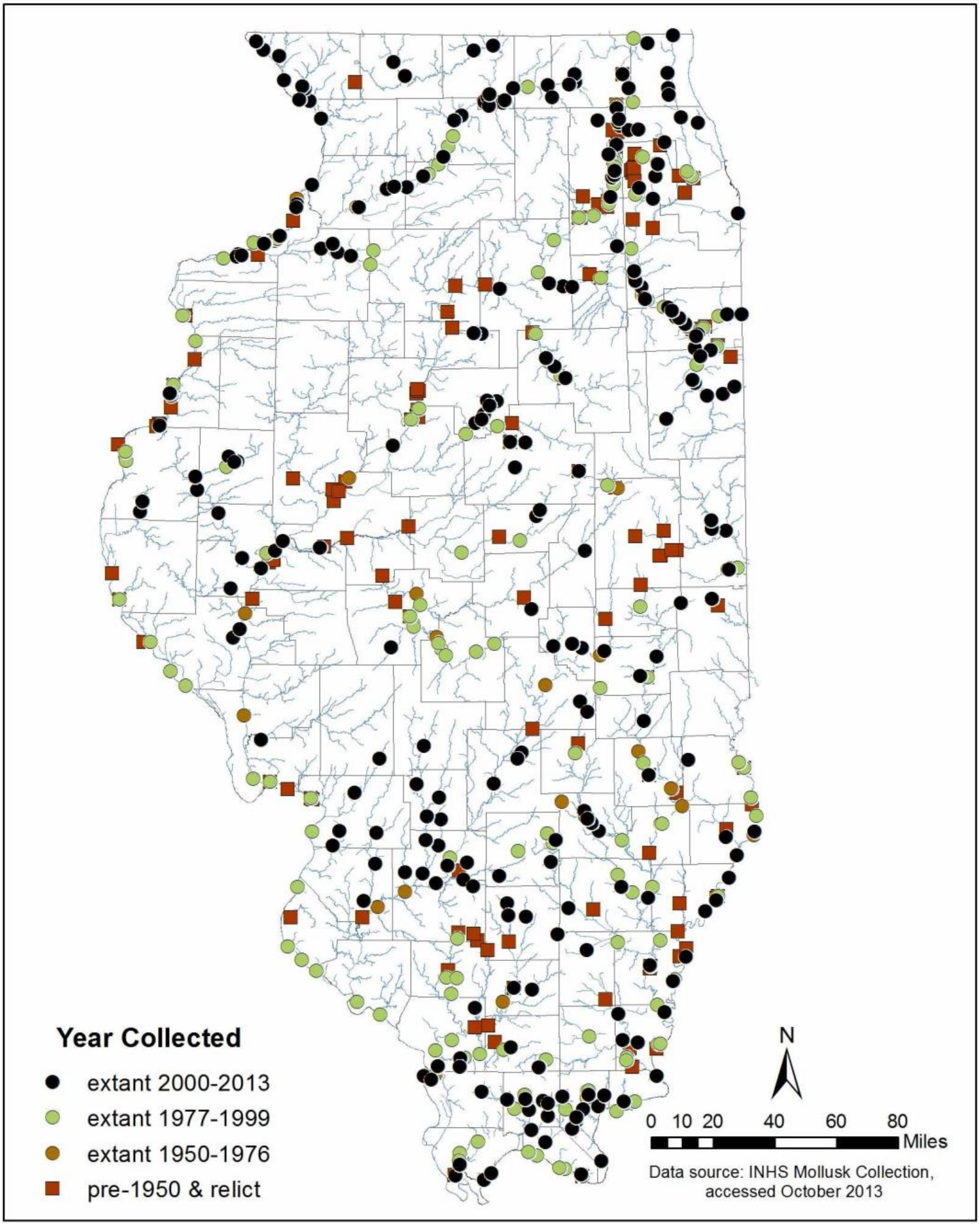



Deertoe (*Truncilla truncata*)
Year Collected
extant 2000-2013
extant 1977-1999
extant 1950-1976
pre-1950 & relict
N
0 10 20 40 60 80
Miles
Data source: INHS Mollusk Collection, accessed October 2013

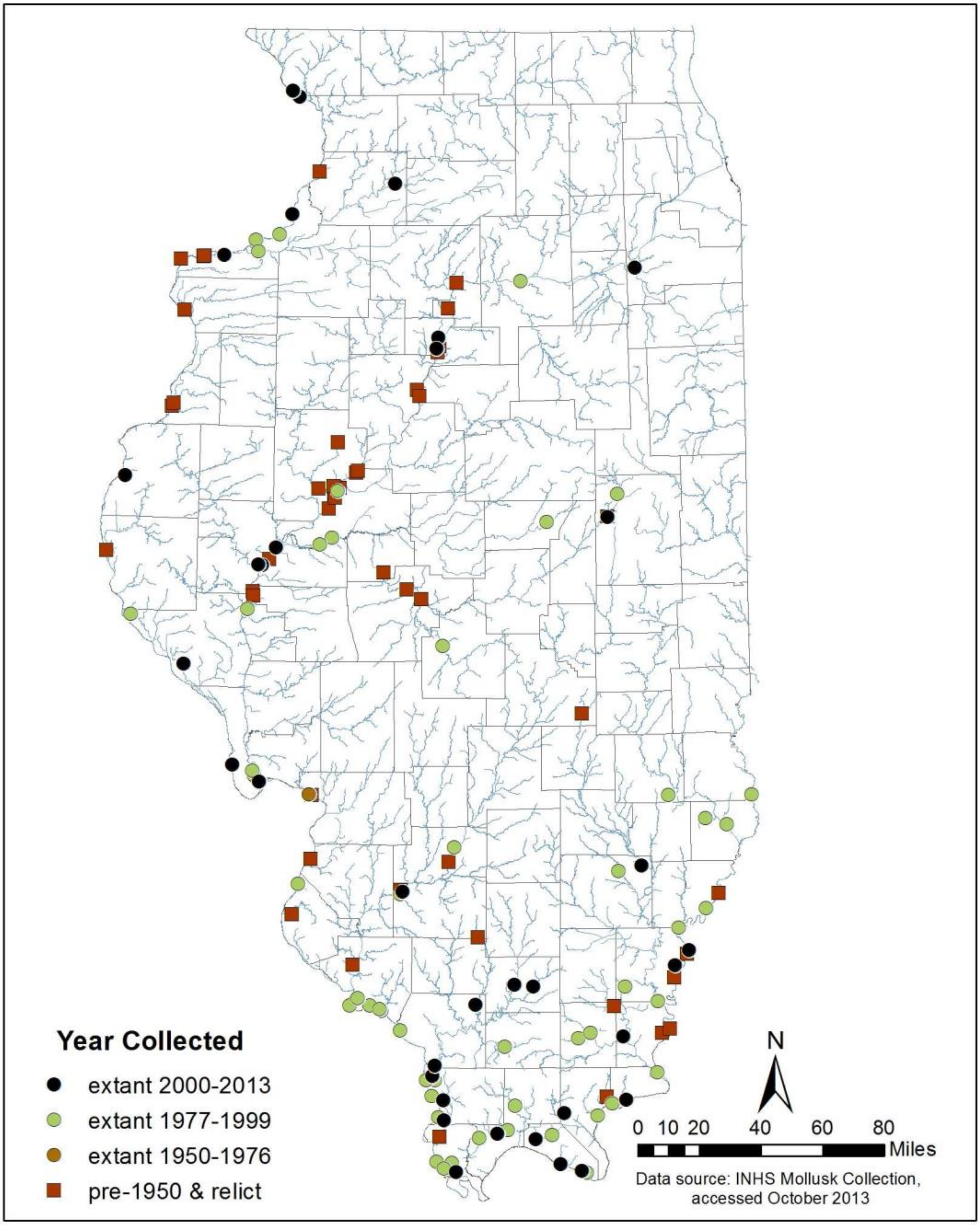
# Pondhorn (*Uniomerus tetralasmus*)



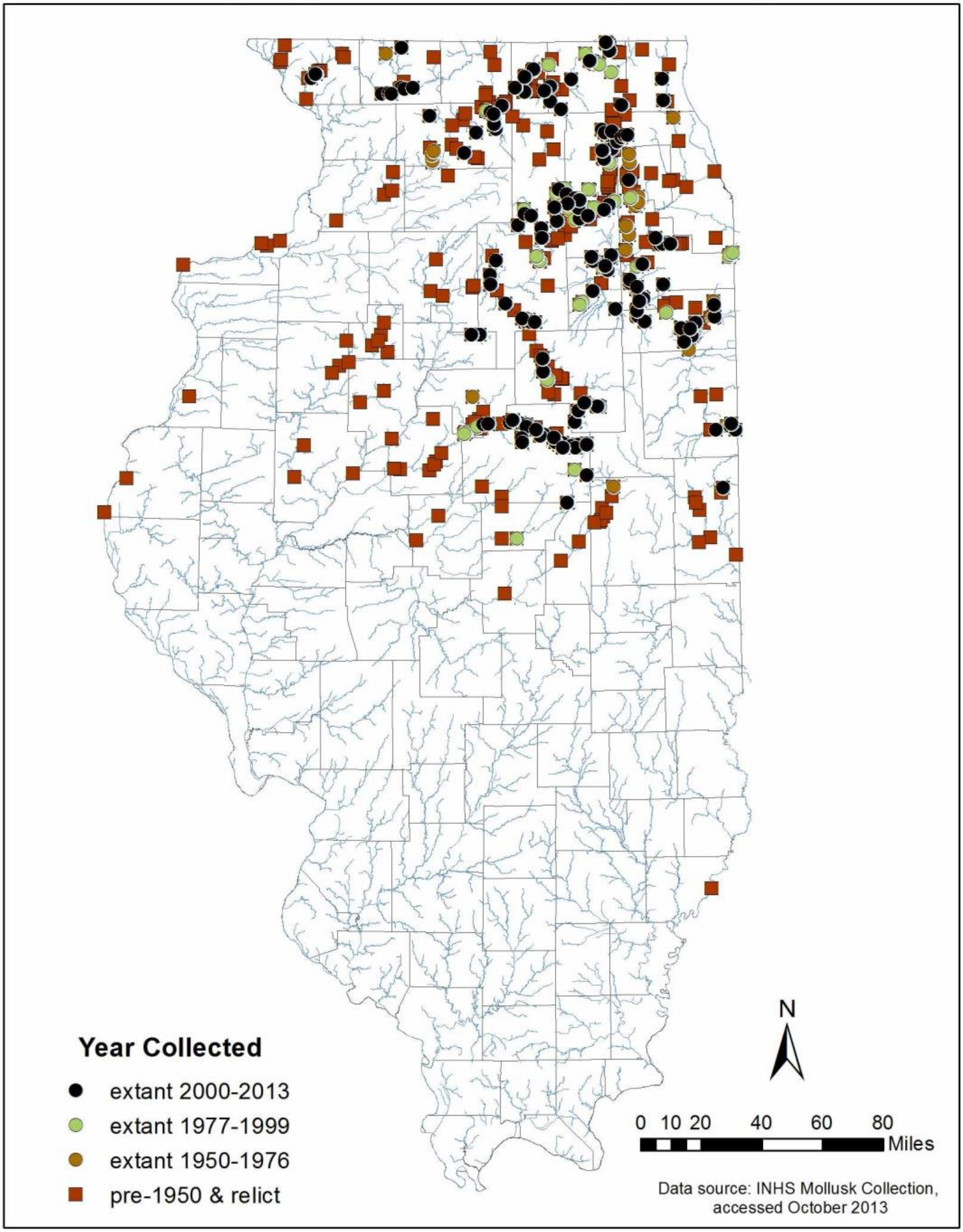
# Paper pondshell (*Utterbackia imbecillis*)



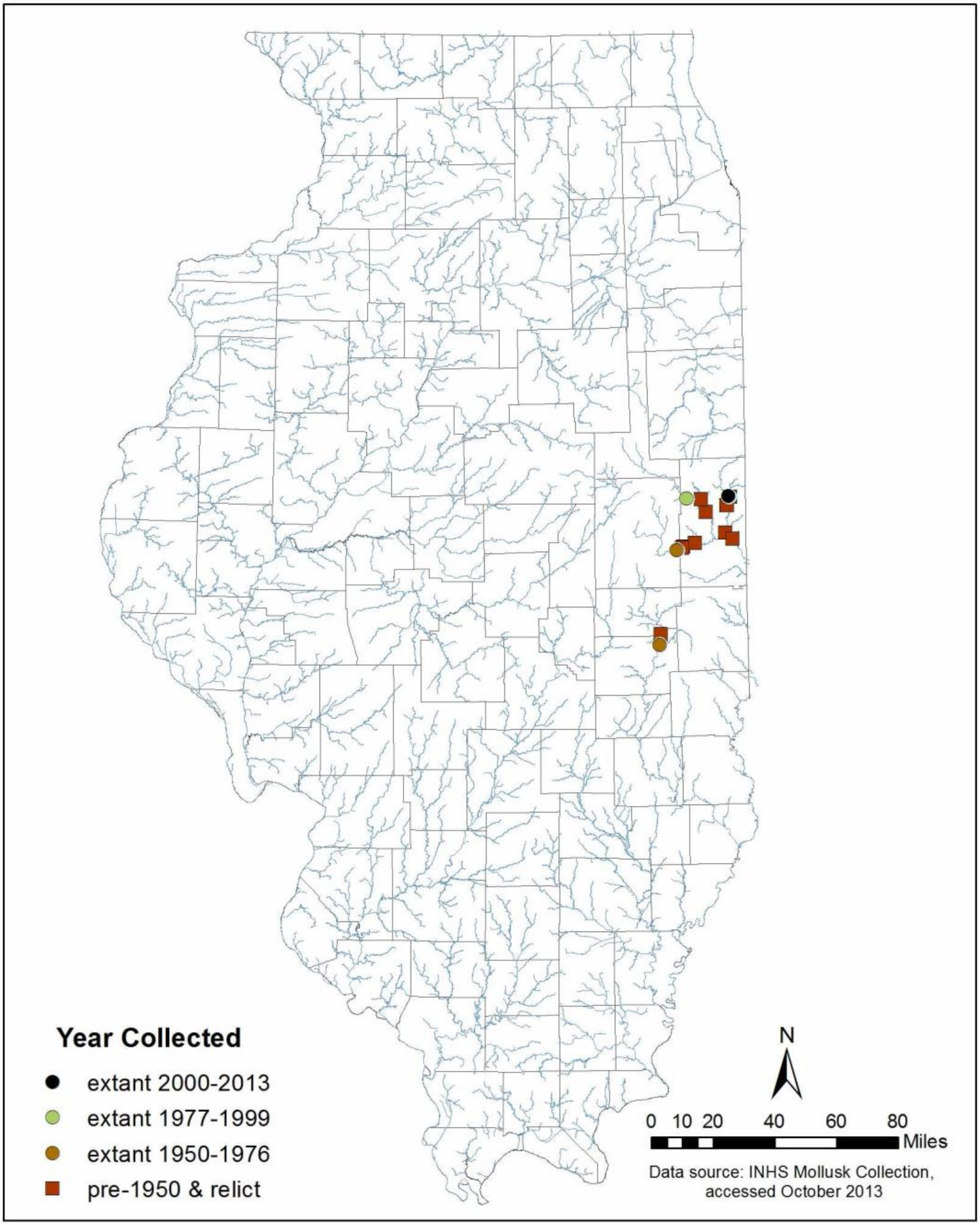
# Flat floater (*Utterbackia suborbiculata*)

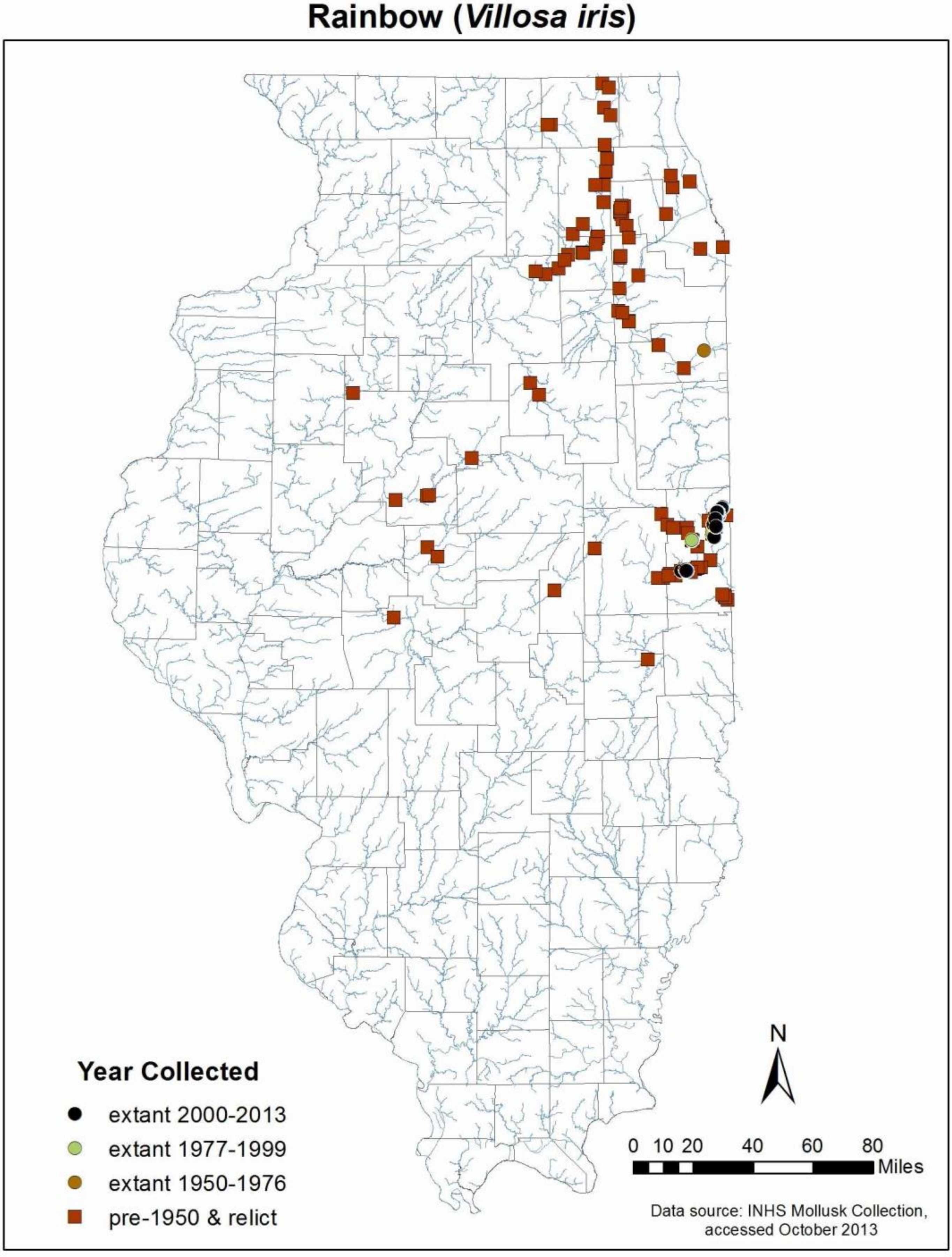


## Ellipse (*Venustaconcha ellipsiformis*)

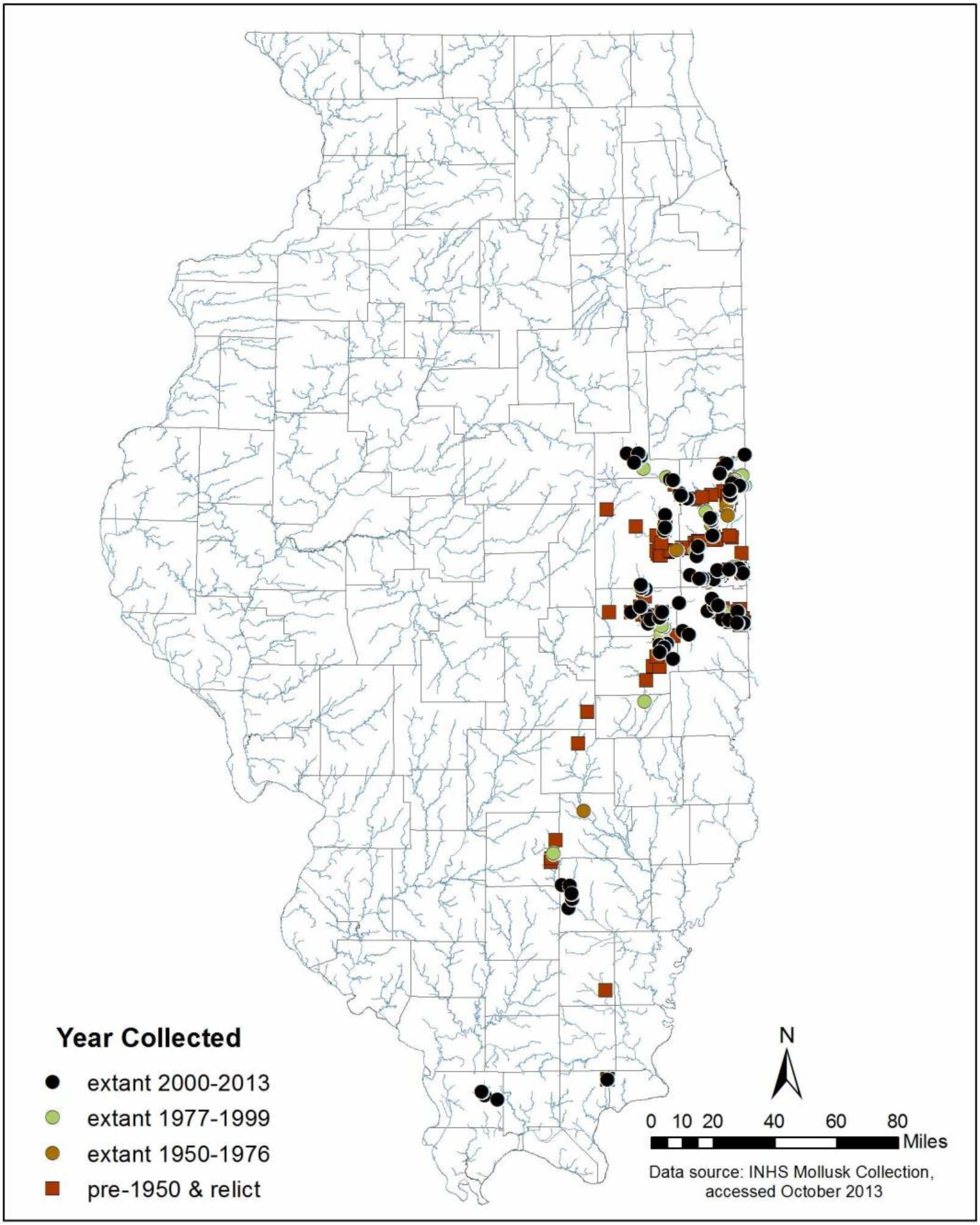


# Rayed bean (*Villosa fabalis*)




Rainbow (*Villosa iris*)
Year Collected
extant 2000-2013
extant 1977-1999
extant 1950-1976
pre-1950 & relict
N
0 10 20 40 60 80
Miles
Data source: INHS Mollusk Collection, accessed October 2013

# Little spectaclecase (*Villosa lienosa*)



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# Section 3:

# Fish Host Information

Each fish-mussel relationship is summarized in the following tables. For each table, abbreviations are as explained below, with a full description located in Section 1 (Methods).

NS: not stated
NI: natural infestation
NT: natural transformation
LI: lab infestation
LT: lab transformation

Table 1: Fish host information as of October 2014 for mussel species believed to be extirpated in Illinois.

| Fish Species | | | Mussel Species | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family** | **Scientific Name** | **Common Name** | ***Epioblasma obliquata*** | ***Epioblasma torulosa*** | ***Fusconaia subrotunda*** | ***Hemistena lata*** | ***Obovaria retusa*** | ***Plethobasus cicatricosus*** | ***Pleurobema plenum*** | ***Pleurobema rubrum*** | ***Quadrula fragosa*** |
| N/A | N/A | N/A | | hosts unknown | hosts unknown | hosts unknown | hosts unknown | hosts unknown | hosts unknown | | |
| Centrarchidae | *Ambloplites rupestris* | Rock Bass | LT [139] | | | | | | | | |
| Cottidae | *Cottus bairdi* | Mottled Sculpin | LT [139] | | | | | | | | |
| Cyprinidae | *Cyprinella spiloptera* | Spotfin Shiner | | | | | | | | LT [27] | |
| Ictaluridae | *Ictalurus furcatus* | Blue Catfish | | | | | | | | | LT [69,120] |
| | *Ictalurus punctatus* | Channel Catfish | | | | | | | | | LT, NT [69]<br>LT [61,66,120,112] |
| | *Noturus flavus* | Stonecat | LT [139] | | | | | | | | |
| Percidae | *Percina maculata* | Blackside Darter | LT [139] | | | | | | | | |
| | *Etheostoma blennioides* | Greenside Darter | LT [139] | | | | | | | | |
| | *Percina caprodes* | Logperch | LT [139] | | | | | | | | |

Table 2: Fish host information as of October 2014 for mussel species believed to be stable in Illinois.

| Fish Species | | | Mussel Species | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family** | **Scientific Name** | **Common Name** | ***Actinonaias ligamentina*** | ***Amblema plicata*** | ***Amphinaias pustulosa*** | ***Anodontoides ferussacianus*** | ***Arcidens confragosus*** | ***Fusconaia flava*** | ***Lampsilis cardium*** | ***Lampsilis siliquoidea*** | ***Lampsilis teres*** |
| Acipenceridae | *Scaphirhynchus platorynchus* | Shovelnose Sturgeon | | | NI [22] | | | | | | NI [122,154] |
| Ambystomatidae | *Ambystoma tigrinum* | Tiger Salamander | | | | | | | LT [147] | | |
| Anguillidae | *Anguilla rostrata* | American Eel | NI [22] | | | | NI [154] | | | | |
| Catostomidae | *Carpoides cyprinus* | Quillback | | | | | LT [134] | | | | |
| | *Catostomus commersonii* | White Sucker | | | | NS [40] | LT [67,134] | | | NS [40] | |
| | *Hypentelium nigricans* | Northern Hog Sucker | | NI [152] | | | | | | | |
| | *Ictiobus bubalus* | Smallmouth Buffalo | | | | | LT [134] | | | | |
| | *Moxostoma duquesnei* | Black Redhorse | | NI [152] | | | | | | | |
| | *Moxostoma erythrurum* | Golden Redhorse | | NI [152] | | | | | | | |
| | *Moxostoma macrolepidotum* | Shorthead Redhorse | | | | | LT [67,134] | | | | |
| Centrarchidae | *Ambloplites rupestris* | Rock Bass | LT [91,92,148] | LT [119] | | | NI [122,154] | | | LT [151] LI [36,37] | LI [92] |
| | *Lepomis cyanellus* | Green Sunfish | LT [92,161] NI [22,154] | LT [119] | | LT [32] | LT [134] | | LT [137] | LT [143] | NI [22,122] |
| | *Lepomis gibbosus* | Pumpkinseed | | LT [119] NI [22,154] | | | | LI [73] | LT [30] | NI [127] | |
| | *Lepomis gulosus* | Warmouth | | | | | | | | | NI [154] |
| | *Lepomis humilis* | Orangespotted Sunfish | LT [161] | | | | LT [134] | | | | NI [22,122] |
| | *Lepomis macrochirus* | Bluegill | NI [154] NILI [22] | LT [73,119,152] | | LT [32,135] | | LI [73] | LT [22] | LI [36] NILT [22] NI [37,127] LT [30,76,101,145,151] | LI [92] LT [79] |
| | *Lepomis megalotis* | Longear Sunfish | | | | | | | | LT [101,145] | |
| | *Lepomis microlophus x L. cyanellus* | Hybrid Sunfish | | | | | | | | | LT [79] |
| | *Micropterus dolomieu* | Smallmouth Bass | NI [22,78] | | | LT [32] | | | LT [22] | NS [24] LT [22,101,145] | |
| | *Micropterus salmoides* | Largemouth Bass | NILT [22] NI [154] LT [91,92,129,148,161] | LT [73,92] NILT [22] | | LT [32,101,135] | | LI [73] | LT [22,30,92,107,132,143,147] | NI [127] LT [2,22,30,71,76,101,107,143,145] | NI [22,154] NS [21] |
| | *Pomoxis annularis* | White Crappie | LT [92,161] NI [154] NILT [22] | NILT [73] LT [119] NI [22,122,154] | LI [70] NI [122,154] | | NI [122,154] | LI [73] NI [22,154] | NI [154] NILT [22] | LT [22] NI [76,127] | LI [92] NI [22,122,154] |
| | *Pomoxis nigromaculatus* | Black Crappie | LT [22] | NILT [73] LT [22] | | LT [32,55] | | LI [73] NI [22,122,154] | LT [30] | NI [127] LT [22,76] | LI [92] NI [22,122] |
| Clupeidae | *Dorosoma cepedianum* | Gizzard Shad | | | | | NI [122,154] | | | | |
| Cottidae | *Cottus bairdi* | Mottled Sculpin | LT [129] | | | NS [19] | | | | | |
| Cyprinidae | *Campostoma anomalum* | Central Stoneroller | LT [148] | | | | | | | | |
| | *Cyprinella spiloptera* | Spotfin Shiner | | NI [152] | | LT [55] | | NT [17] | | | |
| | *Cyprinella whipplei* | Steelcolor Shiner | | NI [152] | | | | | | | |
| | *Cyprinus carpio* | Common Carp | LI [92] | | | | LT [67] | | | | |
| | *Ericymba buccata* | Silverjaw Minnow | LT [148] | | | | | | | | |
| | *Erimyzon oblongus* | Creek Chubsucker | | | | | LT [134] | | | | |
| | *Luxilus chrysocephalus* | Striped Shiner | | | | | LT [134] | | | LT [145] | |
| | *Luxilus cornutus* | Common Shiner | | | | NS [40] | | | | NS [40] | |
| | *Notemigonus crysoleucas* | Golden Shiner | | | | | LT [134] | | | | |
| | *Notropis atherinoides* | Emerald Shiner | | NI [152] | | | | | | | |
| | *Notropis heterolepis* | Blacknose Shiner | | | | NS [40] | | | | | |
| | *Notropis stramineus* | Sand Shiner | | | | | | | | LT [101] | |
| | *Pimephales notatus* | Bluntnose Minnow | | | | NS [40] | | | | LT [101,145] | |
| | *Pimephales promelas* | Fathead Minnow | | | | NS [40] LT [32] | | | | | |
| | *Rhinichthys cataractae* | Longnose Dace | | | | | LT [134] | | | | |
| | *Semotilus atromaculatus* | Creek Chub | | | | | LT [67,134] | LT [101,144] | | | |
| | *Umbra limi* | Central Mudminnow | | | | | LT [134] | | | | |
| Esocidae | *Esox lucius* | Northern Pike | | NI [22,154] | | | | | | | |
| Fundulidae | *Fundulus diaphanus* | Banded Killifish | LT [161] | | | | LT [67,134] | | | | |
| | *Fundulus olivaceus* | Blackspotted Topminnow | | | | | LT [134] | | | | |
| Gasterosteidae | *Culaea inconstans* | Brook Stickleback | | | | NS [40] LT [32] | LT [67] | | | | |
| Gobiidae | *Neogobius melanostomus* | Round Goby | LT [129] | | | | | | | | |
| Hiodontidae | *Hiodon tergisus* | Mooneye | | NI [152] | | | | | | | |
| Ictaluridae | *Ameiurus melas* | Black Bullhead | | | LI [70] LT [73] NILT [22] | | | | | | |
| | *Ameiurus nebulosus* | Brown Bullhead | | | LT [22,73] | | | | | | |
| | *Ameiurus sp.* | Bullhead sp. | | LI [73] | | | | | | | |
| | *Ictalurus punctatus* | Channel Catfish | | LI [73] NI [152] | NTLI [70] NILT [22] LT [73] NI [78,152] | | LT [79,134] | | | | |
| | *Noturus gyrinus* | Tadpole Madtom | NI [22] | | | | | | | NI [22] | |
| | *Pylodictis olivaris* | Flathead Catfish | | LI [73] | NILI [70] LT [73] NI [22,154] | | | | | | |
| Lepisosteidae | *Atractosteus spatula* | Alligator Gar | | | | | | | | | LT [22] NI [72,154] |
| | *Lepisosteus osseus* | Longnose Gar | | | | | | | | | NI [22,72,154] LT [2,87,107] |
| | *Lepisosteus platostomus* | Shortnose Gar | | LT [22] LI [78] | | | | | | | LI [72] NI [154] LT [22,34,78,87,107] |
| Moronidae | *Morone chrysops* | White Bass | NI [154] NILT [22] | NI [22,154] | | | | | | NS [24] LT [22] | |
| Percidae | *Etheostoma exile* | Iowa Darter | | | | NS [40] | | | | | |
| | *Perca flavescens* | Yellow Perch | LT [91] LI [92] NILT [22] | NI [103] LT [22,73,119] | | | LT [67] | | LT [22] | NS [24] NILT [22] LT [30] NI [103,127] | LI [92] |
| | *Percina caprodes* | Logperch | | NI [152] | | | | | | | |
| | *Sander canadensis* | Sauger | LT [22] NI [103] | NI [22,73,122,154] | | | | | NI [22,154] | NS [24] LT [22] | |
| | *Sander vitreus* | Walleye | NT [17] | | | | LT [134] | | LT [132] NT [17] | NILT [22] NI [127] LT [24,25,133] | |
| Petromyzontidae | *Petromyzon marinus* | Sea Lamprey | | | | NI [155] | | | | | |
| Sciaenidae | *Aplodinotus grunniens* | Freshwater Drum | | NI [152] | | | NI [154] | | | | |

Table 2 (continued)

| Fish Species | | | Mussel Species | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family** | **Scientific Name** | **Common Name** | ***Lasmigona complanata*** | ***Leptodea fragilis*** | ***Ligumia subrostrata*** | ***Obliquaria reflexa*** | ***Obovaria olivaria*** | ***Pleurobema sintoxia*** | ***Potamilus alatus*** | ***Potamilus ohiensis*** | ***Pyganodon grandis*** |
| Acipenceridae | *Acipenser fulvescens* | Lake Sturgeon | | | | | LT [18] | | | | |
| | *Scaphirhynchus platorynchus* | Shovelnose Sturgeon | | | | | NI [72] NILT [22] | | | | |
| Atherinidae | *Labidesthes sicculus* | Brook Silverside | | | | | | | | | NILT [128] |
| Catostomidae | *Carpiodes carpio* | River Carpsucker | | | | | | | | | NS [19] |
| | *Catostomus commersonii* | White Sucker | LT [90] | | | | | | | | NS [40] |
| | *Ictiobus sp.* | Buffalo sp. | | | | LT [16] | | | | | |
| | *Moxostoma carinatum* | River Redhorse | NI [152] | | | | | | | | |
| Centrarchidae | *Ambloplites rupestris* | Rock Bass | | | | | | | | | NI [91, 128] LT [130,128] |
| | *Lepomis cyanellus* | Green Sunfish | LT [161,92] | | LT [92,121] | | | | | | LT [130] NI [128,154] |
| | *Lepomis gibbosus* | Pumpkinseed | | | | | | | | | LT [128,143] |
| | *Lepomis gulosus* | Warmouth | | | LT [121] | | | | | | |
| | *Lepomis humilis* | Orangespotted Sunfish | LT [161] | | NI [92] | | | | | | LT [3] |
| | *Lepomis macrochirus* | Bluegill | | | NI [121] | | | LT [143] NI [22,122] | | | NS [19] NI [91,128,154] LT [104,128,143] |
| | *Lepomis megalotis* | Longear Sunfish | LT [138] | | | | | | | | LT [104] |
| | *Micropterus salmoides* | Largemouth Bass | LI [91] LT [161] | | LT [92] | LT [16] | | | | | NS [19] NI [128,154] LT [104,143] |
| | *Pomoxis annularis* | White Crappie | LT [92,161] | | | | | | | NI [154] | NS [19] LT [143] NI [91,154] |
| | *Pomoxis nigromaculatus* | Black Crappie | LT [138] | | | | | | | | NI [154] NILT [128] |
| Clupeidae | *Alosa chrysochloris* | Skipjack Herring | | | | NI [22,154] | | | | | NI [122,154] |
| | *Dorosoma cepedianum* | Gizzard Shad | NI [152] | | | LT [16] | | | | | NI [154] |
| Cyprinidae | *Campostoma anomalum* | Central Stoneroller | | | | | | LT [68,143] | | | NILT [128] |
| | *Carassius auratus* | Goldfish | | | | | | | | | LT [143] |
| | *Chrosomus erythrogaster* | Southern Redbelly Dace | | | | | | LT [143] | | | |
| | *Cyprinella lutrensis* | Red Shiner | | | | | | LT [68] | | | |
| | *Cyprinella spiloptera* | Spotfin Shiner | | | | | | LT [48, 57] NT [17] | | | |
| | *Cyprinella venusta* | Blacktail Shiner | | | | | | LT [68] | | | |
| | *Cyprinus carpio* | Common Carp | LT [91] LI [92] | | | | | | | | NILT [91] NS [19] |
| | *Luxilus chrysocephalus* | Striped Shiner | | | | | | | | | LT [128] NI [91,106] |
| | *Luxilus cornutus* | Common Shiner | | | | LT [139,150] | | LT [68] | | | NILT [128] NS [40] |
| | *Lythrurus umbratilis* | Redfin Shiner | | | | | | | | | LT [128] |
| | *Notemigonus crysoleucas* | Golden Shiner | | | | | | | | | LT [128] |
| | *Notropis boops* | Bigeye Shiner | | | | | | LT [68] | | | |
| | *Notropis buccata* | Silverjaw Minnow | | | | LT [150,139] | | | | | |
| | *Notropis heterodon* | Blackchin Shiner | | | | | | | | | NILT [128] |
| | *Notropis heterolepis* | Blacknose Shiner | | | | | | | | | NILT [128] |
| | *Pimephales notatus* | Bluntnose Minnow | | | | | | LT [48,57,68] | | | NILT [128] |
| | *Pimephales vigilax* | Bullhead Minnow | | | | | | | | | NI [46] |
| | *Rhinichthys atratulus* | Blacknose Dace | | | | | | LT [68] | | | LT [128] |
| | *Rhinichthys cataractae* | Longnose Dace | | | | LT [139,150] | | | | | |
| | *Semotilus atromaculatus* | Creek Chub | | | | | | LT [68] | | | NS [40] LT [128,143] |
| Fundulidae | *Fundulus diaphanus* | Banded Killifish | LT [161] | | | | | | | | LT [128] |
| Gasterosteidae | *Culaea inconstans* | Brook Stickleback | | | | | | LT [68] | | | NS [19] LT [128] |
| Gobiidae | *Neogobius melanostomus* | Round Goby | | | | | | | | | LT [143] |
| Hiodontidae | *Hiodon alosoides* | Goldeye | | | | NI [7] | | | | | |
| Ictaluridae | *Ameiurus natalis* | Yellow Bullhead | | | | | | | | | NI [154] |
| Lepisosteidae | *Lepisosteus osseus* | Longnose Gar | NI [152] | | | | | | | | LT [128] |
| Moronidae | *Morone chrysops* | White Bass | | | | | | | | | NI [154] |
| Percidae | *Etheostoma caeruleum* | Rainbow Darter | | | | | | | | | NILT [128] |
| | *Etheostoma exile* | Iowa Darter | | | | | | | | | NS [19] NILT [128] |
| | *Etheostoma nigrum* | Johnny Darter | | | | | | | | | NI [43] NS [19] NILT [128] |
| | *Perca flavescens* | Yellow Perch | LT [138] | | | | | | | | NILT [128] NI [82,83,91] |
| | *Sander canadensis* | Sauger | NI [152] | | | | | | | | |
| | *Sander vitreus* | Walleye | | | | LT [16] | | | | | |
| Sciaenidae | *Aplodinotus grunniens* | Freshwater Drum | | NT [17] NI [28,70, 78,154] | | LT [16] | | | NS [78] LT [18,114] NI [28,70,154,152] | NT [17] LT [114] NI [23,28,70,122,154] | NI [154] |

Table 2 (continued)

| Fish Species | | | Mussel Species | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family** | **Scientific Name** | **Common Name** | ***Quadrula quadrula*** | ***Strophitus undulatus*** | ***Toxolasma parvum*** | ***Toxolasma texasiensis*** | ***Truncilla donaciformis*** | ***Truncilla truncata*** | ***Uniomerus tetralasmus*** | ***Utterbackia imbecillis*** | ***Utterbackia suborbiculata*** |
| Ambystomatidae | *Ambystoma tigrinum* | Tiger Salamander | | | | | | | | LT [147] | |
| Centrarchidae | *Ambloplites rupestris* | Rock Bass | | LT [116,117] | | | | | | LT [128] | |
| | *Lepomis cyanellus* | Green Sunfish | | LI [35] LT [20,45] | NS [40] LT [49] | | | | | LT [130,128] | LT [79,81] |
| | *Lepomis gibbosus* | Pumpkinseed | | LT [20] | | | | | | LT [128] | |
| | *Lepomis gulosus* | Warmouth | | | NI [154] NS [40] | NI [121] | | | | NI [121] | LT [11,12] |
| | *Lepomis humilis* | Orangespotted Sunfish | | | NS [40] | | | | | | |
| | *Lepomis macrochirus* | Bluegill | | LT [20,45,47,57] | NS [40] | NI [121] | | | | NI [121] LT [88,128] | |
| | *Lepomis megalotis* | Longear Sunfish | | LT [143] | | | | | | LT [102] | LT [79,81] |
| | *Micropterus dolomieu* | Smallmouth Bass | | LT [20] | | | | | | | |
| | *Micropterus salmoides* | Largemouth Bass | | LT [5,20,45,47,57,116,117] | | | | | | LT [88,128,147] | LT [11,12] |
| | *Pomoxis annularis* | White Crappie | | LT [139,148] | NS [40] | | | | | | LT [11] |
| | *Pomoxis nigromaculatus* | Black Crappie | | LT [20] | | | | | | LT [55] | |
| Cottidae | *Cottus cognatus* | Slimy Sculpin | | LT [117,153] | | | | | | | |
| Cyprinidae | *Campostoma anomalum* | Central Stoneroller | | LT [20] | | | | | | | |
| | *Carassius auratus* | Goldfish | | | | | | | | LT [147] | |
| | *Cyprinella spiloptera* | Spotfin Shiner | | LT [20,47,57] | | | | | | LT [55] | |
| | *Luxilus cornutus* | Common Shiner | | LT [20,116,117] | | | | | | | |
| | *Nocomis micropogon* | River Chub | | LT [116,117] | | | | | | | |
| | *Notemigonus crysoleucas* | Golden Shiner | | LT [153] | | | | | NI [121] | LT [88] | LT [11,12] |
| | *Notropis stramineus* | Sand Shiner | | LT [139,148] | | | | | | | |
| | *Pimephales notatus* | Bluntnose Minnow | | LT [20,139,148] | | | | | | | |
| | *Pimephales promelas* | Fathead Minnow | | LT [20,57,47] | | | | | | | |
| | *Rhinichthys atratulus* | Blacknose Dace | | LT [20,117] | | | | | | | |
| | *Rhinichthys cataractae* | Longnose Dace | | LT [20,116,117,139,148,153] | | | | | | | |
| | *Semotilus atromaculatus* | Creek Chub | | LT [5,20] | | | | | | NI [19] | |
| | *Umbra limi* | Central Mudminnow | | LT [20] | | | | | | | |
| Fundulidae | *Fundulus diaphanus* | Banded Killifish | | | | | | | | LT [128] | |
| Gadidae | *Lota lota* | Burbot | | LT [20] | | | | | | | |
| Gasterosteidae | *Culaea inconstans* | Brook Stickleback | | LT [20] | | | | | | | |
| Ictaluridae | *Ameiurus melas* | Black Bullhead | | LT [20,45,47,57] | | | | | | | |
| | *Ameiurus natalis* | Yellow Bullhead | | LT [20,47,57,117] | | | | | | | |
| | *Ameiurus nebulosus* | Brown Bullhead | | LT [142] | | | | | | | |
| | *Ictalurus punctatus* | Channel Catfish | LT [112] | LT [20] | | | | | | LT [88] | LT [79,81] |
| | *Pylodictis olivaris* | Flathead Catfish | NI [78] | LT [80,81] | | | | | | | |
| Percidae | *Etheostoma caeruleum* | Rainbow Darter | | LT [20,143] | | | | | | | |
| | *Etheostoma exile* | Iowa Darter | | LT [20] | | | | | | | |
| | *Etheostoma flabellare* | Fantail Darter | | LT [20,139,148] | | | | | | | |
| | *Etheostoma nigrum* | Johnny Darter | | LT [20] | LT [143] | | | | | | |
| | *Etheostoma zonale* | Banded Darter | | LT [139,148] | | | | | | | |
| | *Perca flavescens* | Yellow Perch | | LT [20,45,116,117] | | | | | | LT [128] | |
| | *Percina caprodes* | Logperch | | LT [20,142] | | | | | | | |
| | *Percina maculata* | Blackside Darter | | LT [20] | | | | | | | |
| | *Percina phoxocephala* | Slenderhead Darter | | LT [20] | | | | | | | |
| | *Sander canadensis* | Sauger | | | | | NI [122,154] | NI [122] | | | |
| | *Sander vitreus* | Walleye | | LT [47,57] | | | | | | | |
| Poeciliidae | *Gambusia affinis* | Mosquitofish | | | | | | | | NI [121] | |
| Ranidae | *Lithobates catesbeiana* | American Bullfrog | | | | | | | | LT [147] | |
| | *Lithobates pipiens* | Northern Leopard Frog | | | | | | | | LT [147] | |
| Salamandridae | *Notophtalmus v. viridescens* | Red-spotted Newt | | LT [117] | | | | | | | |
| Salmonidae | *Oncorhynchus mykiss* | Rainbow Trout | | LT [117] | | | | | | | |
| | *Salvelinus fontinalis* | Brook Trout | | LT [117] | | | | | | | |
| Sciaenidae | *Aplodinotus grunniens* | Freshwater Drum | | | | | NS [78] LT [114] NI [70,122,72,154] | NS [78] NI [154] LT [114] NT [17] | | | |

Table 3: Fish host information as of October 2014 for mussel SGNC species (based on 2015 revision).

| Fish Species | | | Mussel Species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Family** | **Scientific Name** | **Common Name** | ***Alasmidonta marginata*** | ***Alasmidonta viridis*** | ***Amphinaias nodulata*** | ***Cyclonaias tuberculata*** | ***Cyprogenia stegaria*** | ***Ellipsaria lineolata*** | ***Elliptio crassidens*** | ***Elliptio dilatata*** | ***Epioblasma rangiana*** | ***Epioblasma triquetra*** |
| Catostomidae | *Carpiodes carpio* | River Carpsucker | LT [14] | | | | | | | | | |
| | *Carpoides cyprinus* | Quillback | LT [14] | | | | | | | | | |
| | *Catostomus commersonii* | White Sucker | NI [78] LT [14,90] | | | | | | | | | |
| | *Erimyzon oblongus* | Creek Chubsucker | LT[14] | | | | | | | | | |
| | *Hypentelium nigricans* | Northern Hog Sucker | NI [78] LT [14] | | | | | | | | | |
| | *Ictiobus bubalus* | Smallmouth Buffalo | LT [14] | | | | | | | | | |
| | *Moxostoma anisurum* | Silver Redhorse | LT [14] | | | | | | | | | |
| | *Moxostoma erythrurum* | Golden Redhorse | LT [14] | | | | | | | | | |
| | *Moxostoma macrolepidotum* | Shorthead Redhorse | NI [78] LT [14] | | | | | | | | | |
| Centrarchidae | *Ambloplites rupestris* | Rock Bass | NI [78] | | | | | | | LT [31,93] | | |
| | *Lepomis cyanellus* | Green Sunfish | | | | | | NI [22,122,154] | | | | |
| | *Lepomis gulosus* | Warmouth | NI [78] | | | | | | | | | |
| | *Lepomis macrochirus* | Bluegill | | | LI [73] | | | | | | | |
| | *Micropterus salmoides* | Largemouth Bass | | | LI [73] | | | | | LT [31] | | |
| | *Pomoxis annularis* | White Crappie | | | NI [22,122,154] | | | | | NI [73,154] | | |
| | *Pomoxis nigromaculatus* | Black Crappie | | | LI [73] | | | | | NI [73] | | |
| Clupeidae | *Alosa chrysochloris* | Skipjack Herring | | | | | | | NI [73,75] | | | |
| | *Dorosoma cepedianum* | Gizzard Shad | | | | | | | | NI [154] | | |
| Cottidae | *Cottus bairdi* | Mottled Sculpin | LT [14] | NS [19] | | | LT [86] | | | | LT [95,96,129,142] | LT [129,143] |
| | *Cottus carolinae* | Banded Sculpin | LT [14] | NI [162] | | | NS [111] LT [86] | | | LT [93] | | LT [44,159] |
| | *Cottus cognatus* | Slimy Sculpin | LT [14] | | | | | | | | | |
| | *Cottus sp.* | Holston Sculpin | | | | | | | | LT [31] | | |
| Cyprinidae | *Luxilus chrysocephalus* | Striped Shiner | LT [14] | | | | | | | | | |
| | *Luxilus cornutus* | Common Shiner | LT [14] | | | | | | | | | |
| | *Nocomis biguttatus* | Hornyhead Chub | LT [14] | | | | | | | | | |
| | *Notemigonus crysoleucas* | Golden Shiner | LT [14] | | | | | | | | | |
| | *Rhinichthys cataractae* | Longnose Dace | LT [14] | | | | | | | | | |
| | *Semotilus atromaculatus* | Creek Chub | LT [14] | | | | | | | | | |
| Fundulidae | *Fundulus catenatus* | Northern Studfish | LT [14] | | | | | | | | | |
| | *Fundulus diaphanus* | Banded Killifish | LT [14] | | | | | | | | | |
| | *Fundulus olivaceus* | Blackspotted Topminnow | LT [14] | | | | | | | | | LT [9] |
| Gasterosteidae | *Culaea inconstans* | Brook Stickleback | LT [14] | | | | | | | | | |
| Gobiidae | *Neogobius melanostomus* | Round Goby | | | | | | | | | | LT [129] |
| Ictaluridae | *Ameiurus melas* | Black Bullhead | | | LT [115] | LT [50] | | | | | | |
| | *Ameiurus natalis* | Yellow Bullhead | | | | LT [58,62] | | | | | | |
| | *Ameiurus nebulosus* | Brown Bullhead | | | LT [115] | | | | | | | |
| | *Ictalurus furcatus* | Blue Catfish | | | LT [115] | | | | | | | |
| | *Ictalurus punctatus* | Channel Catfish | | | LT [115] NI [154,22] | LT [50] | | | | | | |
| | *Noturus exilis* | Slender Madtom | | | LT [115] | | | | | | | |
| | *Pylodictis olivaris* | Flathead Catfish | | | NI [22] LT [115] | LT [50] | | | | NI [73] | | |
| Percidae | *Etheostoma blennioides* | Greenside Darter | | | | | LT [86,111] | | | | | |
| | *Etheostoma caeruleum* | Rainbow Darter | | | | | | | | LT [93] | LT [96] | |
| | *Etheostoma camurum* | Bluebreast Darter | | | | | | | | | LT [136] | |
| | *Etheostoma exile* | Iowa Darter | | | | | | | | | LT [95,96] | |
| | *Etheostoma nigrum* | Johnny Darter | | NS [19] | | | | | | | LT [95,96] | |
| | *Etheostoma zonale* | Banded Darter | | | | | LT [86] | | | | LT [142] | |
| | *Percina caprodes* | Logperch | | | | | LT [86] | | | | LT [96] | LT [9,44,45,52,85,113,129,159] |
| | *Percina maculata* | Blackside Darter | | | | | | | | | LT [95] | LT [45] |
| | *Sander canadensis* | Sauger | | | | | | | | NI [73] | | |
| Salmonidae | *Salmo trutta* | Brown Trout | | | | | | | | | LT [136] | |
| Sciaenidae | *Aplodinotus grunniens* | Freshwater Drum | | | | | | NI [154] NT [17] LT [21,110] NILT [22,72,78] | | | | |

Table 3 (continued)

| Fish Species | | | Mussel Species | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Scientific Name | Common Name | *Fusconaia ebena* | *Lampsilis abrupta* | *Lampsilis fasciola* | *Lampsilis higginsii* | *Lampsilis hydiana* | *Lampsilis ovata* | *Lasmigona compressa* | *Lasmigona costata* | *Leptodea leptodon* | *Ligumia recta* | *Margaritifera monodonta* |
| N/A | N/A | N/A | | | | | | hosts unknown | | | | | |
| Amiidae | *Amia calva* | Bowfin | | | | | | | | LT [54,60,125] | | | |
| Anguillidae | *Anguilla rostrata* | American Eel | | | | | | | | LT [125] | | NI [22] | |
| Aphredoderidae | *Aphredoderus sayanus* | Pirate Perch | | | | | | | | LT [54] | | | |
| Catostomidae | *Carpiodes cyprinus* | Quillback | | | | | | | | LT [54] | | | |
| | *Catostomus commersonii* | White Sucker | | | | | | | | LT [125] | | | |
| | *Erimyzon oblongus* | Creek Chubsucker | | | | | | | | LT [54] | | | |
| | *Hypentelium nigricans* | Northern Hog Sucker | | | | | | | | LT [54,125,139,148] | | | |
| | *Ictiobus cyprinellus* | Bigmouth Buffalo | | | | | | | | LT [54,125] | | | |
| | *Moxostoma anisurum* | Silver Redhorse | | | | | | | | LT [54] | | | |
| | *Moxostoma carinatum* | River Redhorse | | | | | | | | NI [152] | | | |
| | *Moxostoma macrolepidotum* | Shorthead Redhorse | | | | | | | | LT [54,125] | | | NI [4] |
| Centrarchidae | *Ambloplites rupestris* | Rock Bass | | | | | | | | LT [54,93] | | LI [92] LT [118] | |
| | *Lepomis cyanellus* | Green Sunfish | | | | LT [131] | LT [79,81] | | LT [94] | LT [93,125] | | LT [118,161] | |
| | *Lepomis gibbosus* | Pumpkinseed | | | | | | | | LT [139,125] | | LT [149] | |
| | *Lepomis humilis* | Orangespotted Sunfish | | | | | | | LT [94] | LT [54,125] | | LT [161] | |
| | *Lepomis macrochirus* | Bluegill | | | | LT [131] | | | LT [94] | LT [60,125,143] | | NS [19] LI [92] NI [22,122,154] LT [59,89,149] | |
| | *Lepomis megalotis* | Longear Sunfish | | | LT [140] | | | | | LT [93] | | LT [149] | |
| | *Lepomis microlophus* | Redear Sunfish | | | | | | | | LT [125] | | | |
| | *Micropterus dolomieu* | Smallmouth Bass | | LT [10] | NS [99] LT [96,98,129,164] | LT [131] | | | LT [94] | LT [54,93,125] | | | |
| | *Micropterus punctulatus* | Spotted Bass | | LT [10] | | | | | | | | | |
| | *Micropterus salmoides* | Largemouth Bass | NI [73] | LT [10] | LT [96,98] | LI [124] LT [131] | | | | LT [54,60,125,139] | | LT [60,89,92,118,149,161] | |
| | *Pomoxis annularis* | White Crappie | NI [73] | | | | | | | | | NS [19] NI [22,154] LT [89,92,161] | |
| | *Pomoxis nigromaculatus* | Black Crappie | NI [73] | | | | | | LT [56,94] | LT [54,125] | | LT [89] | |
| Clupeidae | *Alosa chrysochloris* | Skipjack Herring | NI [73,122,154] LT [21,22,75] | | | | | | | | | | |
| | *Dorosoma cepedianum* | Gizzard Shad | | | | | | | LT [94] | NI [152] | | | |
| Cottidae | *Cottus bairdi* | Mottled Sculpin | | | LT [96,129] | | | | | | | | |
| | *Cottus carolinae* | Banded Sculpin | | | | | | | | LT [93] | | | |
| | *Cottus cognatus* | Slimy Sculpin | | | | | | | LT [56] | | | | |
| Cyprinidae | *Campostoma anomalum* | Central Stoneroller | | | | | | | | LT [54,143] | | LT [149] | |
| | *Carassius auratus* | Goldfish | | | | | | | LI [126] | LT [143] | | | |
| | *Chrosomus erythrogaster* | Southern Redbelly Dace | | | | | | | | LT [125] | | | |
| | *Cyprinella lutrensis* | Red Shiner | | | | | | | | LT [54] | | | |
| | *Cyprinella spiloptera* | Spotfin Shiner | | | | | | | LT [56,94] | LT [54,125] | | | |
| | *Cyprinella venusta* | Blacktail Shiner | | | | | | | | LT [54] | | | |
| | *Cyprinella whipplei* | Steelcolor Shiner | | | | | | | | LT [125] | | | |
| | *Cyprinus carpio* | Common Carp | | | | | | | | LI [92] LT [54,91,125] | | LI [92] | |
| | *Hybognathus hankinsoni* | Brassy Minnow | | | | | | | LT [94] | LT [54,125] | | | |
| | *Hybopsis amblops* | Bigeye Chub | | | | | | | | | | | NI [4] |
| | *Luxilus chrysocephalus* | Striped Shiner | | | | | | | | LT [54] | | | |
| | *Luxilus cornutus* | Common Shiner | | | | | | | | LT [125] | | | |
| | *Lythrurus umbratilis* | Redfin Shiner | | | | | | | | | | LT [149] | |
| | *Macrhybopsis storeriana* | Silver Chub | | | | | | | | LT [54] | | | |
| | *Nocomis biguttatus* | Hornyhead Chub | | | | | | | | LT [54,125] | | | |
| | *Notemigonus crysoleucas* | Golden Shiner | | | | | | | | LT [54,125] | | | |
| | *Notropis atherinoides* | Emerald Shiner | | | | | | | LT [94] | | | | |
| | *Notropis hudsonius* | Spottail Shiner | | | | | | | | LT [54,125] | | | |
| | *Notropis volucellus* | Mimic Shiner | | | | | | | LT [94] | LT [54,125] | | | |
| | *Pimephales notatus* | Bluntnose Minnow | | | | | | | | LT [54,125] | | | |
| | *Pimephales promelas* | Fathead Minnow | | | | | | | | LT [54] | | | |
| | *Pimephales vigilax* | Bullhead Minnow | | | | | | | | LT [54] | | | |
| | *Rhinichthys cataractae* | Longnose Dace | | | | | | | LT [94] | LT [125,139,148] | | | |
| | *Semotilus atromaculatus* | Creek Chub | | | | | | | LT [94] | LT [125,143] | | | |
| | *Umbra limi* | Central Mudminnow | | | | | | | | LT [54] | | | |
| Esocidae | *Esox lucius* | Northern Pike | | | | LT [131] | | | | LT [54,60] | | | |
| Fundulidae | *Fundulus catenatus* | Northern Studfish | | | | | | | | LT [93] | | | |
| | *Fundulus diaphanus* | Banded Killifish | | | | | | | | LT [54] | | LT [161] | |
| | *Fundulus olivaceus* | Blackspotted Topminnow | | | | | | | | LT [125] | | | |
| Gadidae | *Lota lota* | Burbot | | | | | | | | LT [54] | | | |
| Gasterosteidae | *Culaea inconstans* | Brook Stickleback | | | | | | | LT [94] | | | | |
| Hiodontidae | *Hiodon alosoides* | Goldeye | LT [15] | | | | | | | | | | |
| Ictaluridae | *Ameiurus melas* | Black Bullhead | | | | | | | LT [94] | LT [54,125] | | | |
| | *Ameiurus natalis* | Yellow Bullhead | | | | | | | LT [94] | LT [54,125] | | | |
| | *Ameiurus nebulosus* | Brown Bullhead | | | | | | | | LT [54,93] | | | |
| | *Ictalurus furcatus* | Blue Catfish | | | | | LT [81] | | | LT [54] | | | |
| | *Ictalurus punctatus* | Channel Catfish | | | | | LT [81] | | | LT [125] | | | |
| | *Noturus flavus* | Stonecat | | | | | | | | LT [54] | | | |
| | *Pylodictis olivaris* | Flathead Catfish | | | | | | | LT [94] | LT [54] | | | |

(these mussel species continue below)

Table 3 (continued)

| Family | Scientific Name | Common Name | *Fusconaia ebena* | *Lampsilis abrupta* | *Lampsilis fasciola* | *Lampsilis higginsii* | *Lampsilis hydiana* | *Lampsilis ovata* | *Lasmigona compressa* | *Lasmigona costata* | *Leptodea leptodon* | *Ligumia recta* | *Margaritifera monodonta* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lepisosteidae | *Lepisosteus osseus* | Longnose Gar | | | | | | | | LT [54] | | | |
| | *Lepisosteus platostomus* | Shortnose Gar | | | | | | | LT [94] | | | | |
| Moronidae | *Morone americana* | White Perch | | | | | | | | | | LT [118] | |
| Percidae | *Etheostoma caeruleum* | Rainbow Darter | | | | | | | | LT [93,125] | | | |
| | *Etheostoma flabellare* | Fantail Darter | | | | | | | | LT [54,93] | | | |
| | *Etheostoma nigrum* | Johnny Darter | | | | | | | | LT [54] | | | |
| | *Etheostoma zonale* | Banded Darter | | | | | | | | LT [139,148] | | | |
| | *Perca flavescens* | Yellow Perch | | | | LT [131] | | | LT [56] | LT [54,60,125] | | LI [92] LT [118] | |
| | *Percina caprodes* | Logperch | | | | | | | | LT [54] | | | |
| | *Percina maculata* | Blackside Darter | | | | | | | | LT [54] | | | |
| | *Percina phoxocephala* | Slenderhead Darter | | | | | | | | LT [54] | | | |
| | *Percina shumardi* | River Darter | | | | | | | | LT [54] | | | |
| | *Sander canadensis* | Sauger | | | | NI [22,122,154] | | | | LT [54] | | NI [103] LT [89] | |
| | *Sander vitreus* | Walleye | | LT [10] | | LI[124] LT[131] NT [17] | | | | LT [54,60,125] | | LT [60] | |
| Percopsidae | *Percopsis omiscomaycus* | Trout Perch | | | | | | | | LT [54] | | | |
| Poeciliidae | *Gambusia affinis* | Western Mosquitofish | | | | | | | | LT [125] | | | |
| Sciaenidae | *Aplodinotus grunniens* | Freshwater Drum | | | | NI [154] | | | | LT [54] | LT [9] | | |

Table 3 (continued)

| Fish Species | | | Mussel Species | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Family | Scientific Name | Common Name | *Megalonaias nervosa* | *Obovaria subrotunda* | *Plectomerus dombeyanus* | *Plethobasus cooperianus* | *Plethobasus cyphyus* | *Pleurobema clava* | *Pleurobema cordatum* | *Potamilus capax* | *Potamilus purpuratus* | *Ptychobranchus fasciolaris* |
| N/A | N/A | N/A | | | hosts unknown | hosts unknown | | | | | | |
| Acipenceridae | *Scaphirhynchus platorynchus* | Shovelnose Sturgeon | LT [140] | | | | | | | | | |
| Amiidae | *Amia calva* | Bowfin | NI [73] | | | | | | | | | |
| Anguillidae | *Anguilla rostrata* | American Eel | NI [22,123,154] | | | | | | | | | |
| Catostomidae | *Carpiodes velifer* | Highfin Carpsucker | LI [73] | | | | | | | | | |
| | *Hypentelium nigricans* | Northern Hog Sucker | | | | | | LT [41] | | | | |
| Centrarchidae | *Lepomis cyanellus* | Green Sunfish | LILT [73] LT [22,140,157] | | | | | | | | | |
| | *Lepomis gulosus* | Warmouth | NI [152] | | | | | | | | | |
| | *Lepomis macrochirus* | Bluegill | LILT [73] NILT [22] LT [146] | | | | | | NI [22,122] | | | |
| | *Lepomis megalotis* | Longear Sunfish | LT [146] | | | | | | | | | |
| | *Micropterus punctulatus* | Spotted Bass | NI [152] | | | | | | | | | |
| | *Micropterus salmoides* | Largemouth Bass | LI [73] LT [140,146] | | | | | | | | | |
| | *Pomoxis annularis* | White Crappie | NILT [22] LILT [73] NI [152] | | | | | | | | | |
| | *Pomoxis nigromaculatus* | Black Crappie | LILT [73] LT [22] | | | | | | | | | |
| Clupeidae | *Alosa chrysochloris* | Skipjack Herring | NI [22,154] | | | | | | | | | |
| | *Dorosoma cepedianum* | Gizzard Shad | NI [22,73,152] | | | | | | | | | |
| Cottidae | *Cottus carolinae* | Banded Sculpin | | LT [33] | | | | | | | | |
| Cyprinidae | *Campostoma anomalum* | Central Stoneroller | LT [146] | | | | LT [42,143] | LT [41,101,144] | | | | |
| | *Chrosomus erythrogaster* | Southern Redbelly Dace | | | | | LT [42] | | | | | |
| | *Cyprinella lutrensis* | Red Shiner | | | | | LT [42] | | | | | |
| | *Cyprinella spiloptera* | Spotfin Shiner | | | | | LT [42,156] | | | | | |
| | *Cyprinella venusta* | Blacktail Shiner | | | | | LT [42] | | | | | |
| | *Cyprinella whipplei* | Steelcolor Shiner | | | | | LT [42,156] | | | | | |
| | *Hybognathus hankinsoni* | Brassy Minnow | | | | | LT [42] | | | | | |
| | *Luxilus chrysocephalus* | Striped Shiner | | | | | LT [42,156] | LT [101,144] | | | | |
| | *Luxilus cornutus* | Common Shiner | | | | | LT [42,156] | LT [41,97] | | | | |
| | *Lythrurus ardens* | Rosefin Shiner | | | | | | | LT [160] | | | |
| | *Macrhybopsis storeriana* | Silver Chub | | | | | LT [156] | | | | | |
| | *Nocomis biguttatus* | Hornyhead Chub | | | | | LT [156] | | | | | |
| | *Nocomis micropogon* | River Chub | | | | | | LT [97] | | | | |
| | *Notemigonus crysoleucas* | Golden Shiner | LT [140] | | | | LT [156] | | | | | |
| | *Notropis blennius* | River Shiner | | | | | LT [42] | | | | | |
| | *Notropis hudsonius* | Spottail Shiner | | | | | LT [156] | | | | | |
| | *Notropis nubilus* | Ozark Minnow | | | | | LT [42] | | | | | |
| | *Notropis volucellus* | Mimic Shiner | | | | | LT [42] | | | | | |
| | *Phenacobius mirabilis* | Suckermouth Minnow | | | | | LT [42] | | | | | |
| | *Pimephales notatus* | Bluntnose Minnow | | | | | LT [42,156] | LT [41] | | | | |
| | *Pimephales promelas* | Fathead Minnow | | | | | LT [42,156] | LT [41] | | | | |
| | *Pimephales vigilax* | Bullhead Minnow | | | | | LT [42] | | | | | |
| | *Rhinichthys atratulus* | Blacknose Dace | | | | | LT [42] | LT [41] | | | | |
| | *Rhinichthys cataractae* | Longnose Dace | | | | | LT [42] | | | | | |
| | *Semotilus atromaculatus* | Creek Chub | | | | | LT [156] | LT [41] | LT [41,141,143] | | | |
| Fundulidae | *Fundulus catenatus* | Northern Studfish | LT [140] | | | | | | | | | |
| | *Fundulus diaphanus* | Banded Killifish | | | | | LT [156] | | | | | |
| | *Fundulus olivaceus* | Blackspotted Topminnow | | | | | LT [42] | | | | | |
| Gasterosteidae | *Culaea inconstans* | Brook Stickleback | | | | | | | LT [141,143] | | | LT [143] |
| Hiodontidae | *Hiodon alosoides* | Goldeye | LT [15] | | | | | | | | | |
| Ictaluridae | *Ameiurus melas* | Black Bullhead | LILT [73] LT [22,140,157] | | | | | | | | | |
| | *Ameiurus natalis* | Yellow Bullhead | LT [140] | | | | | | | | | |
| | *Ameiurus nebulosus* | Brown Bullhead | LT [22] | | | | | | | | | |
| | *Ictalurus punctatus* | Channel Catfish | LILT [73] LT [22,157] | | | | | | | | | |
| | *Noturus gyrinus* | Tadpole Madtom | NI [22] | | | | | | | | | |
| | *Pylodictis olivaris* | Flathead Catfish | NI [73,152] NILT [22] | | | | | | | | | |
| Lepisosteidae | *Lepisosteus osseus* | Longnose Gar | NI [152] LT [146] | | | | | | | | | |
| Moronidae | *Morone chrysops* | White Bass | NILT [73] NI [22,152,154] | | | | | | | | | |
| Percidae | *Etheostoma blennioides* | Greenside Darter | | LT [33] | | | | | | | | |
| | *Etheostoma caeruleum* | Rainbow Darter | | | | | | | | | | LT [140] |
| | *Etheostoma exile* | Iowa Darter | | LT [96] | | | | | | | | |
| | *Etheostoma flabellare* | Fantail Darter | | LT [33,96] | | | | | | | | LT [140] |
| | *Perca flavescens* | Yellow Perch | LT [146] | | | | | | | | | |
| | *Percina caprodes* | Logperch | LT [146] | | | | | LT [101,144] | | | | |
| | *Percina maculata* | Blackside Darter | | LT [96] | | | | LT [101,144] | | | | |
| | *Percina phoxocephala* | Slenderhead Darter | LT [146] | | | | | | | | | |
| | *Sander canadensis* | Sauger | LI [73] | | | | NI [122,154] | | | | | |
| Poeciliidae | *Gambusia affinis* | Western Mosquitofish | | | | | LT [42] | | | | | |
| Sciaenidae | *Aplodinotus grunniens* | Freshwater Drum | NILT [22] LILT[73] NI [122,123,152,154] | | | | | | | NI [28] LT [6,8] | NI [122,154] NS[78] | |

Table 3 (continued)

| Family | Scientific Name | Common Name | *Quadrula nobilis* | *Simpsonaias ambigua* | *Theliderma cylindrica* | *Theliderma metanevra* | *Toxolasma lividum* | *Tritogonia verrucosa* | *Venustaconcha ellipsiformis* | *Villosa fabalis** | *Villosa iris* | *Villosa lienosa* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Catostomidae | *Moxostoma erythrurum* | Golden Redhorse | | | LT [38] | | | | | | | |
| Centrarchidae | *Ambloplites rupestris* | Rock Bass | | | | | | | | | LI [164] NS [99,163] LT [98,129] | |
| | *Lepomis cyanellus* | Green Sunfish | | | | NI [73,122,154] | LT [84,44] | | | | LT [145] | LT [29] |
| | *Lepomis humilis* | Orangespotted Sunfish | | | | | | | | | | LT [29] |
| | *Lepomis macrochirus* | Bluegill | | | | NI [22,73,122,154] | | | | | | LT [88] |
| | *Lepomis megalotis* | Longear Sunfish | | | | | LT [44,84] | | | | | LT [29] |
| | *Lepomis microlophus* | Redear Sunfish | | | | | | | | | | LT [29] |
| | *Micropterus dolomieu* | Smallmouth Bass | | | | | | | | | LI [164] NS [99,163] LT [143,145] | |
| | *Micropterus punctulatus* | Spotted Bass | | | | | | | | | LT [100] | |
| | *Micropterus salmoides* | Largemouth Bass | | | | | | | | | LT [100,145] | LT [88] |
| Cottidae | *Cottus bairdi* | Mottled Sculpin | | | | | | | LT [1,63] | | LT [129,143] | |
| | *Cottus cognatus* | Slimy Sculpin | | | | | | | LT [1,51] | | | |
| Cyprinidae | *Campostoma anomalum* | Central Stoneroller | | | | LT [39] | | | | | | |
| | *Campostoma oligolepis* | Largescale Stoneroller | | | | LT [39] | | | | | | |
| | *Cyprinella lutrensis* | Red Shiner | | | | LT [39] | | | | | | |
| | *Cyprinella spiloptera* | Spotfin Shiner | | | LT [38,142*,158*] | LT [26,39,57] | | | | | | |
| | *Cyprinella venusta* | Blacktail Shiner | | | LT [38] | LT [39] | | | | | | |
| | *Cyprinella whipplei* | Steelcolor Shiner | | | | LT [39] | | | | | | |
| | *Hybognathus hankinsoni* | Brassy Minnow | | | | LT [39] | | | | | | |
| | *Hybognathus nuchalis* | Missississippi Silvery Minnow | | | | LT [39] | | | | | | |
| | *Hybopsis amblops* | Bigeye Chub | | | LT [158*] | | | | | | | |
| | *Luxilus chrysocephalus* | Striped Shiner | | | LT [38,140] | LT [39] | | | | | LT [145] | |
| | *Luxilus cornutus* | Common Shiner | | | | LT [39] | | | | | | |
| | *Macrhybopsis storeriana* | Silver Chub | | | | LT [39] | | | | | | |
| | *Nocomis biguttatus* | Hornyhead Chub | | | | LT [39] | | | | | | |
| | *Notropis atherinoides* | Emerald Shiner | | | LT [38] | | | | | | | |
| | *Pimephales notatus* | Bluntnose Minnow | | | | LT [26,39] | | | | | | |
| | *Pimephales promelas* | Fathead Minnow | | | | LT [39] | | | | | | |
| | *Pimephales vigilax* | Bullhead Minnow | | | LT [38] | | | | | | | |
| | *Rhinichthys atratulus* | Blacknose Dace | | | | LT [26] | | | | | | |
| | *Rhinichthys cataractae* | Longnose Dace | | | | LT [39] | | | | | | |
| | *Semotilus atromaculatus* | Creek Chub | | | | LT [26,39] | | LI [67] | | | | |
| Fundulidae | *Fundulus notatus* | Blackstripe Topminnow | | | LT [38] | | | | | | | |
| Gasterosteidae | *Culaea inconstans* | Brook Stickleback | | | | | | | LT [1,63,64] | | | |
| Gobiidae | *Neogobius melanostomus* | Round Goby | | | | | | | | | LT [129] | |
| Ictaluridae | *Ameiurus melas* | Black Bullhead | | | | | | LI [67] | | | | |
| | *Ameiurus natalis* | Yellow Bullhead | | | | | | LI [67] LT [64,105] | | | | |
| | *Ameiurus nebulosus* | Brown Bullhead | | | | | | LT [65,67] | | | | |
| | *Ictalurus punctatus* | Channel Catfish | LT [81] | | | | | LT [81] | | | | LT [88] |
| | *Pylodictis olivaris* | Flathead Catfish | LT [80,81] | | | | | LT [53,67,80,81] | | | | |
| Percidae | *Etheostoma asprigene* | Mud Darter | | | | | | | LT [1] | | | |
| | *Etheostoma blennioides* | Greenside Darter | | | | | | | NI [109] | | LT [145] | |
| | *Etheostoma caeruleum* | Rainbow Darter | | | LT [140,142] | | | | LT [108,109] NILT [1] | | LT [145] | |
| | *Etheostoma camurum* | Bluebreast Darter | | | | | | | | | LT [145] | |
| | *Etheostoma exile* | Iowa Darter | | | | | | | LT [1,63] | | | |
| | *Etheostoma flabellare* | Fantail Darter | | | | | | | LT [63] NILT [1] | | | |
| | *Etheostoma nigrum* | Johnny Darter | | | | | | | LT [51] NILT [1] | | | |
| | *Etheostoma spectabile* | Orangethroat Darter | | | | | | | NI [109] LT [13] | | | |
| | *Etheostoma zonale* | Banded Darter | | | | | | | LT [1,142] | | | |
| | *Perca flavescens* | Yellow Perch | | | | | | | | | LT [145] | |
| | *Percina caprodes* | Logperch | | | | | | | LT [63] | | | |
| | *Percina maculata* | Blackside Darter | | | | | | | NI [1] LT [45,63] | | | |
| | *Sander canadensis* | Sauger | | | | NI [22,73,103] | | | | | | |
| Poeciliidae | *Gambusia affinis* | Western Mosquitofish | | | | | | | | | LT [100] | |
| Proteidae | *Necturus maculosus* | Mudpuppy | | NILT [74] NS [78] NILT [77] LT [3,9] | | | | | | | | |

**Villosa fabalis* has no host with distributions in Illinois. Confirmed hosts are *Etheostoma maculatum* (Spotted Darter) and *E. tippecanoe* (Tippecanoe Darter), LT[41].

## Literature Review: Section 3


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**Appendix 5:** Modelling and mapping the distribution, diversity, and abundance of freshwater mussels (Family Unionidae) in wadeable streams of Illinois, U.S.A.

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# Modelling and mapping the distribution, diversity and abundance of freshwater mussels (Family Unionidae) in wadeable streams of Illinois, U.S.A.

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## SUMMARY

1. Freshwater mussels are one of the most imperilled animal groups in the world. Their effective conservation and restoration require a better understanding of their spatial distributions at a relevant scale and of their relationships with natural environmental factors and human disturbances.
2. In this study, we sampled over 900 sites on wadeable streams throughout Illinois, U.S.A., and compiled environmental data for a wide range of natural and anthropogenic factors related to climate, geology, land use, and connections to large rivers, dams and ponds.
3. Using random forest classification and regression, we modelled the presence–absence of mussels as a group (87% accuracy), the abundances of 29 individual mussel species ($R^2$ = 0.2–0.51), species richness ($R^2$ = 0.52) and total mussel abundance in a standard sample ($R^2$ = 0.41).
4. The abundances of most species increased with stream size, the proportion of agricultural land in the catchment and the distance to the nearest dam or pond, but decreased with increasing catchment or channel slope and the proportion of forest in the catchment. Species varied in their relationships with climate variables, suggesting that they respond differently to climate change. Geology, particularly bedrock depth, was important for many species. Species richness and total mussel abundance responded positively to stream size and negatively to the slope of streams or catchments.
5. The models were applied to unsampled wadeable stream reaches to generate mussel distribution maps at the reach scale, useful tools for resource managers to effectively protect and restore mussel biodiversity. The models also improve our understanding of how mussel populations and assemblages are structured by natural factors and human disturbances at a broad scale.

*Keywords*: aquatic biodiversity, freshwater mussels, random forest regression, species modelling, wadeable streams

## Introduction

The importance of freshwater mussels (Unionidae) for aquatic ecosystem functions and services has been widely recognised (Strayer, 2008; Vaughn, 2010; Allen *et al*., 2012; Atkinson *et al*., 2013). Understanding of the spatial distribution of mussel species and their relationships with environment is critical for sustaining and restoring mussel biodiversity and their ecological functions (Haag & Williams, 2014). Ecologists have long noticed the close associations between mussel species and their habitats (e.g. Ortmann, 1919; van der Schalie, 1938). Recently, numerous studies have examined the response of mussel assemblage composition and species diversity to human disturbances such as land-use changes, flow alteration and water-quality degradation (Haag & Warren, 1998; Arbuckle & Downing, 2002; Downing, Van Meter & Woolnough, 2010; Cao *et al*., 2013; Daniel & Brown, 2013; Johnson, Kristolic & Ostby, 2014). Others have modelled the distributions of individ-

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ual species in relation to local and landscape-level environmental factors and fish hosts (Strayer, 1993; Mynsberge *et al.*, 2009; Wilson, Roberts & Reid, 2011; Cao *et al.*, 2013; Shea *et al.*, 2013; Hegeman, Miller & Mock, 2014). These studies have improved our understanding of the effects of environmental factors on mussel species and assemblages. However, models built in those studies were often based on relatively low numbers of sampling sites in small areas. They also usually required detailed data on local habitat variables (e.g. substrata, water depth and water quality) and, to a lesser extent, fish hosts (but see Shea *et al.*, 2013 for exception). Therefore, such models cannot be applied to unsampled streams over a large region at the resolution of sites or reaches, the scales most relevant for management.

Field sampling data are often insufficient to directly answer many important questions in aquatic conservation and restoration (Prie, Molina & Gamboa, 2014). For example, to identify stream reaches with high species diversity, we are limited to a (usually small) subset of the sampled sites and may overlook unsampled reaches that could better meet conservation objectives. To assess population fragmentation, we need to understand the spatial distribution of species across the whole area of interest, not just at a small number of sites. And to maximise the ecological return on restoration efforts, we also need to find the nearest source of a species or diversity hotspots (for the whole assemblage), sites which may fall outside the sampled domain (Sundermann, Stoll & Haase, 2011; Merovich *et al.*, 2013; Stoll *et al.*, 2013, 2014).

Modelling based on landscape variables can be a powerful tool to extrapolate sampling data to a large number of unsampled stream reaches (Carlisle, Falcone & Meador, 2009; Waite *et al.*, 2010; Merovich *et al.*, 2013) and remedy the limitations noted above. First, robust statistical methods (e.g. random forests and k-nearest neighbour regressions) can be combined with a range of increasingly available landscape environmental data (e.g. Brenden *et al.*, 2006; Wang *et al.*, 2012) to eliminate many difficulties associated with conventional approaches. For example, random forest regression (Breiman, 2001) can minimise model over-fitting, reduce the effect of predictor colinearity and accommodate different types of response curves (e.g. linear, nonlinear and step functions) and variable interactions (Cutler *et al.*, 2007). Second, landscape variables, such as landcover, topography, climate, soil and geology, are also known to affect in-stream habitats, flow and water quality (Richards, Johnson & Host, 1996; Tong & Chen, 2003; Price *et al.*, 2011; Olson & Hawkins, 2012; Frederico, De Marco & Zuanon, 2014). Fish distributions also are often strongly affected by the same set of broad-scale environmental factors (Wang *et al.*, 2003; Allan, 2004; Hopkins & Burr, 2009). As a result, the distributions and abundances of many aquatic species could be adequately modelled based on landscape environmental variables only.

In this study, we used a mussel data set derived from an extensive survey of wadeable streams at over 900 sites in Illinois, U.S.A., and a range of GIS-based environmental variables to model mussel presence–absence, species abundance, species richness and total abundance for a standard sampling effort. We then applied these models to all wadeable stream reaches across the study region to map mussel distributions. We also used the models to infer the effects of individual environmental variables on mussel species and diversity.

## Sampling and analytical methods

### *Site selection*

A total of 1011 sites were sampled for freshwater mussels in the state of Illinois, U.S.A., during 2009–2013. We chose a state as the study region because aquatic resources are managed mainly by individual states, and because sampling methods are often standardised at the state level. The majority of the sites were selected because they have been used by the Illinois Department of Natural Resources and the Illinois Environmental Protection Agency as basin-intensive survey sites (referred to here as fish survey) (IL-EPA, 2007). Typically, macroinvertebrates, fish, local habitat and water-quality information are collected at sites. The remaining sites were chosen as substitutes for fish-survey sites where flow was too high or low at the sampling time or as part of separate research projects. Although the choice of sampling sites was not based on a random design, the number of sites was large enough to represent all major river basins and catchments of Hydrologic Unit Code 8 (HUC8) (Fig. 1).

Of the 1011 sampled sites, 915 at which backpack shocking or electro-seining had been conducted were considered to be wadeable and were used for modelling. Based on the maximum stream order and the number of contributing 1st-order stream reaches (link) (Shreve, 1966) at the known wadeable sites, we identified 53 024 unsampled reaches with a high likelihood of being wadeable. The proportions of different land uses were similar between sampled and unsampled reaches. However, unsampled streams tended to be smaller (Table 1).

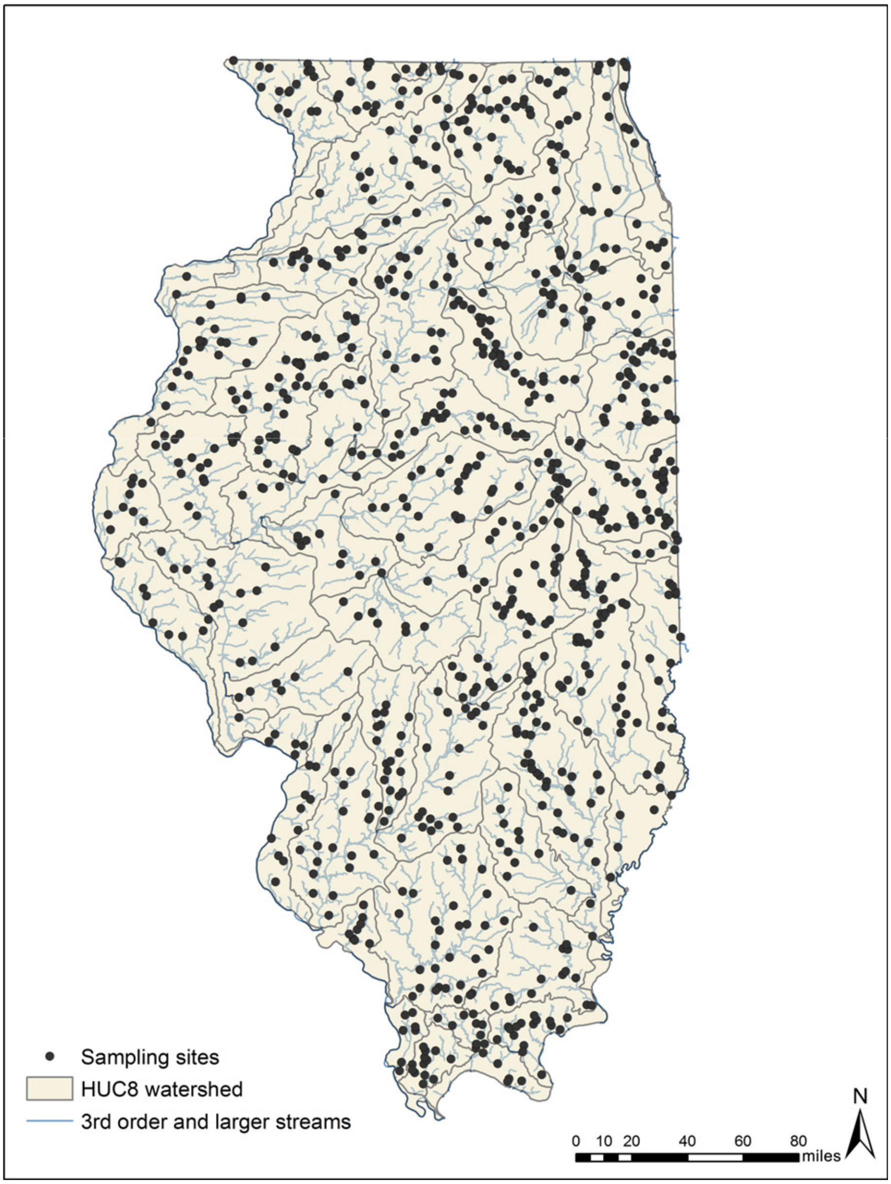


**Fig. 1** Locations of 915 sites in wadeable streams of Illinois sampled with four-person-hour search during 2009–2013.

*Mussel sampling and habitat measurement*

A four-person-hour search was conducted over a *c.* 200 m subreach at each site by crews of 3–6 people. All available habitats were searched, and every individual mussel encountered was collected. All individuals were identified, measured and returned to the stream after a small number of ambiguous individuals were vouchered and identified in the laboratory. Time-based sampling approaches like this are the most cost-effective for determining species presence at a location (Strayer & Smith, 2003), but they are still known to miss species and mussel individuals in Illinois streams (Huang, Cao & Cummings, 2011). To reduce the bias in species richness estimates, we first tried the Chao-2 statistical estimator of true species richness (Chao, 1984), but it yielded unrealistically high estimates for some sites (e.g. >35 species). We therefore took a second approach: in estimating species richness, we included freshly dead mussels, that is those with periostracum present, nacre pearly and (optionally) soft tissue remaining. On average, freshly dead mussel shells contributed one species per site, with a range of 0–8 species. Understanding the potential for additional missing species, we used this estimate as an index (rather than an estimate) of the true richness. Similarly, we used the number of mussels collected in the four-person-hour search as an index of the true abundance, both for individual species and for the whole assemblage.

We revisited 28 of the 915 sites to assess the interannual variability of mussel assemblages in terms of spe-

**Table 1** Main environmental characteristics of sampling reaches and unsampled wadeable reaches of streams in Illinois, U.S.A.

| Variables | Mean | Median | SD | Max | Min |
|---|---|---|---|---|---|
| Sampling wadeable reaches (915) | | | | | |
| Length (km) | 3.8 | 2.0 | 3.2 | 24.3 | 0.1 |
| Stream order | 3.5 | 3 | 1.1 | 7 | 1 |
| Link (number of 1st-order reaches) | 62.5 | 21 | 126.8 | 1600 | 1 |
| Total catchment size ($km^2$) | 416 | 135 | 812 | 8147 | 1 |
| Channel gradient (m over reach) | 0.15 | 0.1 | 0.02 | 2.5 | <0.01 |
| Total catchment slope (%) | 1.16 | 0.68 | 1.35 | 8.62 | 0.02 |
| % of Agri. Land in the total catchment | 63.8 | 69.9 | 23.8 | 95 | 1 |
| % of Grass land in total catchment | 18.3 | 16.2 | 10 | 64.7 | 0.01 |
| % of Forest land in total catchment | 12.6 | 7.7 | 17 | 89.5 | 0 |
| % of Urban land in total catchment | 4.4 | 1.3 | 10.9 | 91.2 | 0 |
| Unsampled wadeable reaches (53024) | | | | | |
| Length (km) | 2.4 | 2.8 | 1.8 | 47.9 | <0.1 |
| Stream order | 1.9 | 1 | 1.2 | 7 | 1 |
| Link (number of 1st-order reaches) | 24.6 | 1 | 112 | 1941 | 1 |
| Total catchment size ($km^2$) | 154.6 | 6.2 | 743.7 | 13170 | <0.1 |
| Channel gradient (m over reach) | 0.6 | 0.4 | 1.3 | 2.03 | <0.01 |
| Total catchment slope (%) | 1.4 | 0.9 | 1.5 | 13.2 | <0.01 |
| % of Agri. Land in the total catchment | 62.5 | 67.5 | 25.1 | 100 | 0 |
| % of Grass land in total catchment | 19.5 | 16.6 | 13.1 | 100 | 0 |
| % of Forest land in total catchment | 13.5 | 7.7 | 17 | 100 | 0 |
| % of Urban land in total catchment | 3 | 0.1 | 9.9 | 100 | 0 |

cies richness, the number of mussels and species composition. Sample similarity of visit replicates was compared to among-reach similarity using clustering (Bray–Curtis Index and β-flexible UPGMA, β = −0.25) and square-root-transformed species abundance. If replicates from a site always clustered together first, the assemblage stability was considered to be 100%, and if never, the stability to be 0%.

### *Landscape environmental variables*

For our modelling, we used the spatial framework and associated environmental database developed by the Great Lakes Regional Aquatic Gap Analysis Project (Brenden *et al.*, 2006; Seelbach *et al.*, 2010; McKenna, Carlson & Payne-Wynne, 2013). The framework defines a reach, the basic spatial unit of a stream network, as a stream section bounded by two adjacent tributaries (based on a 1 : 100 000 NHD map). If a lake or reservoir is present between the two tributaries, three reaches are delineated: the lake *per se*, and the upstream and downstream sections. A wide range of environmental variables on climate, geology, land use, soils and topography were summarised at four different spatial scales, all of which are related to the reach: (i) the total catchment (WT), the drainage above the downstream end of a reach; (ii) the local catchment (W), the area that drains into a reach directly; (iii) the 30-m riparian zone in the total catchment (RT); and (iv) the 30-m riparian zone in the local catchment (R). The effectiveness of reaches in partitioning the variation in fish assemblages and habitat variables among sampling sites has been confirmed in two recent studies (Warner *et al.*, 2010; Wang *et al.*, 2012).

The original database contains >300 environmental variables, including detailed geological and land-use categories (e.g. different types of urban lands and moraines) for multiple states. Seelbach *et al.* (2010) and Hinz (unpublished data) combined similar categories (e.g. different types of urban lands) into a major group (e.g. urban land). We adopted their grouping in this study to reduce the number of variables, assuming that the majority of information was retained by the major groups. We further removed those variables that have few nonzero values in Illinois, and ended with 112 variables.

Based on the literature and our experience, we selected 69 of the 112 environmental variables as the predictors. Three variables were used to describe the size of a stream reach and two to describe the size of the reach immediately downstream. We chose variables that summarised climate (6) and geology (19) at the WT level (Appendix S1) rather than at the W, R or RT level because flow and water chemistry are mainly controlled by processes in the total catchment (Brenden *et al.*, 2006; Olsen & Hawkins, 2013). However, we included four major types of land use: agriculture, forests, grasslands and urban lands at both the W and WT levels. These land uses are often highly correlated between the two scales, but differences exist and may be important. We included two minor land uses (water and wetlands) only at the W level because they seem more important for mussels than at the WT level (Cao *et al.*, 2013). Land-use variables at the R and RT levels were all excluded because of their high correlations with those at the W and WT levels, except the per cent water at the R level and the per cent grassland at the RT level. In this study, the per cent of urban and agricultural land use (mainly row crops) at the W and WT levels were used as surrogates of general broad-scale human disturbances, such as water-quality degradation, nutrient loading and habitat alternation. Three categories of bedrock depth along a reach's channel were also included, because this depth may affect channel morphology and substrata. Fifteen variables were used to describe the connection of a reach to ponds/lakes, dams (mostly low-head ones), the Great Lakes, the Mississippi River and other big rivers. Five variables were used to describe stream topography, including sinuosity and the slopes of the channel, the W and the WT. Four variables were used to describe soil hydrological properties at the W and WT levels, including soil permeability and the Darcy Index (Appendix S1).

### *Modelling*

We built four types of mussel models. First, we modelled the presence–absence of mussels as a group, with the collection of any individuals (including freshly dead shells) indicating presence. We then used random forest (RF) classification (Breiman, 2001) to predict the occurrence probability of mussels. In this effort, we excluded all climate variables because mussels as a group occur over a much wider range of climate than are present in Illinois. This modelling effort aimed to identify the environmental factors associated with mussel presence–absence. More importantly, we used its predictions to constrain the output of the other three types of models. The abundance of individual species, species richness and total mussel abundance in a reach were taken to be zero unless mussels were predicted to occur in the reach ($P \geq 0.5$). This step is a modification of a frequently used approach that the prediction of abundance is multiplied by the occurrence probability (Thorson & Ward, 2013; Anlauf-Dunn *et al.*, 2014).

A second type of model was developed for the abundance of individual species. We used RF regression (Breiman, 2001) to model the abundance of 39 species that were recorded at ≥15 reaches. When a site was sampled more than once, average abundance was used. Species abundance data are often associated with substantial sampling variability. We used [log (x + 1)] to transform the raw data of abundance to reduce the overdispersion and shift the focus of modelling to the change over the lower range (e.g. 0–10 individuals), which is often more ecologically meaningful than over the high range (e.g. 150–200). After modelling, predictions of abundance were transformed back to the number of individuals. Back-transformation often introduces biases into the prediction, and some form of correction is needed (Duan, 1983). No similar method is available for RF regression to our knowledge; however, this technique seems little affected by the bias (Hudak *et al.*, 2008). The last two models were for species richness and log-transformed total mussel abundance, respectively. Again, when a site was sampled more than once, average abundance and species richness were used. Predictions of total mussel abundance were transformed back to the number of individuals.

For each of the four types of modelling described above, we built multiple RF models by progressively increasing the number of environmental variables used for splitting (i.e. mtry in R-package, randomForest) and rerunning RF five times at each level of mtry using different random seeds. We identified a subset of models that explained similar proportions of the variance (within 1%) in the 1/3 of samples set aside before calibration (i.e. out-of-bag samples) and chose the one with the lowest mtry value. The relative importance of a variable was evaluated based on how much the mean standard error (MSE) of the model predictions increased (% MSE increase) when the values of a given variable were randomised in the out-of-bag samples. The greater the MSE increases, the more important a variable was considered. The overall importance of a variable was evaluated with the average % MSE increase across all species modelled. However, a variable may be critical only for one or a few species. We therefore also recorded the maximum, minimum and standard deviation of % MSE increase. The directional response of a species to a given variable was inferred with a partial-dependence plot, which averages out the effects of other variables. We examined the plots of the 10 most important environmental predictors for each model. The responses were classified into three types: positive, negative and multimodal (V- or U-shape, or irregular). RF modelling was implemented using randomForest in R environment (R Development Core Team 2009).

 

We applied the selected RF model to those unsampled reaches identified as wadeable and mapped the ranked individual species abundance, species richness and total mussel abundance in the state. To clearly show isolated, but highly ranked reaches, we mapped the local catchment of a reach, instead of the reach *per se*.

## Results

### *Mussel fauna*

We collected 42 564 live mussels of 48 species from 915 wadeable stream sites and found live mussels at 80.3% of the sites. We also collected 853 freshly dead shells, most of which belonged to the 48 live species; but two species were found only in these shells, bringing the total number of species to 50. On average, we collected 44 mussels (0–679) and 5.1 species (0–19) per site (a 200 m sub-reach). Fatmucket (*Lampsilis siliquoidea*) was the most abundant (11.9% of all live individuals), followed by plain pocketbook (*Lampsilis cardium*) (10.1%), threeridge (*Amblema plicata*) (8.2%) and white heelsplitter (*Lasmigona complanata*) (8.1%). Purple lilliput (*Toxolasma lividum*), hickorynut (*Obovaria olivaria*) and bleufer (*Potamilus purpuratus*) were the rarest, with only 1–2 individuals collected in the whole study. The frequencies of species occurrences were highly correlated with species abundances (Pearson's $r = 0.85$), implying that abundant species tended to distribute more widely. White heelsplitter (43.6% of all samples) was the most frequently encountered species, followed by giant floater (*Pyganodon grandis*) (41.4%), plain pocketbook (37%) and fatmucket (30%).

Samples obtained by revisiting 28 reaches captured similar species and clustered together with the first visit's sample in 79% of the cases. Species richness between visits was significantly correlated (Pearson's $r = 0.77$, $P < 0.01$), with an average difference of 1.8 species. The numbers of mussels collected in two visits were also correlated ($r = 0.73$, $P < 0.01$), with an average difference of 61 individuals. These results indicate that samples during the study period described mussel assemblages fairly consistently, but that the variation between visits was higher than expected, probably due to varying sampling efficiencies associated with different water depth, flow velocity and water temperature.

### *Presence–absence of mussels*

For mussel presence–absence, the selected RF model (mtry = 5) had an overall accuracy of 84%. Ninety-six per cent of the reaches where mussels were recorded during the field survey were correctly predicted (high sensitivity). In comparison, only 33% of the reaches where no mussels were recorded were correctly predicted (low specificity), probably due to a low sampling effort or imperfect detectability.

Multiple environmental variables appeared to contribute to presence–absence of mussels at a site. We focused on those ranked as the top 15 based on % MSE increase in the RF model. Partial-dependence plots indicated that mussels were least likely to occur in a stream reach characterised by (i) small WT size (WT_Area) and/or the number of 1st-order stream reaches in the WT (Link); (ii) high slope in channel (Chan_Grad), the local catchment (W_Slope) or total catchment (WT_Slope); and (iii) high % of urban land at the WT level (WT_Urban) (Appendix S2). Mussels were also often absent in those catchments dominated by rocky deposit geology (WT_Rocky). In contrast, streams readily connected to big rivers (Bigriver) or with a high % of water in the local catchment (W_Water) were more likely to support mussels.

When applied to wadeable streams in the state, the model predicted that 62% of reaches would support mussels. This rate is lower than in the sampled reaches (80.1%), a trend that was expected as our sampling sites were positively skewed to relatively large streams (Table 1).

### *Abundance of individual species*

RF species models were built for 39 species recorded at 15 or more reaches (Table 2), with 2–8 variables used for each split (4.8 on average). These models accounted for 5–51% of the total variance ($R^2$ values) for the 39 species, 28% on average, and ≥20% for 29 of them (Table 2). The model performance was not significantly correlated with the total number of sites where a species was recorded ($r = 0.18$, $P > 0.1$) or the total number of individuals collected across all sites ($r = 0.35$, $P < 0.5$), but it was correlated with the average number of individuals per site ($r = 0.53$, $P < 0.001$). Hereafter, we focus on the 29 better-modelled species ($R^2 > 20\%$).

The importance of environmental variables (% MSE increase) varied greatly among species (Table 3). While some variables were important only for a few species, others were generally important. For example, 23 of the 29 models ranked at least one measure of stream size among their top 10 most important predictors (Appendix S3), with average MSE increases of 21% for WT_Area and 20% for Link. Five climate variables were

**Table 2** Summary of mussel sampling data and model performance for all 39 species, species richness, and total mussel abundance (N = total number of individuals collected at all sites, Presence = the number of sites where a species was recorded, Average = average number of individuals per site, mtry = the number of variables used for splitting in random forest regression)

| Species | Species code | N | Presence | Average | $R^2$ | mtry |
|---|---|---|---|---|---|---|
| *Actinonaias ligamentina* | *A. ligamentina* | 714 | 59 | 12 | 0.31 | 4 |
| *Alasmidonta marginata* | *A. marginata* | 225 | 66 | 3 | 0.31 | 4 |
| *Alasmidonta viridis* | *A. viridis* | 150 | 32 | 5 | 0.05 | 2 |
| *Amblema plicata* | *A. plicata* | 3065 | 186 | 16 | 0.23 | 7 |
| *Anodontoides ferussacianus* | *A. ferussacianus* | 996 | 205 | 5 | 0.29 | 4 |
| *Arcidens confragosus* | *A. confragosus* | 66 | 25 | 3 | 0.10 | 2 |
| *Cyclonaias tuberculata* | *C. tuberculata* | 210 | 18 | 12 | 0.21 | 5 |
| *Elliptio dilatata* | *E. dilatata* | 45 | 21 | 2 | 0.10 | 3 |
| *Fusconaia flava* | *F. flava* | 2334 | 227 | 10 | 0.29 | 4 |
| *Lampsilis cardium* | *L. cardium* | 4104 | 331 | 12 | 0.42 | 7 |
| *Lampsilis fasciola* | *L. fasciola* | 43 | 15 | 3 | 0.28 | 4 |
| *Lampsilis siliquoidea* | *L. siliquoidea* | 4427 | 271 | 16 | 0.36 | 8 |
| *Lampsilis teres* | *L. teres* | 370 | 85 | 4 | 0.18 | 3 |
| *Lasmigona complanata* | *L. complanata* | 3388 | 397 | 9 | 0.26 | 7 |
| *Lasmigona compressa* | *L. compressa* | 143 | 92 | 2 | 0.11 | 2 |
| *Lasmigona costata* | *L. costata* | 201 | 57 | 4 | 0.16 | 4 |
| *Leptodea fragilis* | *L. fragilis* | 1128 | 262 | 4 | 0.44 | 6 |
| *Ligumia recta* | *L. recta* | 122 | 22 | 6 | 0.29 | 7 |
| *Ligumia subrostrata* | *L. subrostrata* | 429 | 71 | 6 | 0.24 | 6 |
| *Megalonaias nervosa* | *M. nervosa* | 351 | 35 | 10 | 0.50 | 7 |
| *Obliquaria reflexa* | *O. reflexa* | 129 | 38 | 3 | 0.42 | 5 |
| *Pleurobema sintoxia* | *P. sintoxia* | 841 | 104 | 8 | 0.39 | 7 |
| *Potamilus alatus* | *P. alatus* | 623 | 109 | 6 | 0.38 | 3 |
| *Potamilus ohiensis* | *P. ohiensis* | 241 | 85 | 3 | 0.24 | 7 |
| *Pyganodon grandis* | *P. grandis* | 2670 | 381 | 7 | 0.20 | 4 |
| *Quadrula metanevra* | *Q. metanevra* | 176 | 20 | 9 | 0.41 | 8 |
| *Quadrula nodulata* | *Q. nodulata* | 123 | 17 | 7 | 0.25 | 8 |
| *Quadrula pustulosa* | *Q. pustulosa* | 2712 | 156 | 17 | 0.51 | 6 |
| *Quadrula quadrula* | *Q. quadrula* | 2643 | 215 | 12 | 0.50 | 6 |
| *Strophitus undulatus* | *S. undulatus* | 801 | 230 | 3 | 0.27 | 5 |
| *Toxolasma parvum* | *T. parvum* | 1641 | 233 | 7 | 0.12 | 4 |
| *Toxolasma texasiensis* | *T. texasiensis* | 217 | 44 | 5 | 0.29 | 4 |
| *Tritogonia verrucosa* | *T. verrucosa* | 2091 | 114 | 18 | 0.51 | 6 |
| *Truncilla donaciformis* | *T. donaciformis* | 183 | 47 | 4 | 0.28 | 3 |
| *Truncilla truncata* | *T. truncata* | 626 | 82 | 8 | 0.40 | 3 |
| *Uniomerus tetralasmus* | *U. tetralasmus* | 519 | 92 | 6 | 0.12 | 2 |
| *Utterbackia imbecillis* | *U. imbecillis* | 607 | 99 | 6 | 0.08 | 2 |
| *Venustaconcha ellipsiformis* | *V. ellipsiformis* | 607 | 68 | 9 | 0.18 | 4 |
| *Villosa lienosa* | *V. lienosa* | 95 | 31 | 3 | 0.21 | 3 |
| Species richness | | 915 (sites) | 735 | 5.1 | 0.52 | 4 |
| Abundance (log-transformed) | | 915 (sites) | 735 | 43.8 | 0.41 | 5 |

also important for 17–20 species, and their average MSE increase across the species ranged from 14 to 16% (Table 3). Total catchment slope (WT_Slope), % of forest in the WT level (WT_Forest) and % of agricultural land in the WT level (WT_Agri) were important for 13–15 species (average MSE increase of 13–15%). Distance to a downstream dam (Damdn_L) and soil permeability (WT_Perm) were important for eight species (MSE increase of 16.8% and 14.8%, respectively). Geology was important for a small number of species. For example, the % of the WT with bedrock deeper than 30 m (WT_BRG100) was important for white heelsplitter (23% MSE increase) and the % of the WT dominated by lacustrine geology (lake sediments) (WT_Lacus) for pimpleback (*Quadrula pustulosa*) (19% MSE increase). When a variable type (e.g. climate or land use) had any variable that ranked in the top three, we considered that variable type to be a dominant one for the species. Accordingly, for most species one or two types of variables dominated (Table 4): 23 species by stream size, 14 by climate and 5 by each of stream connection and catchment land use.

**Table 3** Importance values of 41 environmental variables ranked as top 10 predictors by 29 better-modelled species ($r^2 > 0.2$), defined as per cent increase in mean standard error of the prediction when the values of the variable is randomised in the validation samples (variables ordered based on average importance value) (see full variable description in Appendix S1)

| Variables | N | Average | Max | Min | SD |
|---|---|---|---|---|---|
| WT_Area | 24 | 21.3 | 36.6 | 8.6 | 8.2 |
| Link | 23 | 20.0 | 33.4 | 9.6 | 7.5 |
| WT_GDD | 20 | 15.3 | 22.6 | 8.5 | 3.9 |
| WT_AMean | 19 | 14.5 | 21.5 | 7.0 | 4.2 |
| WT_JMean | 19 | 16.0 | 26.3 | 7.1 | 5.3 |
| WT_Precip | 17 | 14.2 | 23.8 | 7.0 | 4.7 |
| WT_JMin | 17 | 16.2 | 22.7 | 9.1 | 4.0 |
| WT_Slope | 15 | 15.1 | 29.2 | 7.9 | 5.8 |
| WT_Forest | 15 | 13.3 | 22.2 | 8.6 | 4.9 |
| WT_Agri | 14 | 14.2 | 22.4 | 7.6 | 4.4 |
| WT_JMax | 13 | 13.7 | 18.1 | 8.6 | 3.5 |
| Downorder | 13 | 15.4 | 22.2 | 9.4 | 3.9 |
| Damdn_L | 8 | 16.8 | 23.0 | 9.0 | 5.5 |
| WT_Perm | 8 | 14.8 | 22.1 | 8.8 | 4.6 |
| Dlink | 7 | 17.8 | 25.9 | 12.3 | 5.0 |
| Damup_L | 6 | 12.1 | 18.3 | 9.2 | 3.3 |
| WT_BRG100 | 5 | 13.4 | 23.6 | 9.0 | 6.3 |
| R_Water | 5 | 12.7 | 19.1 | 8.0 | 5.4 |
| WT_BR50 | 4 | 13.1 | 16.9 | 7.1 | 4.2 |
| W_Slope | 3 | 12.5 | 20.0 | 7.1 | 6.7 |
| Pondup_L | 3 | 14.7 | 18.4 | 7.8 | 6.0 |
| WT_Lacus | 3 | 19.7 | 21.6 | 17.7 | 2.0 |
| WT_Darcy | 3 | 19.3 | 20.7 | 17.0 | 2.0 |
| WT_Shale | 2 | 12.5 | 17.6 | 7.5 | 7.2 |
| WT_OWash | 2 | 7.8 | 7.9 | 7.7 | 0.2 |
| Ponddn_L | 2 | 13.4 | 15.4 | 11.3 | 2.9 |
| Ponddn_S | 2 | 11.7 | 14.3 | 9.1 | 3.6 |
| WT_Carb | 2 | 16.0 | 18.2 | 13.8 | 3.1 |
| Pondup_S | 2 | 8.1 | 8.2 | 8.0 | 0.2 |
| CH_Grad | 2 | 18.9 | 20.3 | 17.6 | 1.9 |
| W_Agri | 2 | 7.6 | 8.1 | 7.2 | 0.7 |
| W_Grass | 1 | 6.8 | 6.8 | 6.8 | NA |
| WT_Grass | 1 | 15.5 | 15.5 | 15.5 | NA |
| WT_Fine | 1 | 7.6 | 7.6 | 7.6 | NA |
| WT_Dune | 1 | 8.5 | 8.5 | 8.5 | NA |
| WT_MMora | 1 | 19.2 | 19.2 | 19.2 | NA |
| WT_Urban | 1 | 8.2 | 8.2 | 8.2 | NA |
| WT_PMuck | 1 | 8.8 | 8.8 | 8.8 | NA |
| WT_Rocky | 1 | 8.9 | 8.9 | 8.9 | NA |
| WT_BR100 | 1 | 8.9 | 8.9 | 8.9 | NA |
| WT_Loess | 1 | 10.7 | 10.7 | 10.7 | NA |

Partial-dependence plots offered some insights into how a species responded to a given environmental variable. We assessed the effects of the top 10 predictors for 29 species (290 plots in total). As mentioned earlier, the effect of an environmental variable was identified as positive, negative or multimodal (Table 5). For brevity, we presented only a small number of plots as examples. Species abundance always increased with stream size (Fig. 2a). The effects of climate variables, however, differed among species. For example, eight species increased with July mean temperature (WT_JMean), but nine decreased (Fig. 2b). Similarly, nine species tended to increase with annual precipitation of the WT (WT_Precip), but three decreased, and another five had multimodal responses.

Among different land uses, the % of agricultural land at the WT level (WT_Agri) was positively related to abundance for 12 species, but negatively related for two others (Table 5, Fig. 2c). In comparison, WT_ Forest affected more species negatively than it did positively (Fig. 2d, Table 5). Many species also responded negatively to WT_Slope (Fig. 2e). The effects of geology varied with species (Table 5). For example, the abundances of cylindrical papershell (*Anodontoides ferussacianus*) and pink heelsplitter (*Potamilus alatus*) significantly decreased with increasing % of <15 m-deep bedrock (WT_BR50), while monkeyface (*Quadrula metanevra*) abundance increased with a high % of loess in the WT (WT_Loess). The effects of dams and ponds were more often negative than positive (Fig. 2f, Table 5).

The models for the 29 species were applied to all unsampled wadeable stream reaches in Illinois. Positive abundances were restricted to sites with presence probabilities ≥0.5, as described earlier. Many species showed restricted distributions, while others were predicted to spread across the state (see Fig. 3 for example).

## *Species richness*

The RF model accounted for 52% of the variance in species richness with four variables used for each split (mtry = 4). The top 10 environmental predictors were associated with 23.9–38.2% increases in MSE, suggesting their strong effects (Fig 4a). Four of the top 10 variables described stream sizes (WT_Area, Link, Dlink and Downorder), and they were all positively related with mussel species richness. Richness also increased with WT_Agri, W_Water and the % of the catchment with bedrock deeper than 30 m (WT_BRG100). In comparison, species richness decreased with increasing WT_Slope, channel gradient (Chan_Grad), WT_Forest and July minimum temperature (WT_JMin) (Appendix S4).

In the 62% of unsampled wadeable reaches that were predicted to support mussels, the predicted richness for a standard sample was generally low (mean ± SD of 4.2 ± 1.9 species), compared with sampled sites (mean of 5.1 species). This matches expectations based on the smaller average size of unsampled stream reaches (Table 1). However, most large streams and many

**Table 4** Number of variables ranked as the top 10 predictors for each of seven groups and the highest rank (in bracket) for 29 mussel species, and the number of species dominated or codominated by each group of variables (the highest rank ≤ 3)

| Species | Climate | Connection | Geology | Land use | Soil | Stream size | Slope |
|---|---|---|---|---|---|---|---|
| *Anodontoides ferussacianus* | 3 (1) | 1 (4) | 2 (3) | 3 (5) | | | 1 (10) |
| *Actinonaias ligamentina* | 4 (3) | | 2 (9) | 1 (7) | | 2 (1) | 1 (6) |
| *Alasmidonta marginata* | 6 (2) | | | 1 (8) | | 2 (1) | 1 (10) |
| *Amblema plicata* | 3 (5) | 1 (7) | | 2 (3) | | 3 (1) | 1 (4) |
| *Cyclonaias tuberculata* | 3 (8) | 1 (2) | | 3 (5) | | 2 (1) | 1 (3) |
| *Fusconaia flava* | 6 (3) | | | | | 2 (1) | 2 (4) |
| *Lampsilis cardium* | 4 (3) | 1 (5) | 1 (9) | 2 (7) | | 2 (1) | |
| *Lasmigona complanata* | 5 (5) | | 2 (3) | | | 2 (1) | 1 (10) |
| *Lampsilis fasciola* | 1 (6) | 1 (1) | 1 (9) | 4 (3) | | 2 (2) | 1 (7) |
| *Leptodea fragilis* | 3 (5) | 1 (7) | 2 (6) | | | 4 (1) | |
| *Ligumia recta* | 1 (4) | 2 (3) | 2 (6) | 2 (8) | | 3 (1) | |
| *Lampsilis siliquoidea* | 6 (2) | 1 (4) | | 2 (6) | | | 1 (1) |
| *Ligumia subrostrata* | 6 (1) | | 1 (7) | 1 (9) | 1 (6) | | 1 (8) |
| *Megalonaias nervosa* | 1 (3) | 1 (5) | | 2 (7) | 1 (10) | 4 (1) | 1 (9) |
| *Obliquaria reflexa* | 2 (7) | 1 (10) | | 2 (6) | 1 (5) | 4 (1) | |
| *Potamilus alatus* | 5 (3) | | 1 (9) | | 1 (10) | 3 (1) | |
| *Pyganodon grandis* | 4 (5) | | 1 (8) | 1 (7) | 1 (1) | 1 (3) | 2 (2) |
| *Potamilus ohiensis* | 6 (3) | | | 1 (10) | | 3 (1) | |
| *Pleurobema sintoxia* | 3 (6) | 1 (4) | 1 (10) | 2 (3) | | 2 (1) | 1 (7) |
| *Quadrula metanevra* | 1 (7) | 2 (2) | 2 (5) | 1 (6) | | 3 (1) | 1 (10) |
| *Quadrula nodulata* | 2 (1) | 2 (7) | 2 (7) | 1 (8) | | 3 (2) | |
| *Quadrula pustulosa* | 1 (10) | 1 (3) | 1 (7) | 2 (8) | | 4 (1) | 1 (5) |
| *Quadrula quadrula* | 3 (5) | 2 (7) | | | 1 (6) | 4 (1) | |
| *Strophitus undulatus* | 6 (1) | 1 (10) | | | | 2 (7) | 1 (5) |
| *Truncilla donaciformis* | 3 (4) | | 3 (6) | 2 (3) | | 2 (1) | |
| *Toxolasma texasiensis* | 6 (1) | 1 (3) | | 1 (7) | | | 2 (5) |
| *Truncilla truncata* | 5 (6) | | | 1 (4) | | 4 (1) | |
| *Tritogonia verrucosa* | 5 (4) | | | | 1 (3) | 4 (1) | |
| *Villosa lienosa* | 4 (2) | 2 (6) | 1 (7) | 2 (1) | 1 (9) | | |
| Number of species with the highest rank ≤ 3 | 14 | 6 | 2 | 5 | 2 | 23 | 3 |

smaller ones in central-eastern Illinois were predicted to support higher species richness (Fig. 5). Ten or more species were predicted to occur at 735 reaches, and these reaches may be considered as candidates for long-term monitoring and special conservation status.

### *Total mussel abundance*

The RF model explained 41% of the variance in the log-transformed abundance. Key predictors were generally similar to those for the species richness model (Fig. 4b). As for species richness, total abundance increased with stream size (WT_Area and Link), WT_Agri, WT_BRG100 and the distance from the nearest upstream pond (Pondup_L), but decreased with increasing Chan_Grad, W_Slope or WT_Slope and WT_Forest (Appendix S5).

When the model was applied to wadeable streams across the state, the predicted number of mussels collected per 4 person-hour search of a site/subreach averaged 7.8 (SD = 11.1) with 92 (0.17%) of the reaches supporting more than 100 individuals per site. Predicted abundance showed strong spatial patterns: high in north-eastern and east-central Illinois, but low in western and southern Illinois, except in some large streams. The highest abundance was predicted in many reaches of the Sangamon and Vermilion Rivers. These predictions are highly correlated with the sum of the abundances predicted for 39 individual species ($r = 0.89$, $P < 0.01$), an observation that supports the spatial patterns observed and the reliability of the total abundance model.

## Discussion

In past decades, many efforts have been undertaken to understand how mussel abundance and diversity are affected by the prevalence of fish hosts and by environmental processes operating at various spatial scales (Arbuckle & Downing, 2002; Cao *et al.*, 2013; Daniel & Brown, 2013; Johnson *et al.*, 2014). While further research

**Table 5** Directional responses of 29 species to six groups of environmental variables based on partial-dependence plots in random forest regression (see full variable description in Appendix S1)

| Group | Variables | Total | Positive | Negative | Biomodal |
|---|---|---|---|---|---|
| Stream size (24 species) | WT_Area | 24 | 24 | 0 | 0 |
| | Link | 23 | 23 | 0 | 0 |
| | Downorder | 13 | 13 | 0 | 0 |
| | Dlink | 7 | 7 | 0 | 0 |
| Climate (29 species) | WT_GDD | 20 | 8 | 7 | 5 |
| | WT_AMean | 19 | 8 | 6 | 5 |
| | WT_JMean | 19 | 8 | 9 | 2 |
| | WT_Precip | 17 | 9 | 3 | 5 |
| | WT_JMin | 16 | 2 | 14 | 1 |
| | WT_JMax | 13 | 8 | 5 | 0 |
| | WT_Darcy | 3 | 2 | | 1 |
| Land use (22 species) | WT_Forest | 15 | 4 | 9 | 2 |
| | WT_Agri | 14 | 12 | 0 | 2 |
| | R_Water | 5 | 4 | 1 | 0 |
| | W_Agri | 2 | 2 | 0 | 0 |
| | W_Grass | 1 | 1 | 0 | 0 |
| | WT_Grass | 1 | 1 | 0 | 0 |
| | WT_Urban | 1 | 1 | 0 | 0 |
| Topography (17 species) | WT_Slope | 15 | 0 | 14 | 1 |
| | W_Slope | 3 | 1 | 2 | 0 |
| | CH_Grad | 2 | 0 | 2 | 0 |
| Geology (16 species) | WT_BRG100 | 5 | 5 | 0 | 0 |
| | WT_BR50 | 4 | 0 | 2 | 2 |
| | WT_Lacus | 3 | 3 | 0 | 0 |
| | WT_Carb | 2 | 1 | 1 | 0 |
| | WT_OWash | 2 | 2 | 0 | 0 |
| | WT_Shale | 2 | 1 | 0 | 1 |
| | WT_BR100 | 1 | 1 | 0 | 0 |
| | WT_Dune | 1 | 1 | 0 | 0 |
| | WT_Fine | 1 | 1 | 0 | 0 |
| | WT_Loess | 1 | 1 | 0 | 0 |
| | WT_MMora | 1 | 1 | 0 | 0 |
| | WT_PMuck | 1 | 1 | 0 | 0 |
| | WT_Rocky | 1 | 1 | 0 | 0 |
| Soil (8 species) | WT_Perm | 8 | 1 | 4 | 3 |
| Connection (18 species) | Damdn_L | 8 | 6 | 2 | 0 |
| | Damup_L | 6 | 5 | 1 | 0 |
| | Pondup_L | 3 | 3 | 0 | 0 |
| | Ponddn_L | 2 | 2 | 0 | 0 |
| | Ponddn_S | 2 | 0 | 2 | 0 |
| | Pondup_S | 2 | 2 | 0 | 0 |

in this direction is warranted, resource managers and researchers also need information on mussel diversity and abundance for a great number of unsampled streams at a relevant resolution.

In the present study, we focused on modelling and predicting characteristics of individual mussel species and complete mussel assemblages using only GIS-based landscape-level variables, which are available for many unsampled reaches. The predictions have several important implications for mussel biodiversity conservation and restoration. First, our mapping of species diversity and species relative abundances allows managers to assess the spatial pattern of populations and prioritise streams for biodiversity conservation and restoration. Most previous efforts were focused on local assemblages and habitat conditions. Meta-community theories predict that dispersal is a key factor for maintaining species diversity in a local community (Leibold *et al.*, 2004), and this proposition is supported by empirical studies (Sundermann *et al.*, 2011; Stoll *et al.*, 2013, 2014). Our reach-scale mapping of mussel species and assemblage attributes can also be used to identify stream reaches that

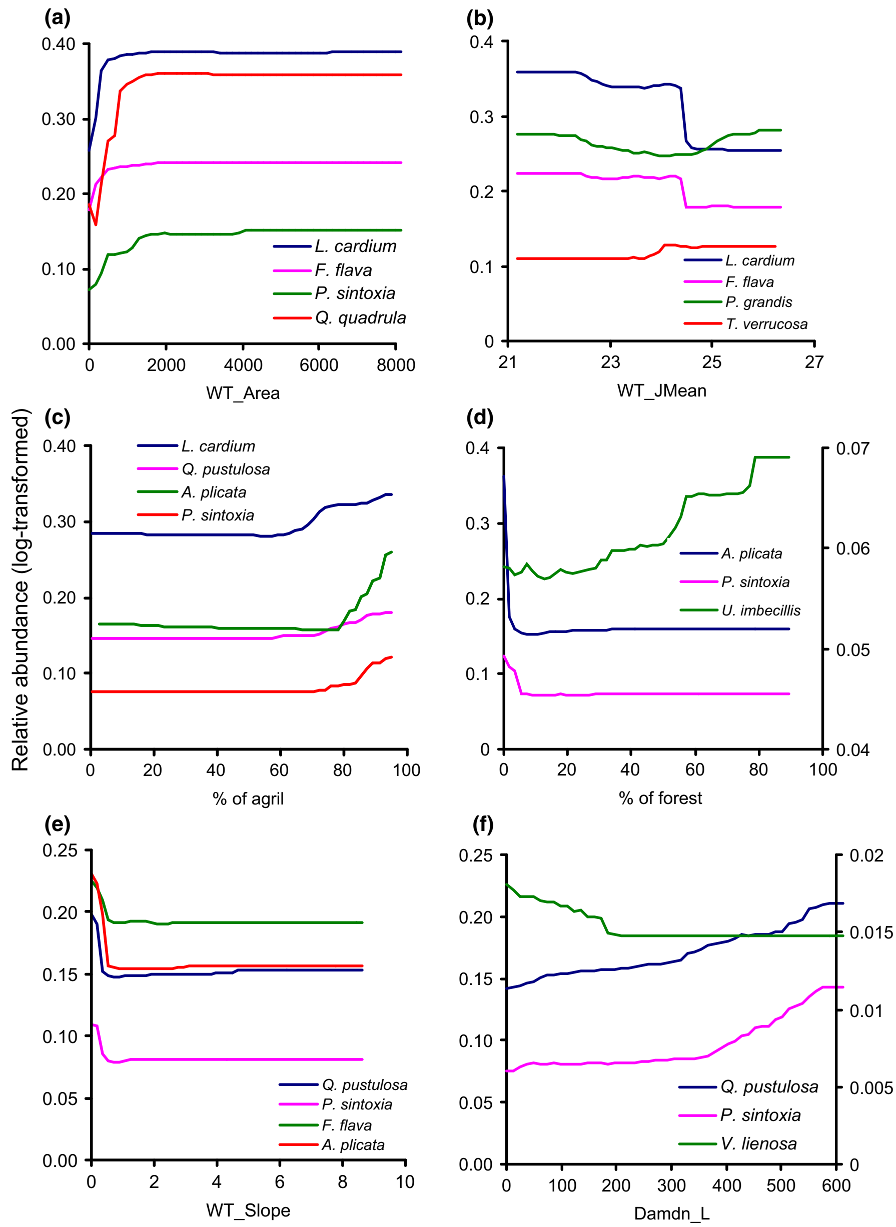


**Fig. 2** Examples of partial-dependence plots based on random forest regression, showing the responses of different mussel species to six key landscape environmental factors: (a) total catchment size (WT_Area), (b) July mean temperature in the total catchment (WT_JMean), (c) % of agricultural land in the total catchment (WT_Agri), (d) % of forest land in the total catchment (WT_Forest) with *Utterbackia imbecillis* and *T. tesasiensis* for the second *y*-axis, (e) total catchment slope (WT_Slope) and (f) distance (km) from downstream dam (Damdn_L) with *Villosa lienosa* for the second *y*-axis.

are good candidates for conservation of particular species (e.g. those with high abundance) or the entire mussel assemblage (e.g. those with high species diversity) in a subbasin or USGS HUC catchment. Similarly, these maps can be used to identify impaired stream reaches in the vicinity of species-rich or well-populated reaches as candidates for restoration. Such candidates would surely need to be evaluated based on field sampling and prioritised after considering available resources and other constraints. We will report the outcomes of this analysis separately. Furthermore, one can use the distribution maps for many other purposes in conservation, such as assessing the proportion of predicted species-rich streams that are currently under protection (e.g. state parks, wildlife refuges or national forests), identifying conservation gaps (Rodriguez *et al.*, 2007) or designing an effective sampling strategy for monitoring mussel 'hotspots' for overall biodiversity and specific species population. Finally, our models could be used, preferably together with other types of models (i.e. an ensemble method), to evaluate the impacts of future climate and land-use changes by comparing current values with their predictions under future scenarios.

Our modelling also provides valuable information about the effects of environmental variables on mussel assemblages. Mussel species and diversity are often cocontrolled by natural environmental factors, the availability of fish hosts and human disturbances (Strayer,

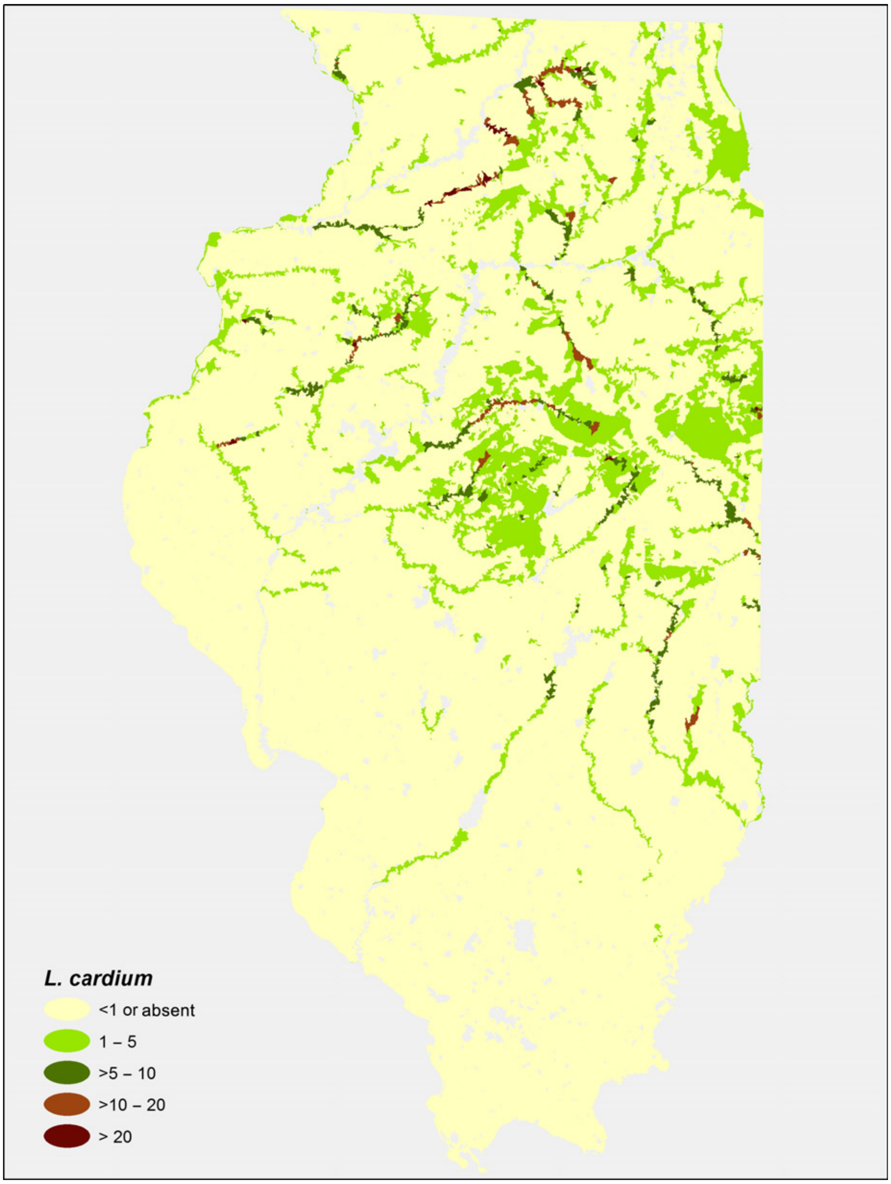


**Fig. 3** Ranked abundance of *Lampsilis cardium* based on four-person-hour search in all wadeable streams in Illinois, predicted with random forest regression; the local catchment is mapped to improve the visibility of infrequent ranks.

1983, 2008; Vaughn & Taylor, 1999; Poole & Downing, 2004; Daniel & Brown, 2013). However, the relative importance of these factors may vary with the spatial scale and with the regions studied. In our models, variation in the abundance of individual species, species richness and total mussel abundance appeared to be better explained by natural environmental factors, particularly stream size, climate and catchment topography than by land use and waterway connections (Table 4) (Fig. 2). Burlakova *et al.* (2011) reported similar results in analysing mussel assemblages in Texas. This finding does not imply that human disturbances are not threats. In fact, the impacts of water pollution, habitat degradation and fragmentation on mussels have been well documented across the U.S.A. (Allan, 2004; Strayer, 2008; Downing *et al.*, 2010). However, quantifying human impacts on mussel assemblages requires comparing potentially altered sites with either reference sites or historical conditions (Stoddard *et al.*, 2006) and relating the differences to detailed data on individual stressors. Such an analysis goes beyond the scope of the present study.

Assessing the effects of individual environmental factors on mussel species and assemblages through modelling is often more challenging than predicting abundance and distribution, largely because of covariation and interactions among variables (Strayer, 2008). RF modelling automatically accounts for environmental variable interactions and is highly robust to the effects of colinearity on prediction (Cutler *et al.*, 2007). However, separating the effects of correlated variables (e.g. %

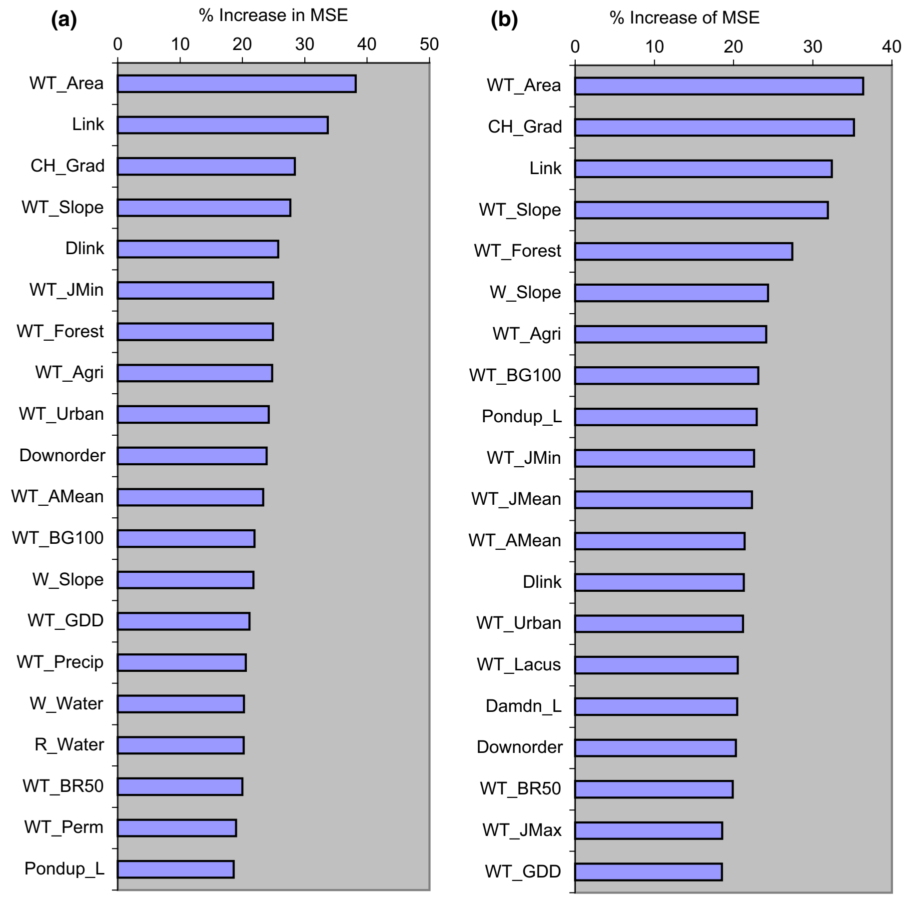


**Fig. 4** Importance values of the top 20 environmental variables for predicting species richness (a) and relative abundance (b) in random forest regression.

agricultural land at the W and WT levels) from one another remains difficult. Importance values in RF regression (i.e. the % increase in MSE) indicate which variable most strongly affected model predictions. Partial-dependence plots of RF also average out the effects of other variables (Cutler *et al.*, 2007). These two features of RF models help us to infer the effects of specific variables on mussels.

The effects of individual environmental variables on mussels that we documented are largely consistent with many previous studies. The observed preference of most mussel species for larger and lower-gradient streams agrees with several early studies (e.g. Ortmann, 1919; van der Schalie, 1938) and many recent ones (Strayer, 1983, 1993; Arbuckle & Downing, 2002; Krebs *et al.*, 2010; Daniel & Brown, 2013). Stable flow and suitable substrata in larger streams may explain this preference (Haag & Warren, 1998, 2008; Golladay *et al.*, 2004; Daniel & Brown, 2013). Troia & Gido (2014) recently reported that fish species grew faster and reproduced more in larger streams because of increased food supplies and temperature. This mechanism could also apply to mussels, and because of mussel–fish host relationships, the benefits of larger and slower streams for mussel could be doubled. Few studies have examined the associations of mussel species distribution with climate variables (Strayer, 2008), probably because broad-scale mussel surveys are rare. However, this knowledge, together with laboratory-based thermal-tolerance tests (Spooner & Vaughn, 2008; Ganser, Newton & Haro, 2013), is essential to predict the impacts of climate changes. The relative abundance of all 29 better-modelled species ($R^2 > 20\%$) were associated with at least one and often several climate variables (Table 5). This climate association was much stronger in some species than in others, and it also varied in its sign (Table 3–4). Some of the climate associations may have resulted from the co-variation with other factors that more directly affect mussels, such as discharge (Galbraith, Spooner & Vaughn, 2010); these factors may (e.g. geology) or may not (e.g. biogeographical history) be included in our modelling. Other associations could be real or direct. Because of the uncertainty in deciphering causality, one should be cautious when interpreting the climate associations and using them to predict the effects of climate changes. Meta-analyses and experiments would be useful to

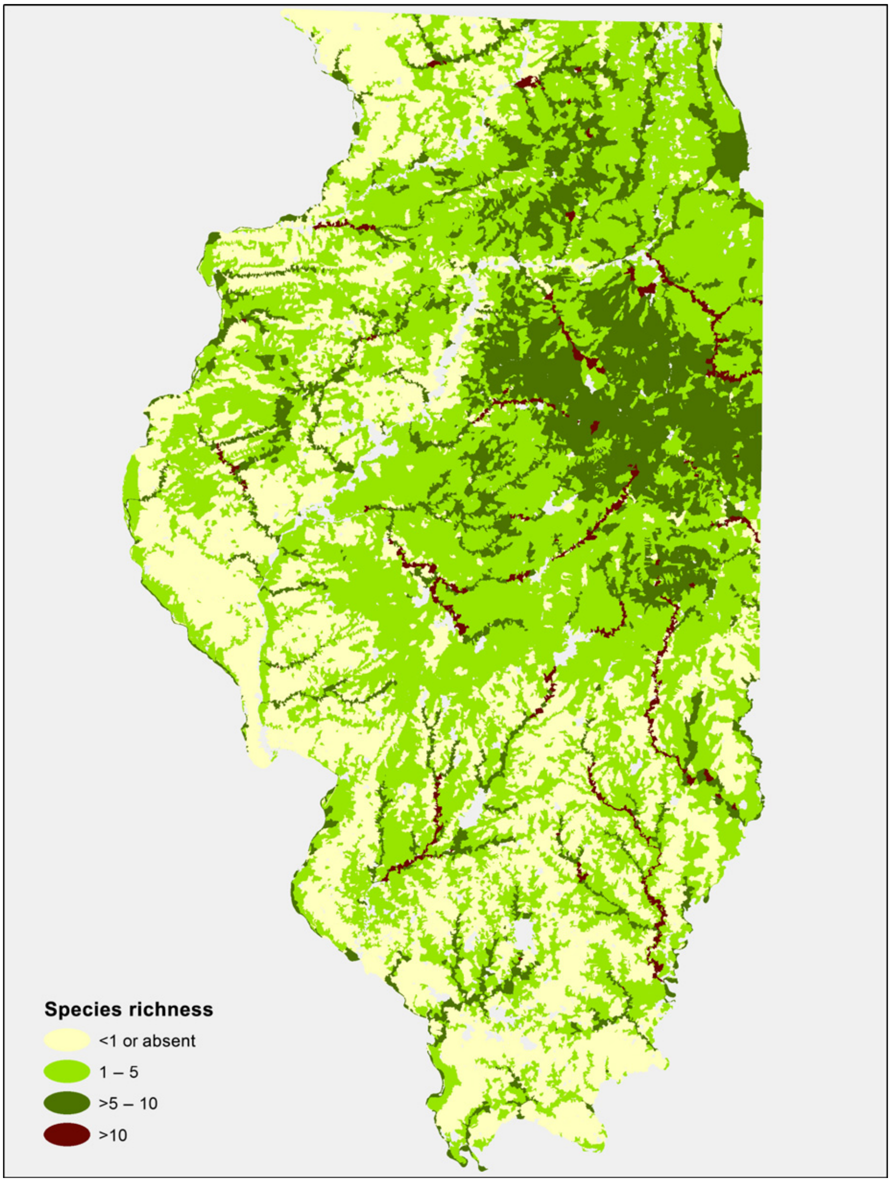


**Fig. 5** Spatial patterns of species richness predicted across all wadeable streams in Illinois based on random forest regression models, and mapped for the local catchment to improve the visibility of different ranks.

determine the temperature preferences of individual species. Nevertheless, our results suggest that various mussel species respond differently to climate changes. Of the climate variables examined, growing-degree days (GDD) and annual mean temperature (WT_AMean) were important predictors in most species models; therefore, these seem to be the most relevant measure for assessing the impacts of climate changes in the study area.

Several geological variables were found to be important for species richness, total mussel abundance (Appendices S4 and S5), mussel presence–absence and abundance of some species (Tables 3–5). Geology, together with climate and topography, shapes substratum composition, stream channel morphology and flow regimes (Schomberg *et al*., 2005; Snelder, Lamouroux & Pella, 2011; Kasprak *et al*., 2013), all of which are known to be important for mussel assemblages at certain spatial scales (Brim Box, Dorazio & Liddell, 2002; McRae, Allan & Burch, 2004). Thus, these effects of geology could be better interpreted through flow and habitat modelling. In the management perspective, the strong effects of natural environmental variables on mussel species and assemblages mean that, to set attainable ecological restoration and conservation targets, we must adjust our expectations for natural mussel assemblages and diversity in different stream reaches.

In spite of the generally stronger effects of natural variables, many mussel species were also associated with land use and connections to dams/ponds, two main forms of human disturbances examined in our study (Table 3–5). Those species tended to increase with distance from a dam or pond (i.e. negative effects). Total mussel abundance responded similarly to the connection measures. These findings are largely supported by previous field studies (Vaughn & Taylor, 1999; Tiemann *et al.*, 2007; Shea *et al.*, 2013; Haag & Williams, 2014; but see Gangloff, 2013). However, the positive association of mussels with the % of agricultural land in the WT (Table 5, Appendices S4 and S5) appeared counterintuitive, and contradicts several previous reports (e.g. Poole & Downing, 2004; Daniel & Brown, 2013). In agriculture-dominant regions like Illinois, the alternative land-use types are mainly urban areas and forest. Urbanisation generally affects aquatic species more adversely than agriculture (Wang *et al.*, 2000). Forest land has been associated with higher mussel abundance and diversity (e.g. Gagnon *et al.*, 2006; Hopkins & Whiles, 2011). However, in our modelling, species richness, total mussel abundance and the abundance of many individual species tended to decrease with increasing % of forest in the catchment (WT_Forest) (Table 5, Appendices S4 and S5). Most forests in Illinois are located in the southern and western part of the state (Luman *et al.*, 2004), where streams tend to have higher slopes, coarser substrata and less stable flows; therefore, these areas generally support few mussels. The strong correlation between the % of forested land in the catchment (WT_Forest) and catchment slope ($r = 0.87$, $P < 0.01$) or latitude ($-0.58$, $P < 0.01$) supports this explanation. As a result, agricultural land appeared to be less detrimental to mussel assemblages than other land uses. Wang *et al.* (2000) also observed a positive relationship of fish species richness and IBI with agricultural land in Wisconsin, where the landscape is also dominated by agriculture. On the other hand, our broad-scale modelling confirmed the benefit of riparian wetland (W_Wet) to mussel assemblages (Poole & Downing, 2004; Gagnon *et al.*, 2006; Cao *et al.*, 2013).

Noticeably, the relationships between mussel species and their environments were only partly explained by our models (i.e. frequently low $R^2$). One possible reason is that some key factors were missed. Among those are flow stability and water quality, which are known to be important for freshwater mussels (McRae *et al.*, 2004; Downing *et al.*, 2010). Our models did include many related environmental variables, such as geology, climate, soil and land use (Schomberg *et al.*, 2005). However, directly modelling flow and water quality at the stream reach level and incorporating the predictions into mussel models may significantly improve accuracy. Substrata and fish hosts are also known to be important (Brim Box & Mossa, 1999; McRae *et al.*, 2004; Cao *et al.*, 2013; Daniel & Brown, 2013; Hegeman *et al.*, 2014), but both were not included in our modelling because these data were unavailable for unsampled reaches. However, many studies have modelled the presence–absence or abundance of fish species (e.g. Oberdorff *et al.*, 2001; Steen *et al.*, 2008). We are in the process of modelling nearly 100 fish species in the study region, and the predictions can be used to refine mussel models in the future. However, temporal variability in fish assemblages at the reach scale may significantly compromise the effort. It is also possible to model some local habitat characteristics, such as certain substratum measures (Schomberg *et al.*, 2005; Snelder *et al.*, 2011), or to associate local variables with some landscape ones (Peterson *et al.*, 2009). Again, heterogeneity of habitats within reaches likely makes commonly used substratum measures (e.g. % of fine sediments or median particle size) not too useful as predictors (Strayer, 2008). Indeed, when using a subset of our sampling sites for which host fish and certain local habitat data (substratum, water depth and width) were available to rebuild the models, we found little improvement in most species (Stodola *et al.*, unpubl. data). Effectively incorporating substratum and fish host information into large-scale mussel modelling remains challenging.

A second reason for low $R^2$-values in our modelling may be high sampling error. The within-habitat distribution of mussel individuals is often patchy, and a low sampling effort means low repeatability or high sampling error. Our revisiting data indicated that the sampling effort used in our study (four-person-hour search), although higher than in many any studies (Huang *et al.*, 2011), was associated with some high sampling efforts. A low sampling effort essentially introduces noise into species–environment relationships and constrains model performance. High sampling efforts can reduce the noise level. Cao *et al.* (2013) achieved a higher $R^2$ for total abundance when using a 16-person-hour search relative to a four-person-hour search. Large-scale mussel studies therefore need to carefully balance competing needs to sample a large number of sites and to maintain a high sampling intensity at each site. Alternatively, one may choose to model how habitat conditions affect the detectability of individuals in a species based on multiple visits (Royle & Dorazio, 2008). However, such an approach may be not practical in large-scale assemblage surveys, and its utility depends on model performance (Banks-Leite *et al.*, 2014).

Another possible way to improve predictions is to building a separate model for each major river basin, thus better capturing the effects of more local environmental gradients. However, it likely reduces model transferability, which is critical for extrapolation over space or time (Heikkinen, Marmion & Luoto, 2012). In fact, RF regression, although often highly accurate, may not be the most transferable model (Wenger & Olden, 2012). However, our focus here is on predicting the current abundance and distribution of mussels to better inform resource management; hence, accuracy is our priority. Predicting future changes in mussel species may be better served using multiple modelling techniques, that is an ensemble approach (Grenouillet *et al*., 2011; Comte & Grenouillet, 2013). Future mussel modelling also should include non-wadeable streams, large rivers and lakes, which supports different types of mussel assemblages, to produce a complete picture of freshwater mussel biodiversity in the study region. Finally, we would like to emphasise that GIS-based environmental data similar to that used in our modelling is available for all states in the U.S.A. (http://fishhabitat.org) and many other parts of the developed world (e.g. Chu & Jones, 2010; Bergerot, Hugueny & Belliard, 2013). Our modelling framework is therefore generally applicable to those regions.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Appendix S1.** Predictor variables used for RF regression (WT = total catchment, W = local catchment, R = riparian zone in a local catchment, RT = riparian zone in the total catchment).

**Appendix S2.** Partial-dependence plots of selected variables for mussel presence based on random forest classification models applied to 915 sites at wadeable streams of Illinois (see Cutler *et al*. 2007 Appendix C for interpretation of *y*-axis).

**Appendix S3.** Top 10 predictors in random forest regression models of 29 mussel species in Illinois wadeable streams and their responses, positive (+), negative (−), bimodal (v or u) or irregular (~) based on partial-dependence plots (see full descriptions of predictor variables in Appendix 1).

**Appendix S4.** Partial-dependence plots of selected variables for species richness based on random forest regression models applied to 915 sites at wadeable streams of Illinois.

**Appendix S5.** Partial-dependence plots of selected variables for total abundance based on random forest regression models applied to 915 sites at wadeable streams of Illinois.

*(Manuscript accepted 10 May 2015)*

# Modeling historic distributions of Illinois's freshwater mussels using Maximum Entropy

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## Preface

A component of State Wildlife Grant T-82-R-1 (Defining expectations for mussel communities in Illinois wadeable streams) is to evaluate species' abundance, distribution, habitat requirements, ecological role and amount of information available regarding the species for all mussel Species in Greatest Need of Conservation (SGNC) in Illinois. This information will be used to update the freshwater mussel SGNC accounts included in the Illinois Comprehensive Wildlife Conservation Plan developed in 2005. This document updates Appendix I and II and Actions for the Streams Campaign for mussel SGNC to include in the 2015 revised Illinois Comprehensive Wildlife Action Plan. Additionally, distribution maps and host fish information for mussel SGNC and other species found currently or historically in Illinois are included.

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## Introduction

A major goal of Illinois' Wildlife Action Plan is to protect existing populations of species of concern and their habitats. Freshwater mussels are imperiled throughout much of their range, and 26 species are listed at the state or federal level in Illinois (Illinois Endangered Species Protection Board [IESPB] 2015) and an additional five species are considered in species of conservation need. Understanding the breadth of distribution change over time is crucial to guide conservation efforts. Historical data from field surveys are often the sole information source to explain species' ranges, yet data may not be available for time periods prior to human settlement or development. Modeling approaches have been advocated for delimiting species distribution, as these can fill information gaps in field-collected data. Modeling approaches like Maximum Entropy (Maxent) generally use summaries of landscape features derived from geographic information systems (GIS) and known locations of species to identify similar areas on the landscape.

Our objectives for this project were to:

1) Re-construct the historic distributions of mussel species in 46,462 wadeable Illinois stream reaches
2) Re-construct the historic mussel species richness in the wadeable streams

Understanding the extent of the historic distribution of species will give us a clearer picture of the current status of species loss and direct conservation efforts in the future.

## Methods

*Preparation of mussel data* - Species and locality data for freshwater mussels were gathered through the Illinois Natural History Survey Mollusk Collection and related records obtained from cooperating natural history collections (e.g., University of Michigan Museum of Zoology, Ohio State University, etc.). These data date to the late 1800s to present day. Each sample was associated with a unique stream reach (confluence to confluence reach), and a set of reaches that were well sampled historically were used for model validations. Any species recorded in less than 15 unique reaches were removed from the dataset due to insufficient data available to model.

Background reaches are segments of streams that serve as "pseudo-absences" or areas with no records for a particular species, and the minimum number of background reaches required for Maxent models is 10,000 reaches. Background reaches were restricted to those USGS Hydrological Unit Code 6 (HUC6; water.usgs.gov/GIS/huc.html) watersheds where a targeted species was recorded. Because some species also were only recorded in a single or a couple of HUC6 watersheds, the number of reaches where the species were absent in the watersheds (background reaches) was small; thus, these species were dropped from the analysis. These species were also dropped if the available background was far smaller than the required (10,000 reaches). As a result, 45 species were available to model.

*Preparation of environmental data* - Forty environmental variables were used to predict mussel distribution, which describe climate, geology, soil, and 1800s land-covers, mostly at the watershed scale. All variables except land-covers were based on Great Lakes Aquatic Gap Analysis (Cao et al. 2016). Land-covers were based on the Illinois Land Cover Map (Luman et al. 2004). These variables were chosen because of their known or assumed importance to mussel species (Strayer 2008; Haag 2012).

*Modeling* - Maxent models were built based on default settings (i.e., standard model; Phillips et al. 2014). The predictions of Maxent were transferred into species presence-absence based on the threshold for equal training sensitivity and specificity (ETSS) (Phillips et al. 2006). The predictions of individual species were stacked to estimate the number of species (i.e., richness) at each reach.

**Results**

We used 36,263 species records for the analysis, and a total of 18,810 occurrences (one occurrence = a species in a reach) were available for model calibration. After species with inadequate data were removed, we were able to model historical distributions of 45 species (Table 1; Appendix I).

Predicted species richness ranged from no more than 1 species to 38 species within each HUC6 watershed (Figure 1). The watersheds predicted to be the most diverse were tributaries to the large rivers (i.e., Illinois River, Wabash River, and Rock River) such as the Kankakee River, Vermilion River of the Illinois and Wabash rivers, Fox River, and Kishwaukee River.

**Discussion**

These maps give us an idea of the historical or pre-settlement range of 45 mussel species in Illinois. Only using museum records may provide an underestimation of the historic range of a species, due to factors such as inadequate preservation of specimens or lack of transportation to remote field sites. In many cases, the modeled historic distributions reveal areas of Illinois that likely had populations of particular species that have no historic mussel collection records (e.g., Spike - *Elliptio dilatata* or Flat Floater- *Utterbackia suborbiculata*). Conversely, some species' historic distributions were apparently under-predicted in their historic distribution (i.e., Little Spectaclecase - *Villosa lienosa* and Louisiana Fatmucket – *Lampsilis hydiana*). Louisiana Fatmucket presumably did not perform well due to lack of historical records; this species was only recently documented in Illinois. Regardless, understanding the nature and scope of range declines can guide restoration efforts for freshwater mussels in the future.

The predicted historic species richness across Illinois appears to be fairly accurate based on comparisons with vouchered shell records. Few species populate extreme headwaters of a river system, and species diversity increases as the system becomes larger (e.g., Vannote et al. 1980, among others). Many watersheds had predicted species richness greater than 20 species, but those watersheds have undergone significant species losses in post-settlement years (Tiemann et al. 2007; Douglass and Stodola 2014). Dams, commercial harvest, and agricultural and industrial land-use practices dramatically altered pre-settlement mussel species' distributions and reproduction efforts and led to reduced species richness across the landscape.

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Table 1. Summary of 45 species data for Maxent modeling.

| Species | Domain | Training | Background | Test |
|---|---|---|---|---|
| *Actinonaias ligamentina* | 46317 | 305 | 10000 | 36012 |
| *Alasmidonta marginata* | 40904 | 316 | 10000 | 30588 |
| *Alasmidonta viridis* | 43780 | 233 | 10000 | 33547 |
| *Amblema plicata* | 46317 | 799 | 10000 | 35518 |
| *Amphinaias nodulata* | 46317 | 61 | 10000 | 36256 |
| *Amphinaias pustulosa* | 46317 | 528 | 10000 | 35789 |
| *Anodontoides ferussacianus* | 43567 | 761 | 10000 | 32806 |
| *Arcidens confragosus* | 43567 | 110 | 10000 | 33457 |
| *Cyclonaias tuberculata* | 43780 | 92 | 10000 | 33688 |
| *Elliptio dilatata* | 46443 | 284 | 10000 | 36159 |
| *Fusconaia ebena* | 46317 | 14 | 10000 | 36303 |
| *Fusconaia flava* | 46443 | 746 | 10000 | 35697 |
| *Lampsilis cardium* | 46317 | 891 | 10000 | 35426 |
| *Lampsilis hydiana* | 9427 | 46 | 9381 | 0 |
| *Lampsilis siliquoidea* | 46443 | 883 | 10000 | 35560 |
| *Lampsilis teres* | 46317 | 382 | 10000 | 35935 |
| *Lasmigona complanata* | 46317 | 1075 | 10000 | 35242 |
| *Lasmigona compressa* | 43780 | 335 | 10000 | 33445 |
| *Lasmigona costata* | 43780 | 265 | 10000 | 33515 |
| *Leptodea fragilis* | 46443 | 705 | 10000 | 35738 |
| *Ligumia recta* | 43780 | 124 | 10000 | 33656 |
| *Ligumia subrostrata* | 45986 | 226 | 10000 | 35760 |
| *Megalonaias nervosa* | 46317 | 127 | 10000 | 36190 |
| *Obliquaria reflexa* | 46317 | 87 | 10000 | 36230 |
| *Obovaria olivaria* | 46317 | 10 | 10000 | 36307 |
| *Plethobasus cyphyus* | 43780 | 25 | 10000 | 33755 |
| *Pleurobema sintoxia* | 43780 | 348 | 10000 | 33432 |
| *Potamilus alatus* | 46317 | 260 | 10000 | 36057 |
| *Potamilus ohiensis* | 46317 | 335 | 10000 | 35982 |
| *Pyganodon grandis* | 46443 | 1212 | 10000 | 35231 |
| *Quadrula quadrula* | 46317 | 568 | 10000 | 35749 |
| *Simpsonaias ambigua* | 38578 | 15 | 10000 | 28563 |
| *Strophitus undulatus* | 46443 | 738 | 10000 | 35705 |
| *Theliderma metanevra* | 43780 | 88 | 10000 | 33692 |
| *Toxolasma parvum* | 46443 | 657 | 10000 | 35786 |
| *Toxolasma texasiense* | 9427 | 104 | 9323 | 0 |
| *Tritogonia verrucosa* | 46317 | 319 | 10000 | 35998 |
| *Truncilla donaciformis* | 46317 | 155 | 10000 | 36162 |
| *Truncilla truncata* | 46317 | 235 | 10000 | 36082 |
| *Uniomerus tetralasmus* | 41432 | 356 | 10000 | 31076 |
| *Utterbackia imbecillis* | 46317 | 316 | 10000 | 36001 |
| *Utterbackia suborbiculata* | 46317 | 45 | 10000 | 36272 |
| *Venustaconcha ellipsiformis* | 40904 | 318 | 10000 | 30586 |
| *Villosa iris* | 26054 | 46 | 10000 | 16008 |
| *Villosa lienosa* | 20673 | 18 | 10000 | 10655 |

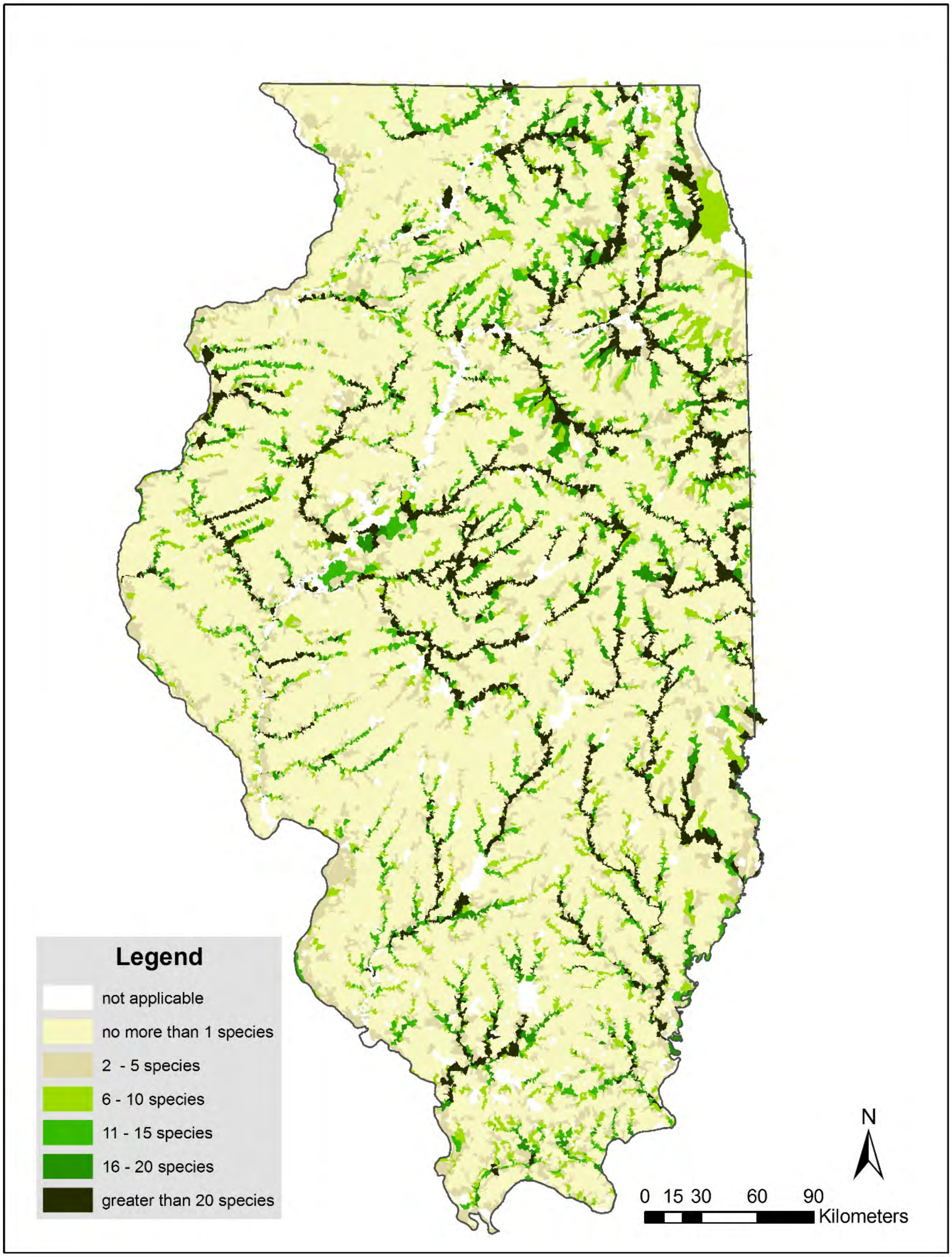
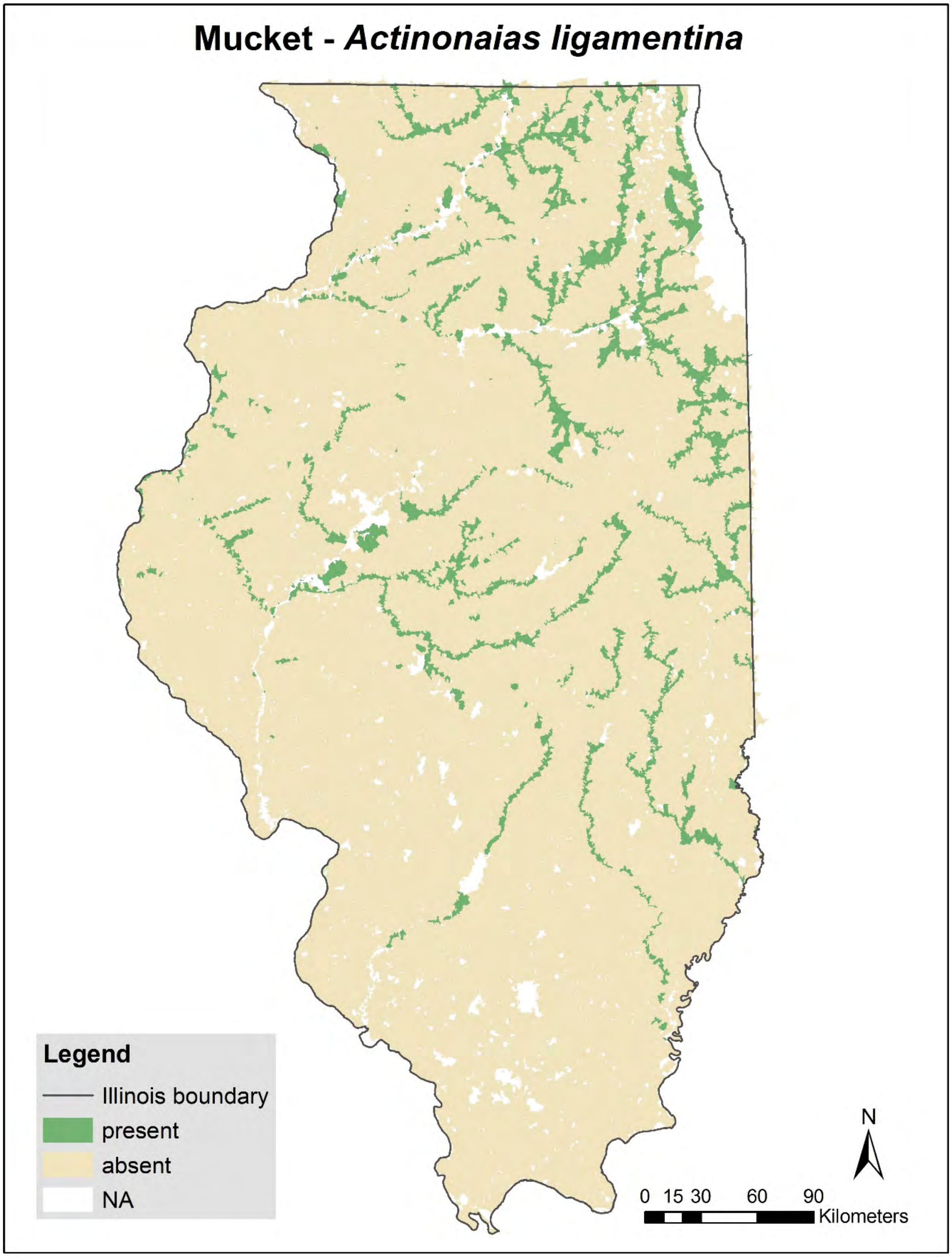



Figure 1: Predicted historical species richness based on standard Maxent models for 45 species.

Appendix I. Historical distribution maps as predicted by Maxent models.



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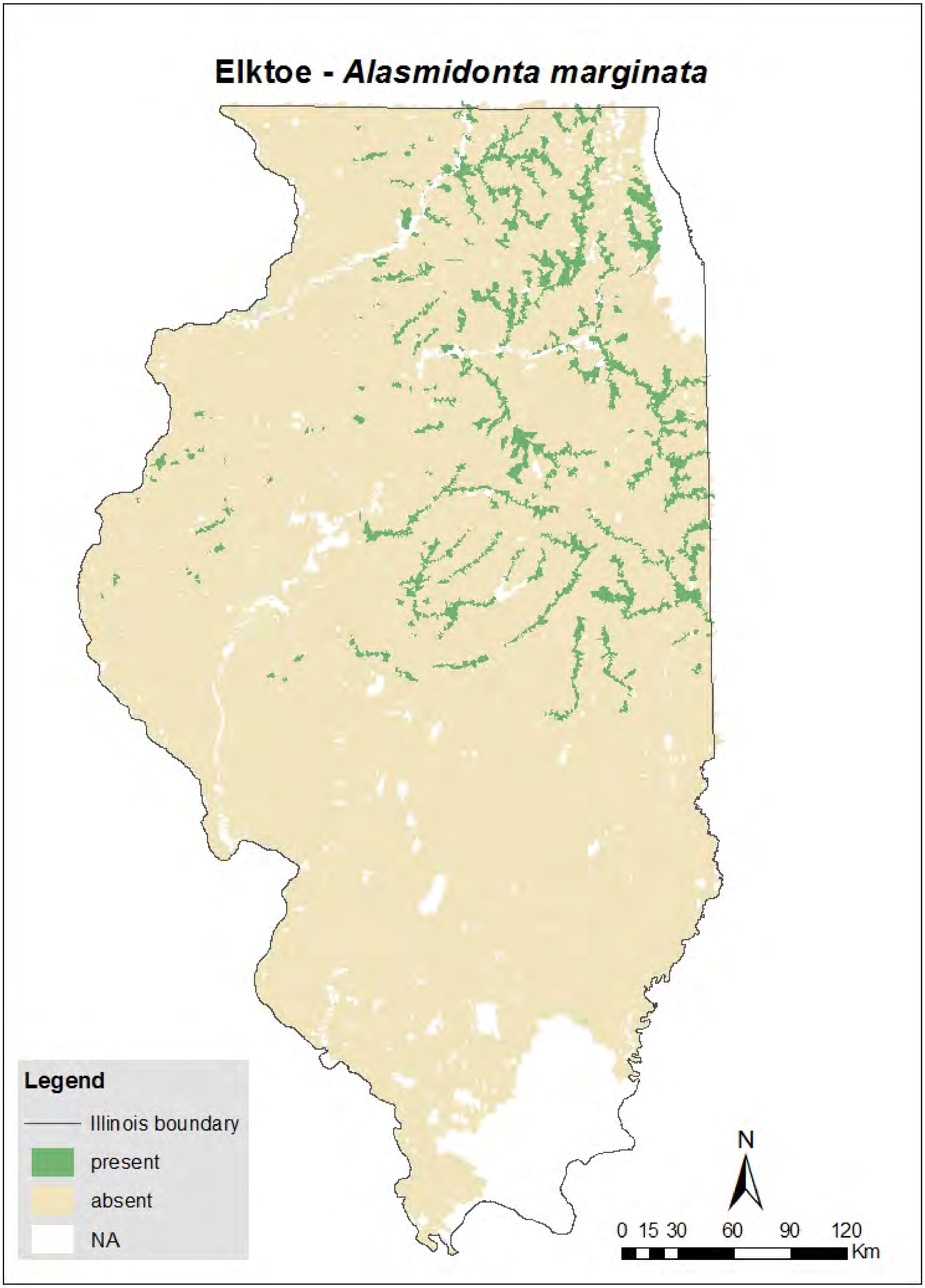

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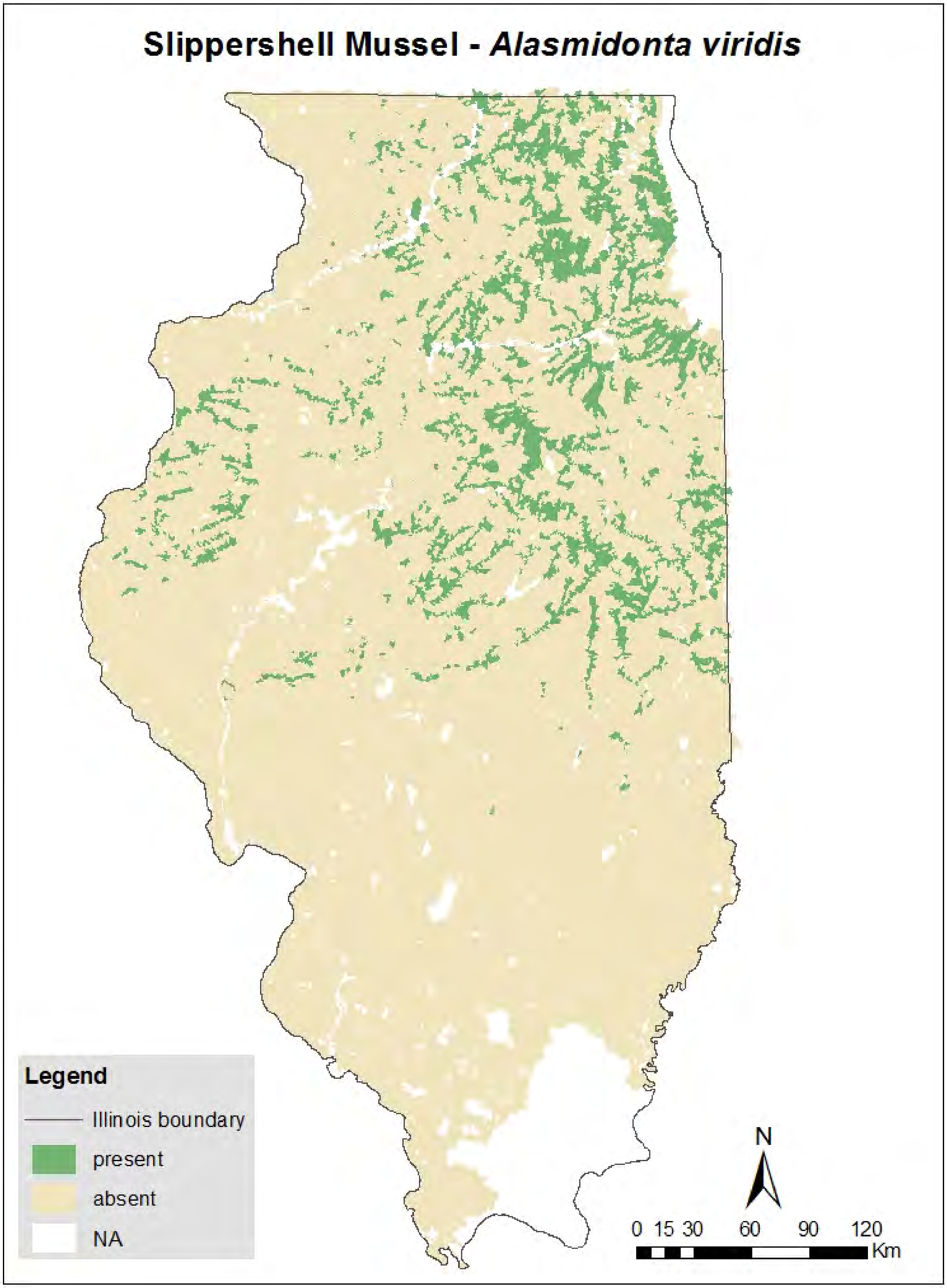

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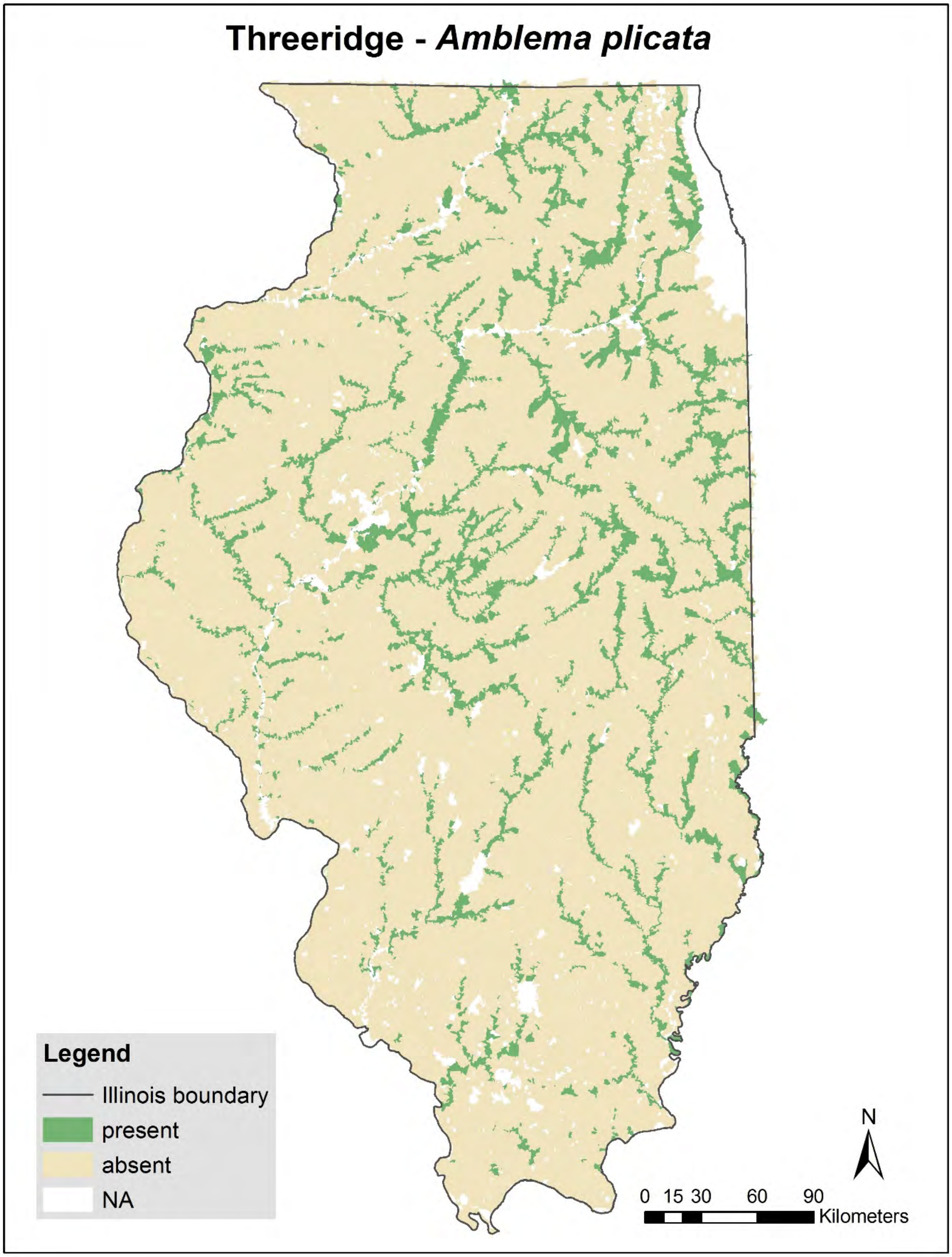

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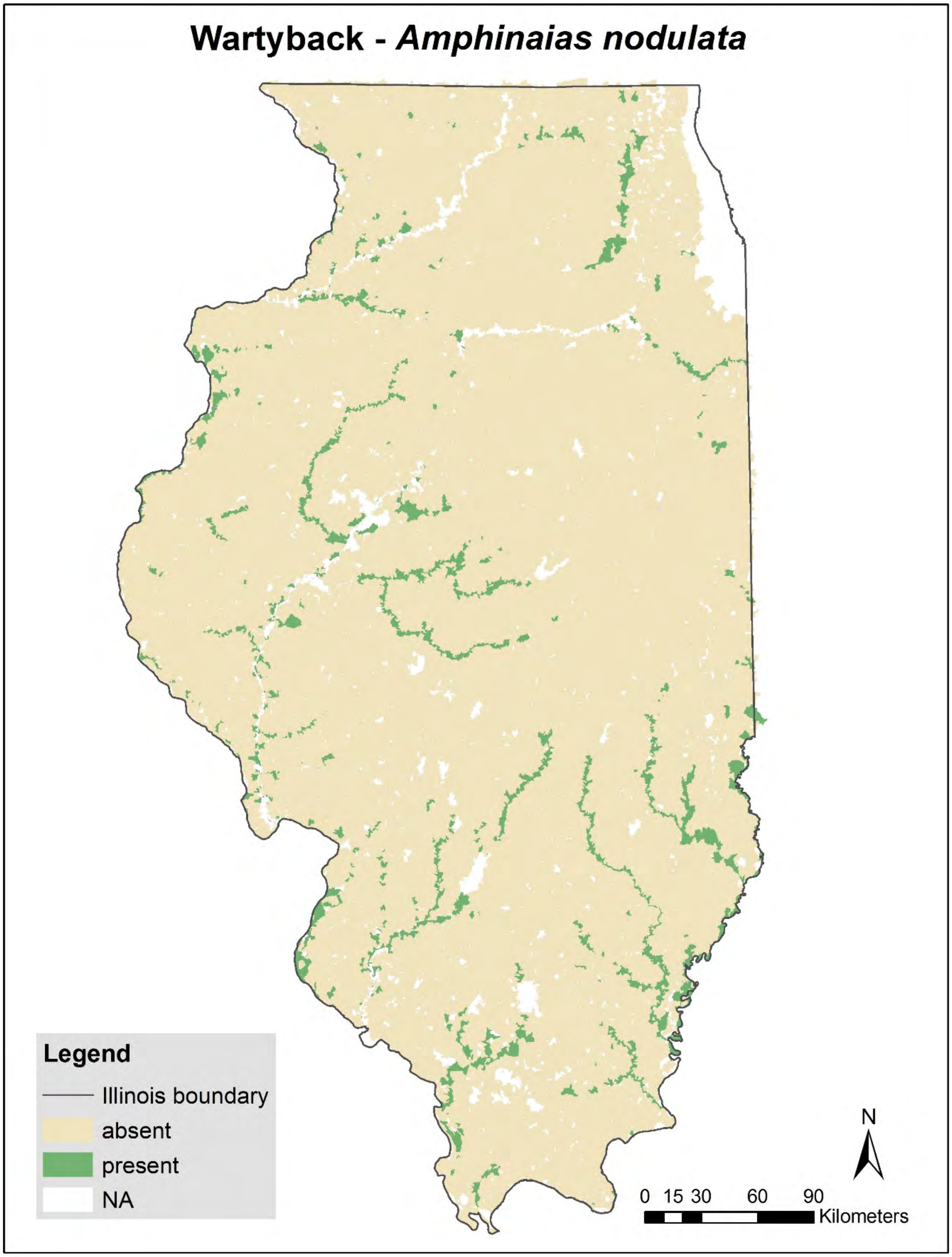

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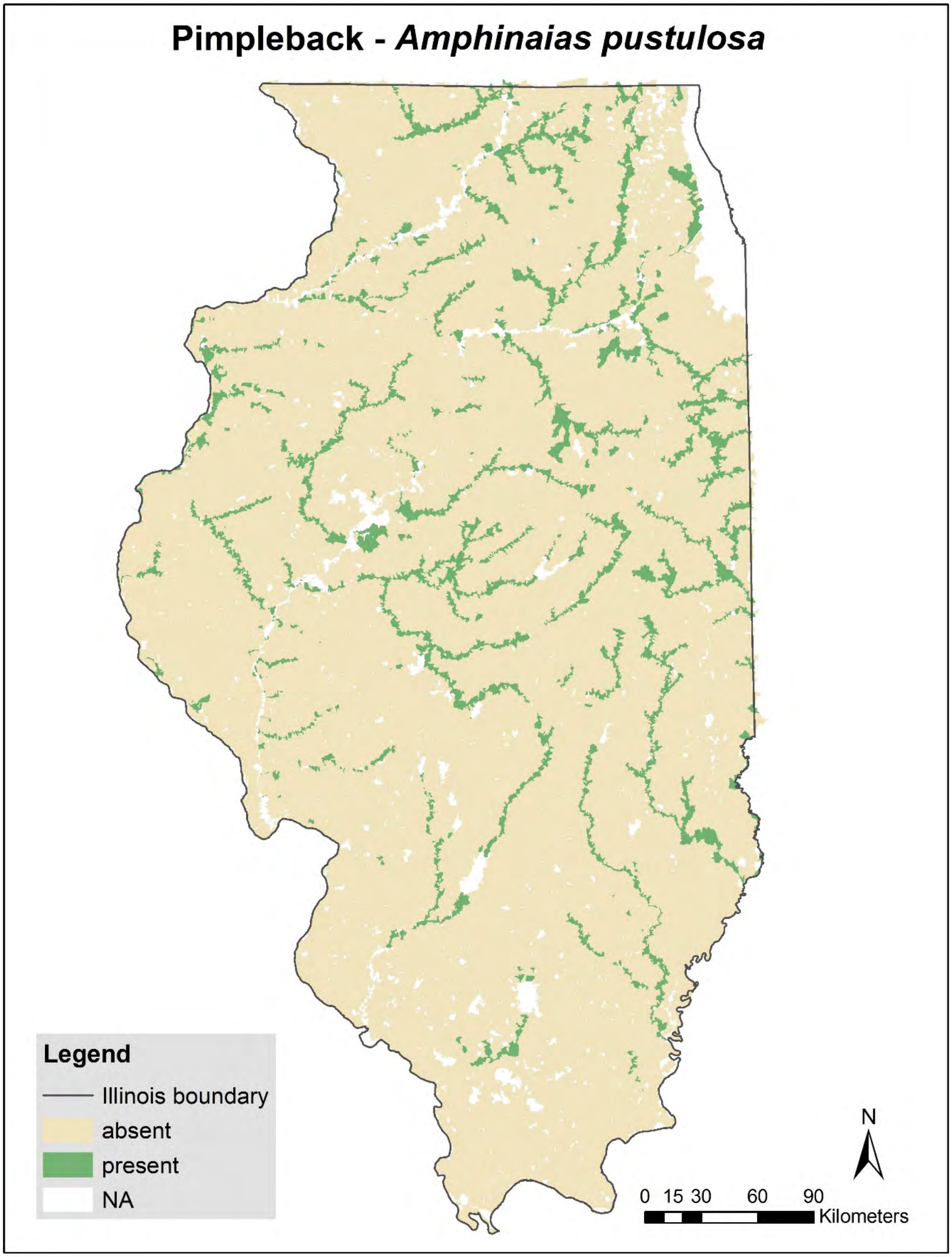

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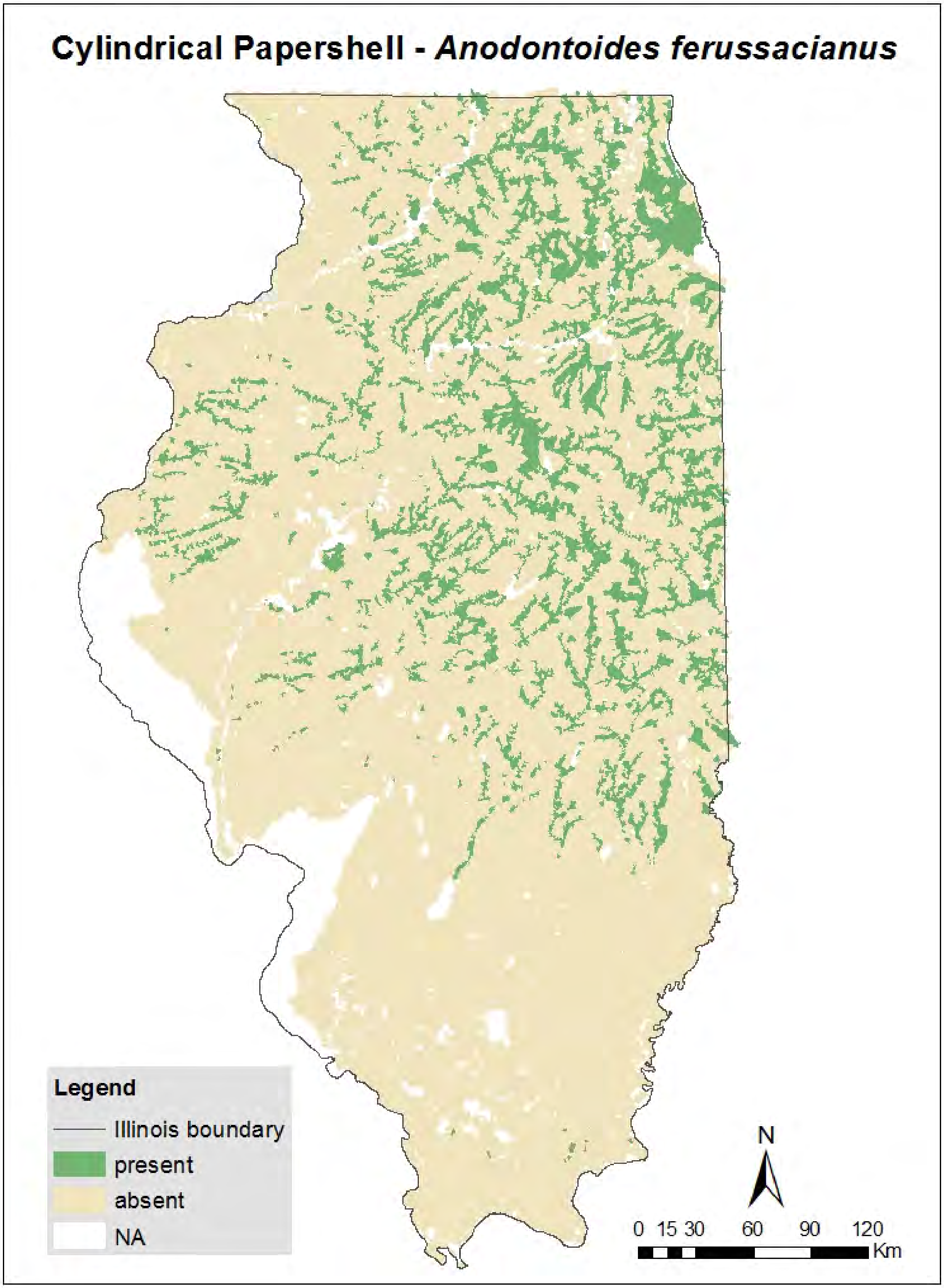

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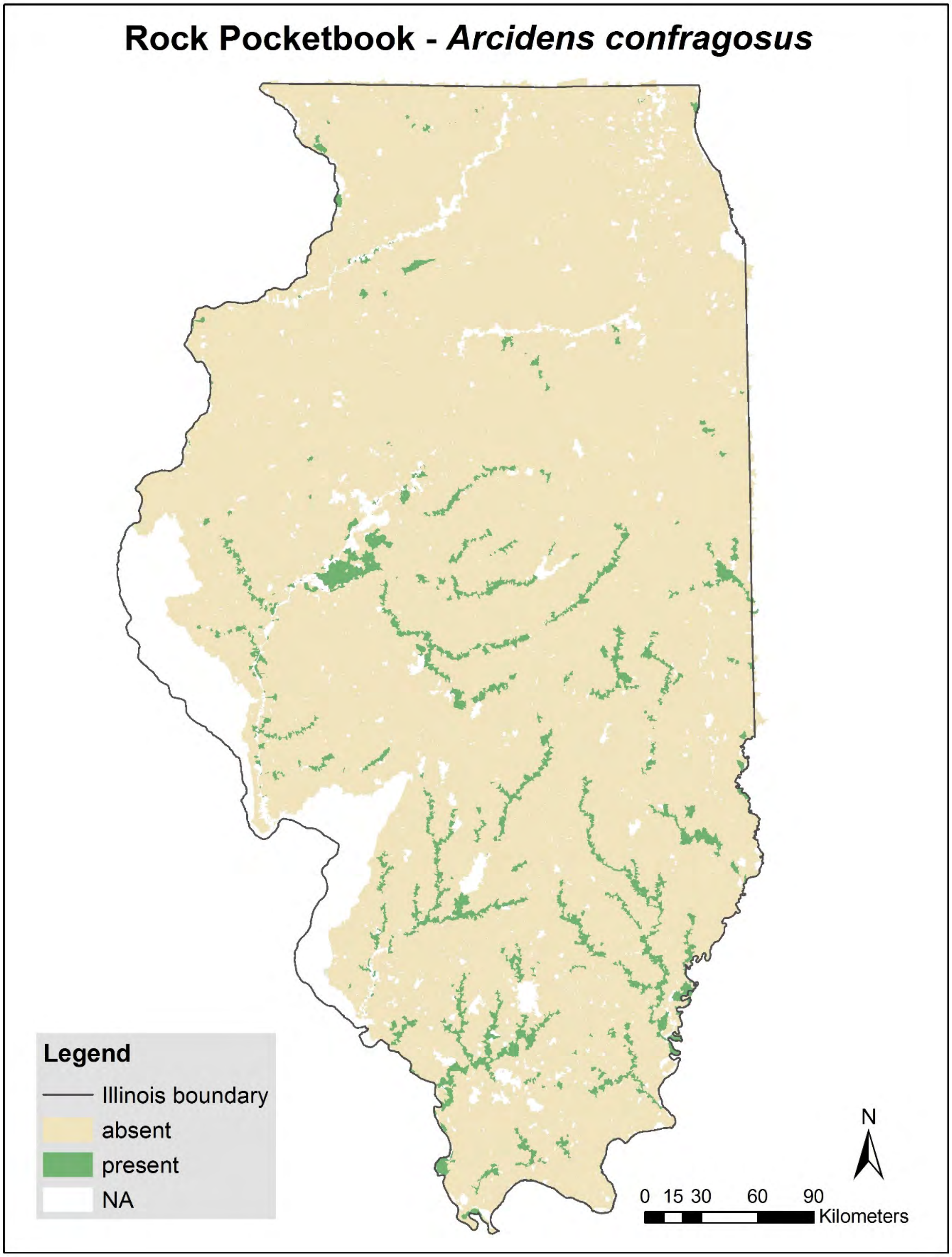

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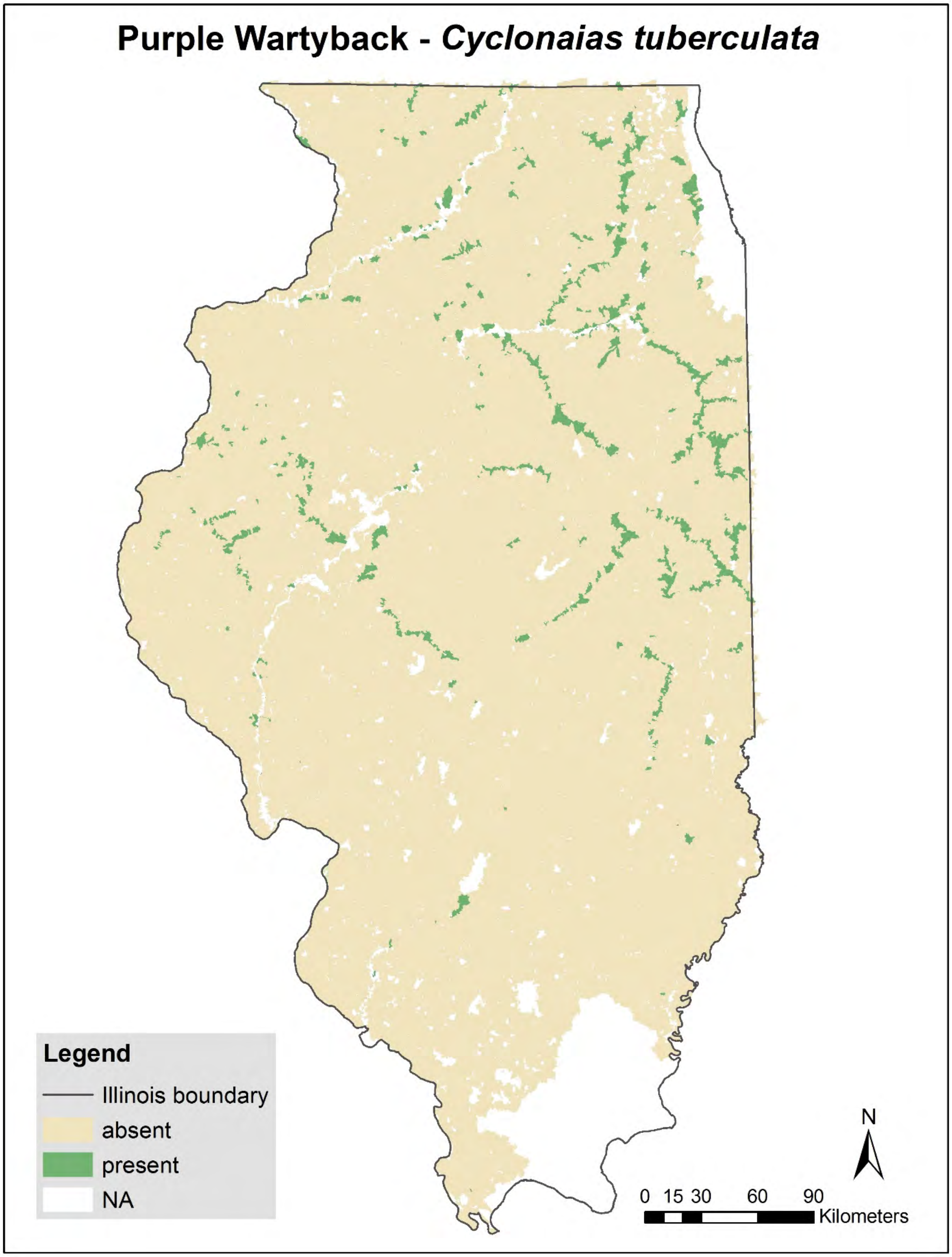

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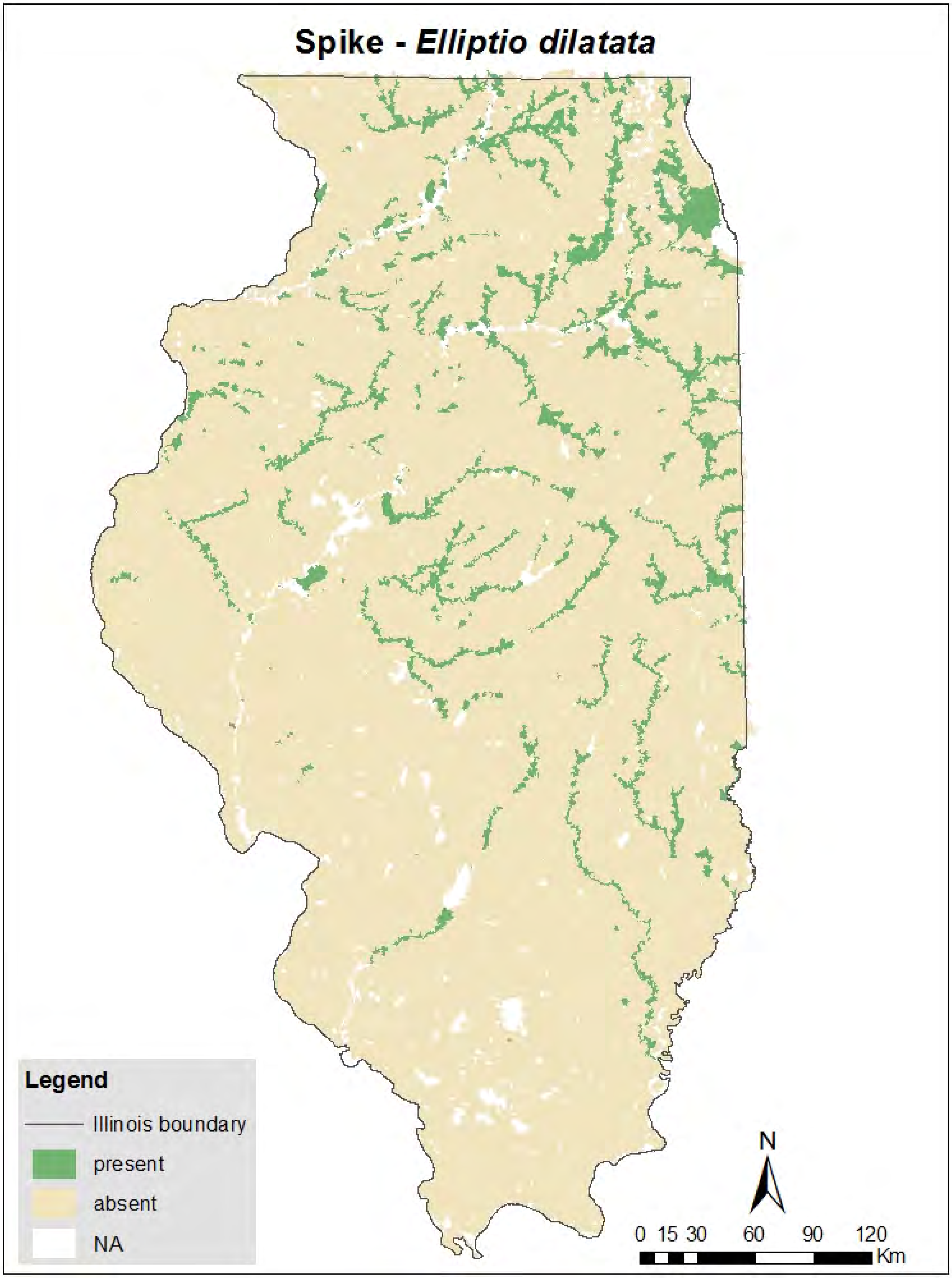

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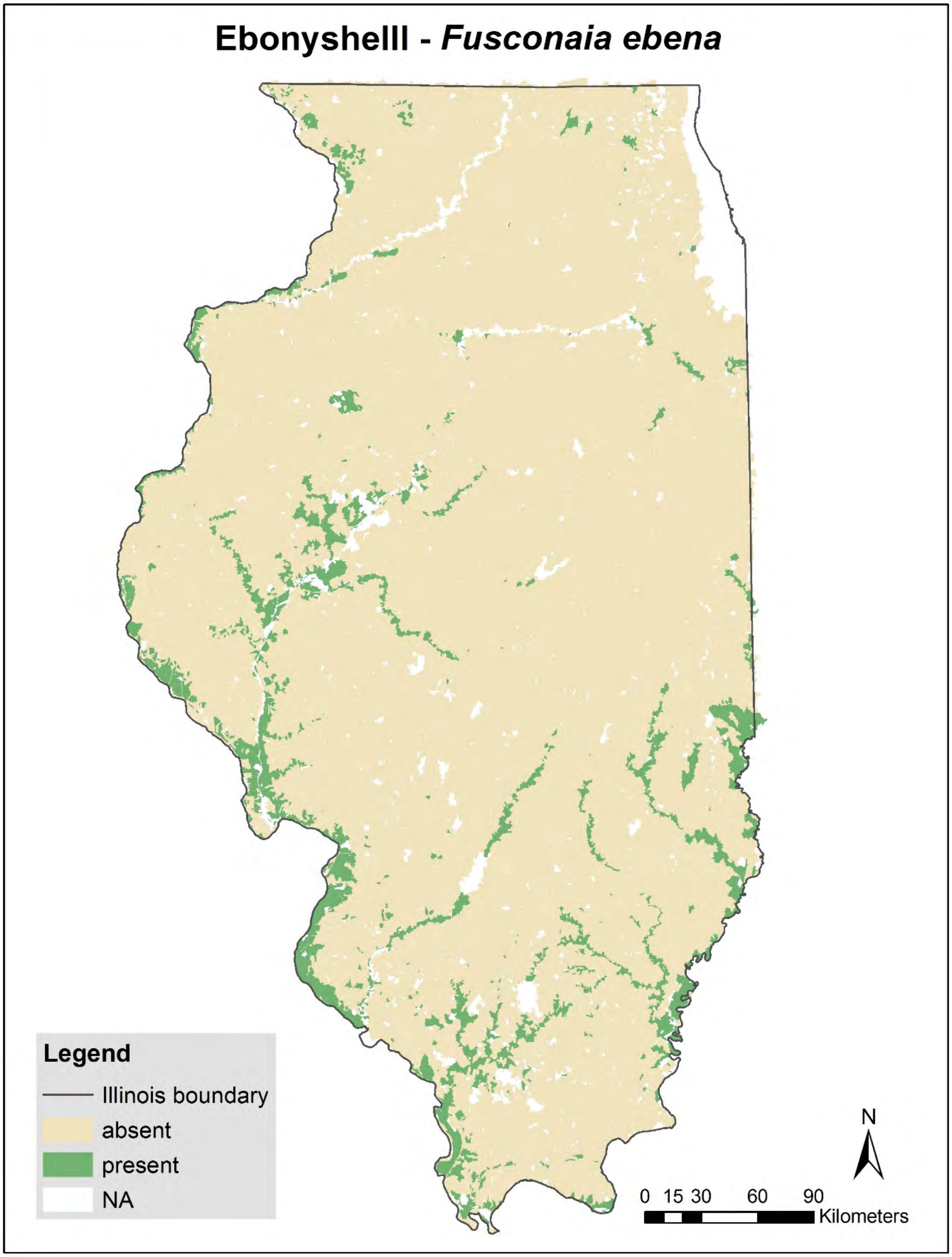

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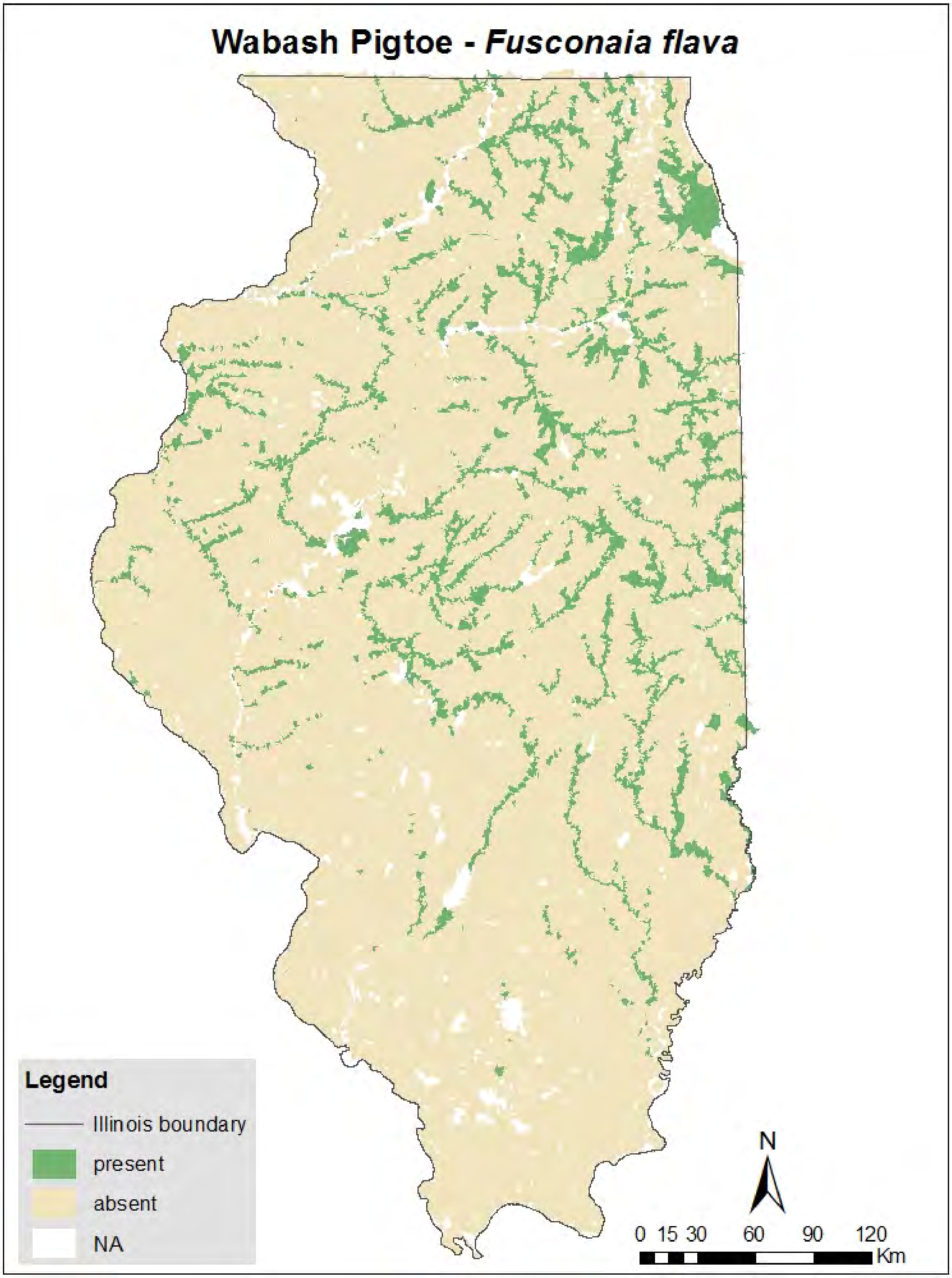

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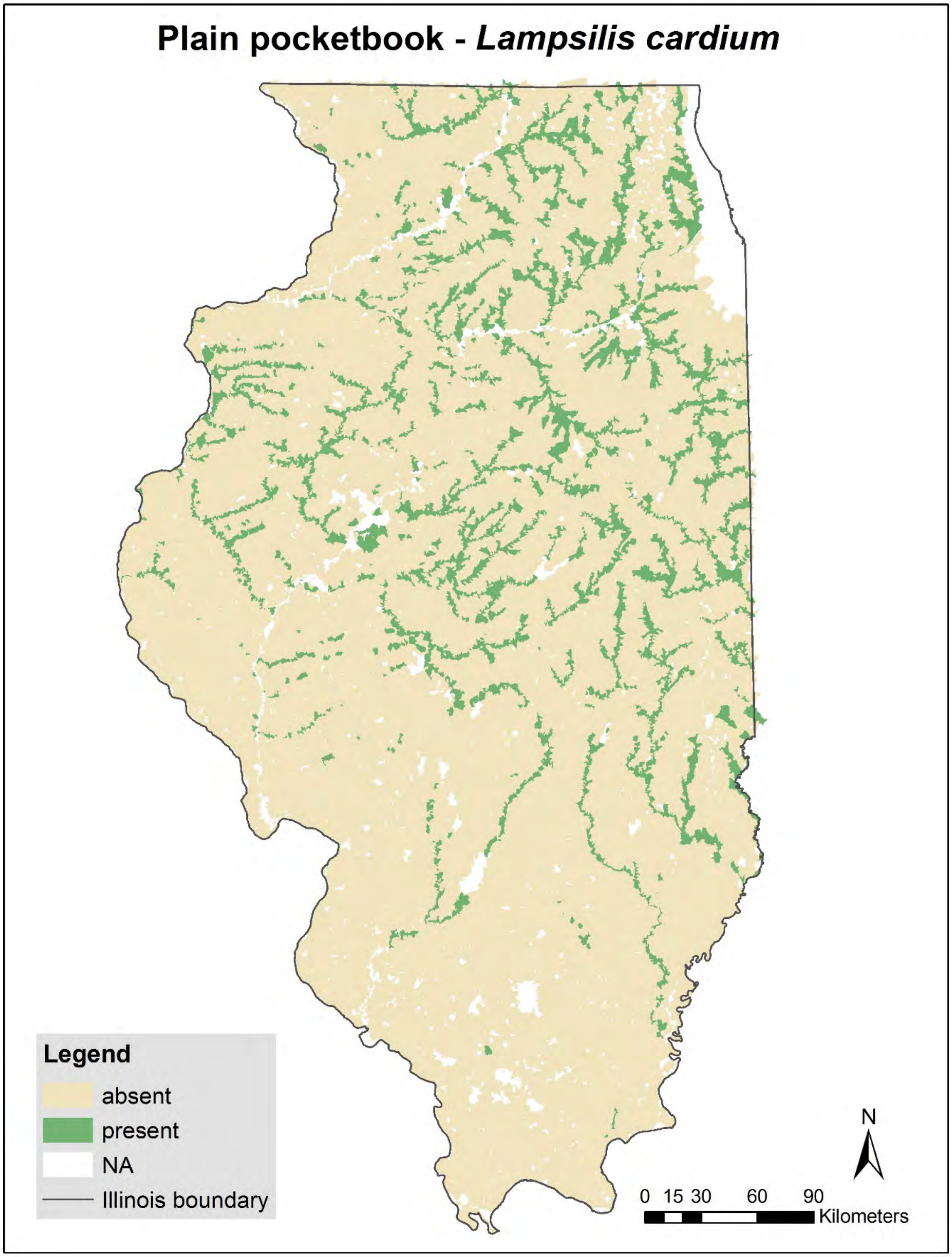

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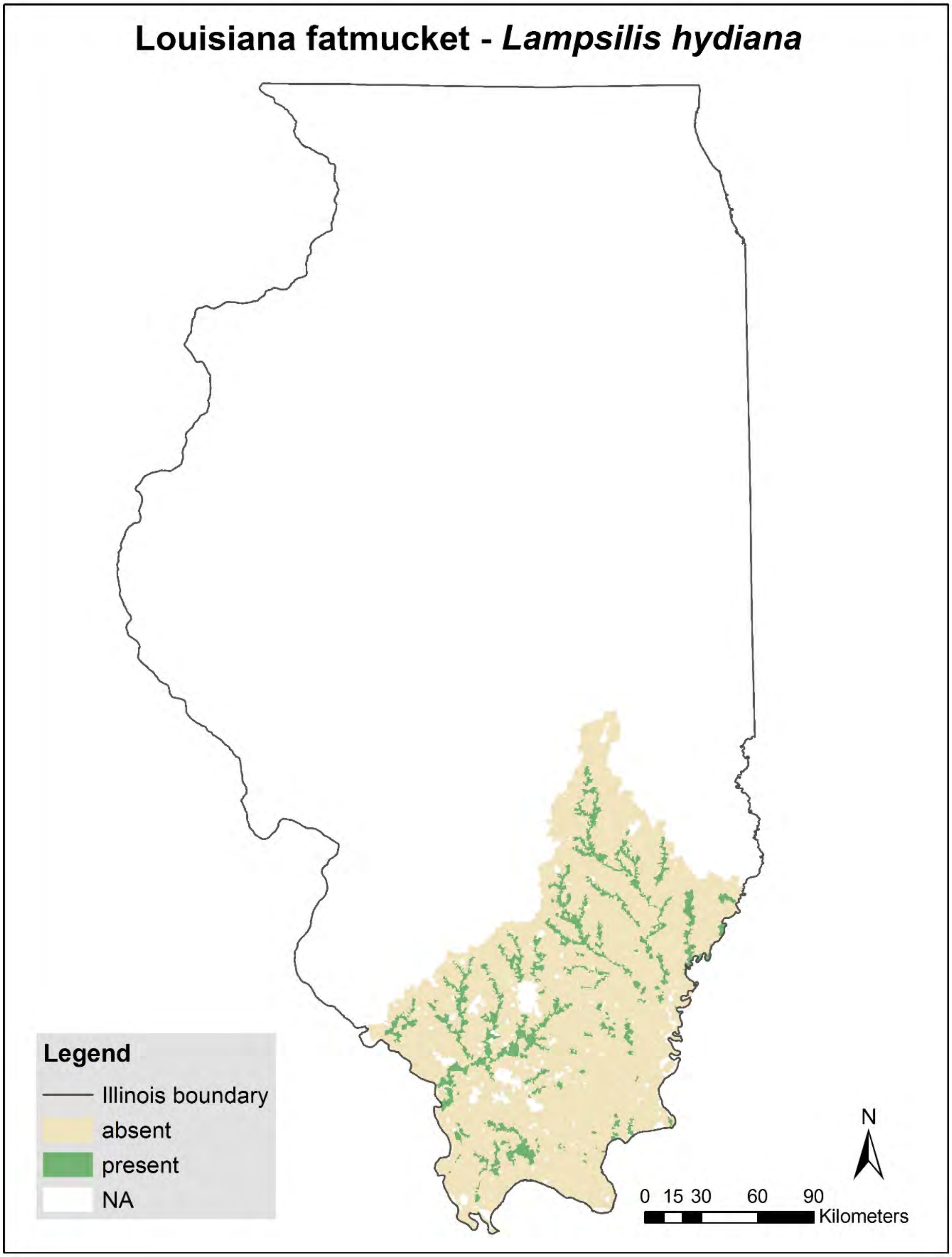

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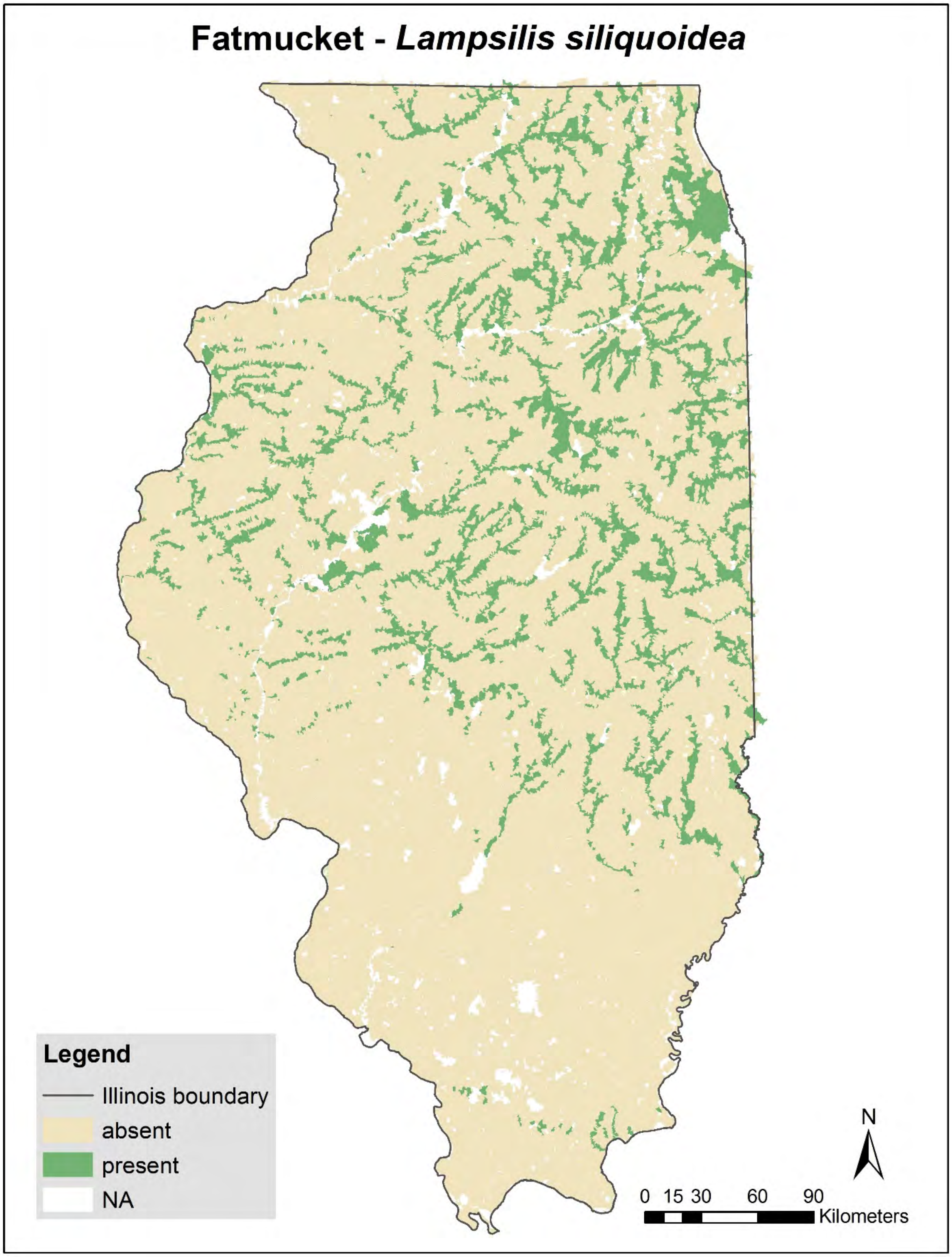

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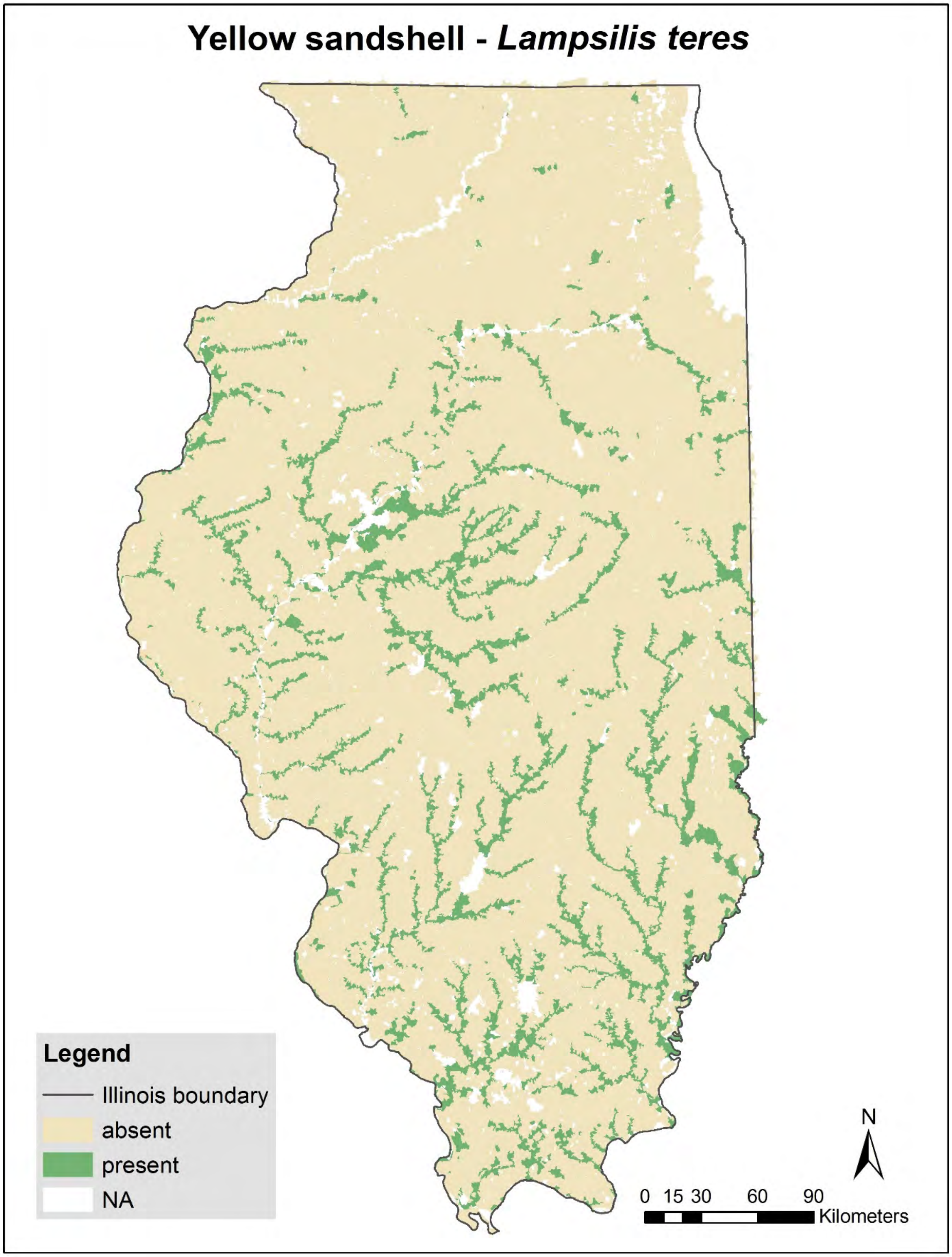

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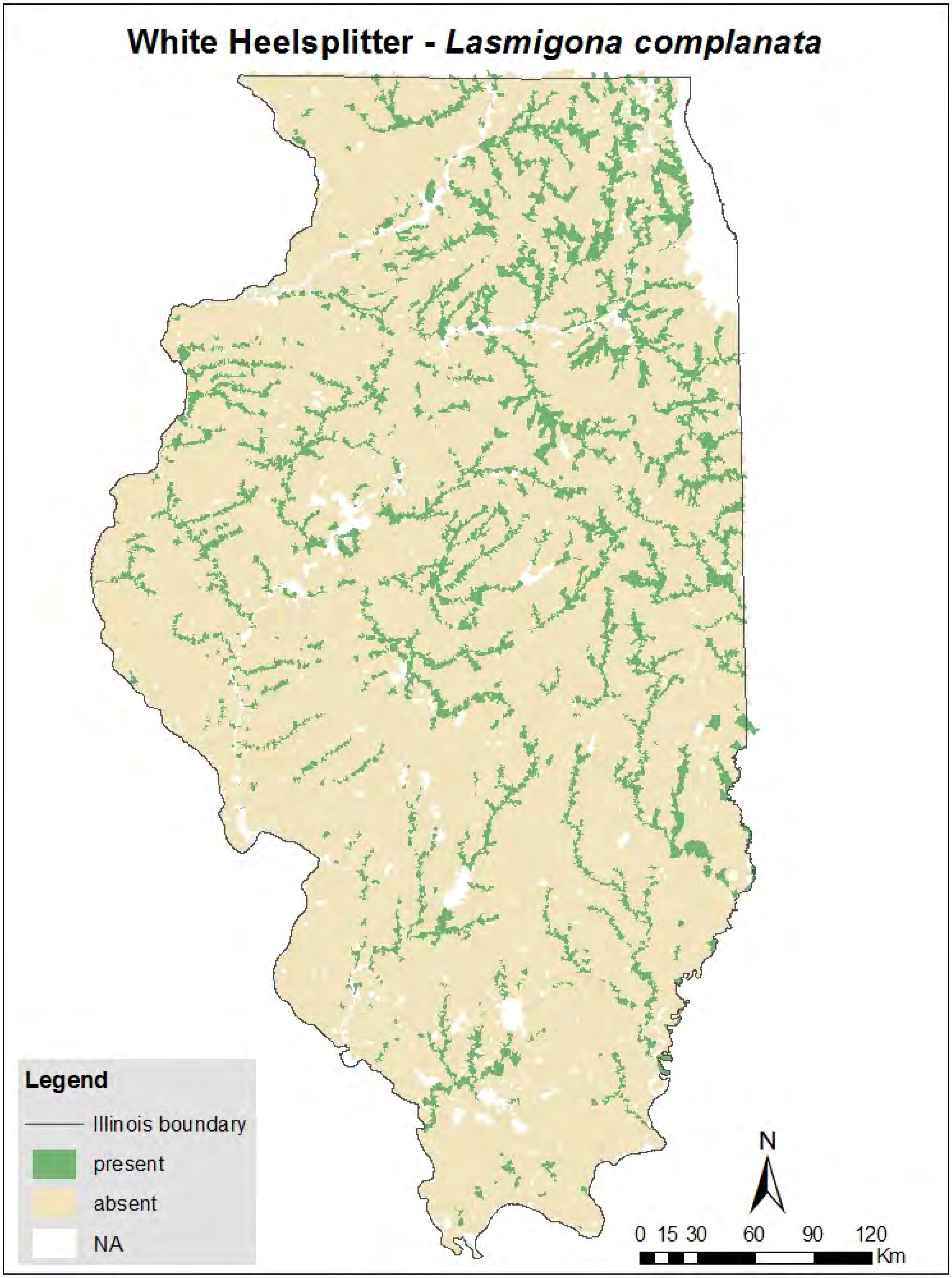

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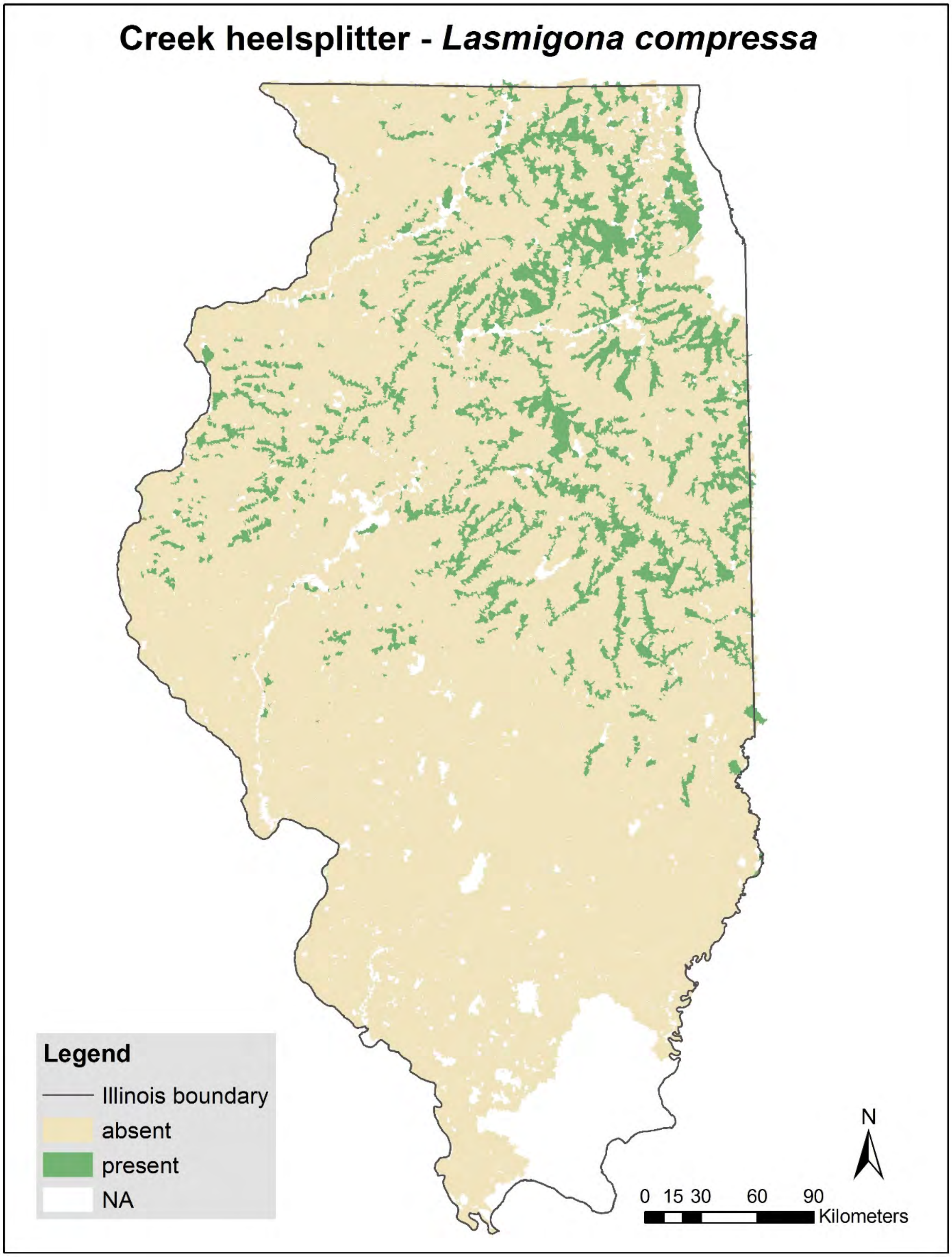

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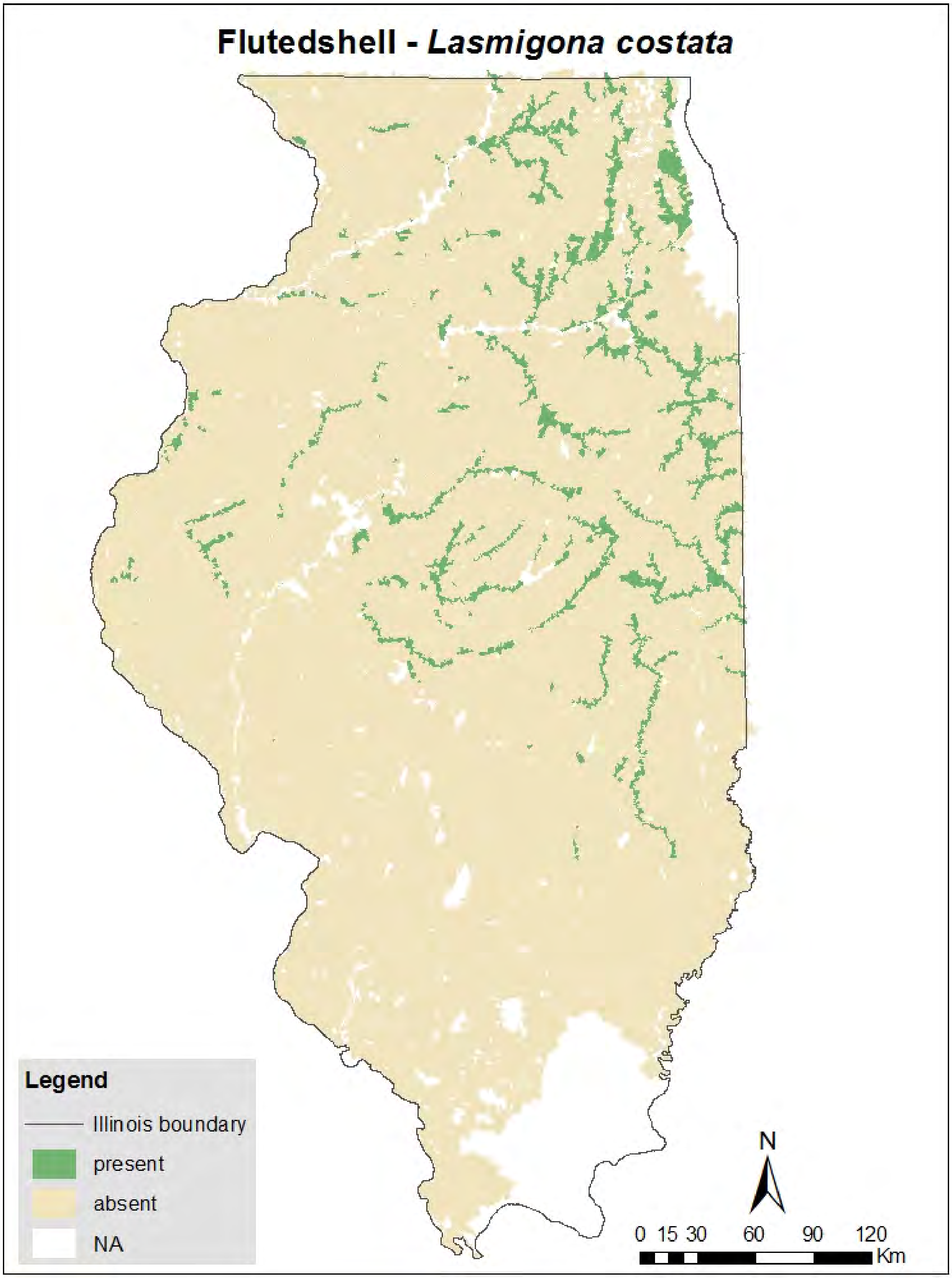

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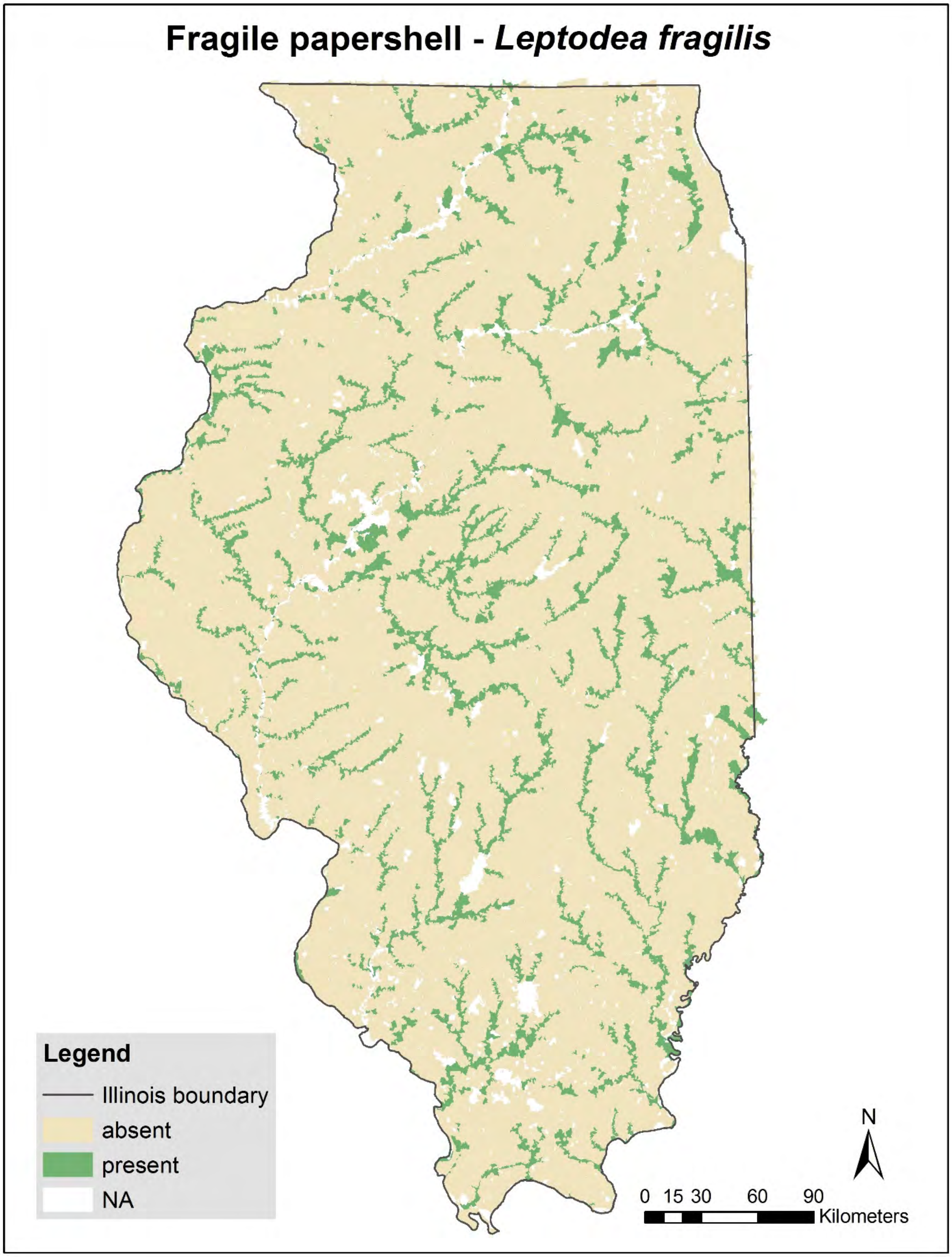

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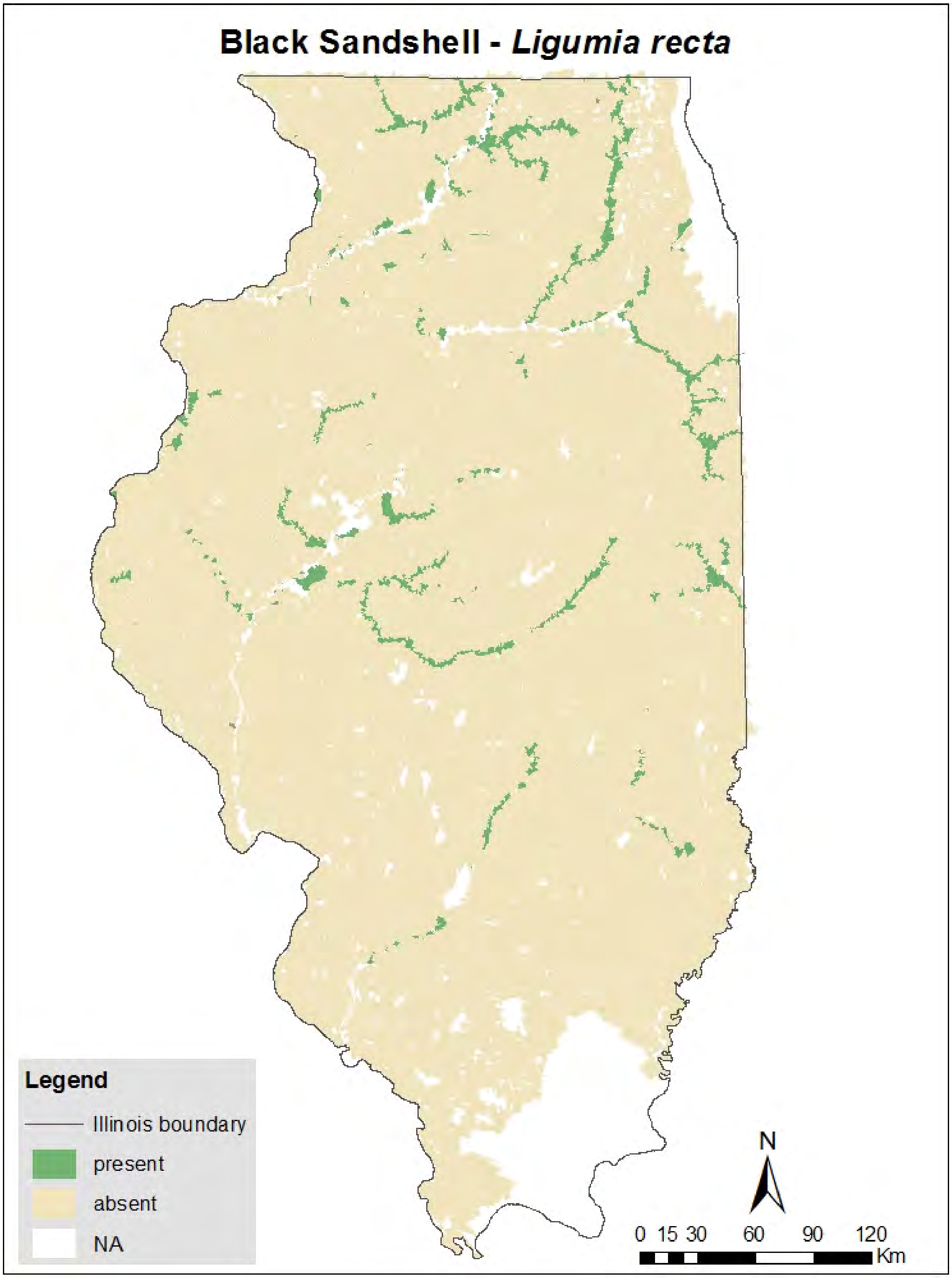

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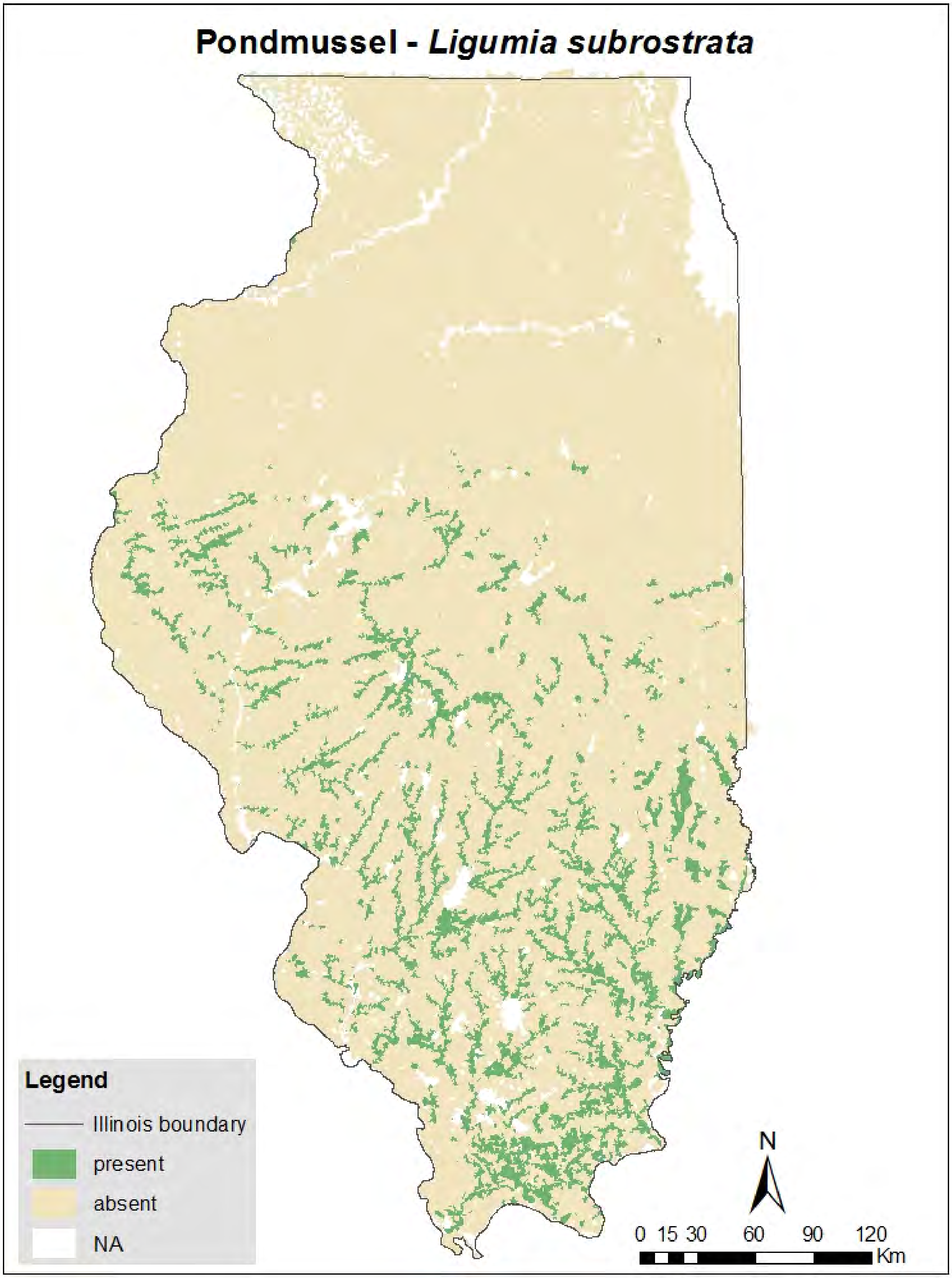

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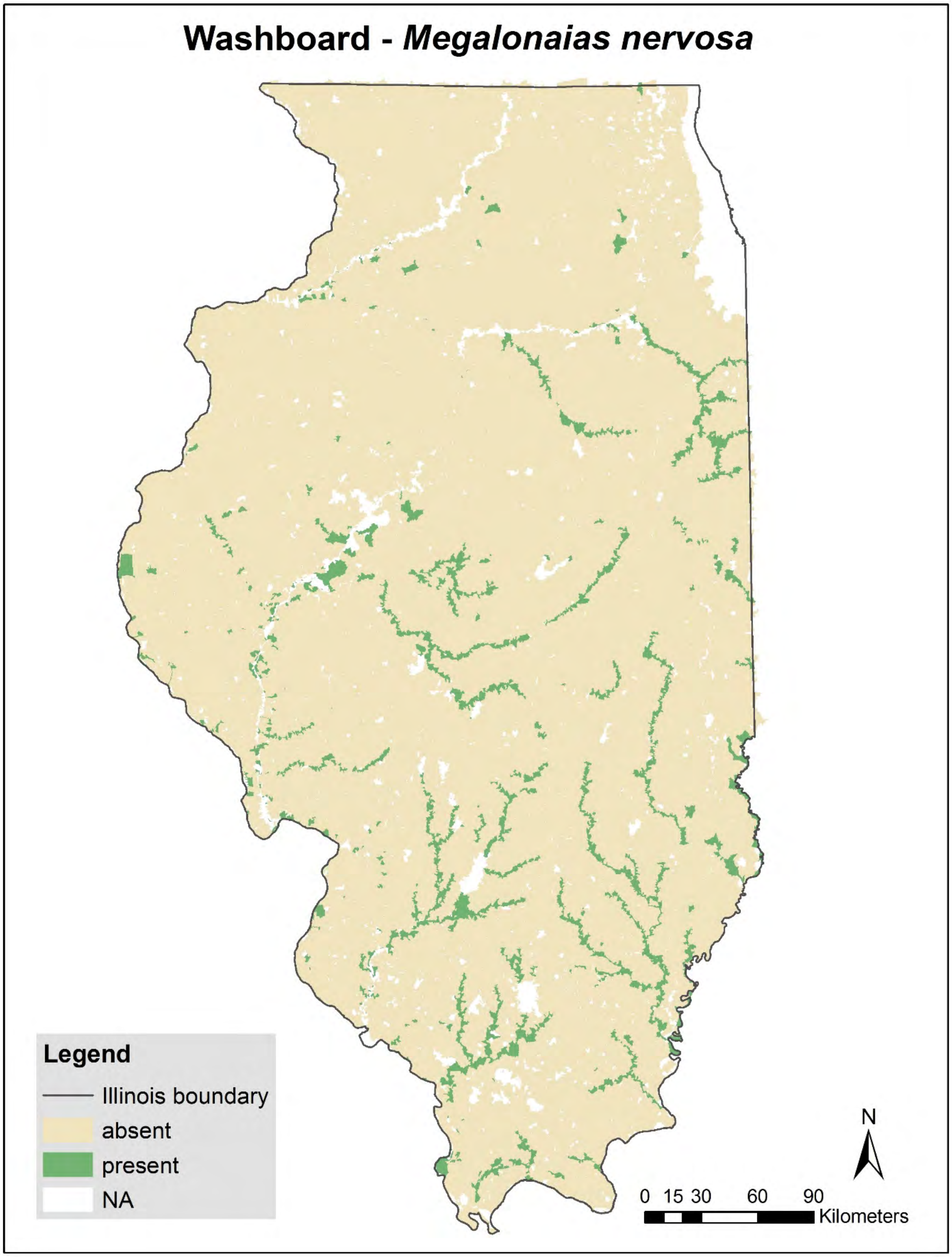

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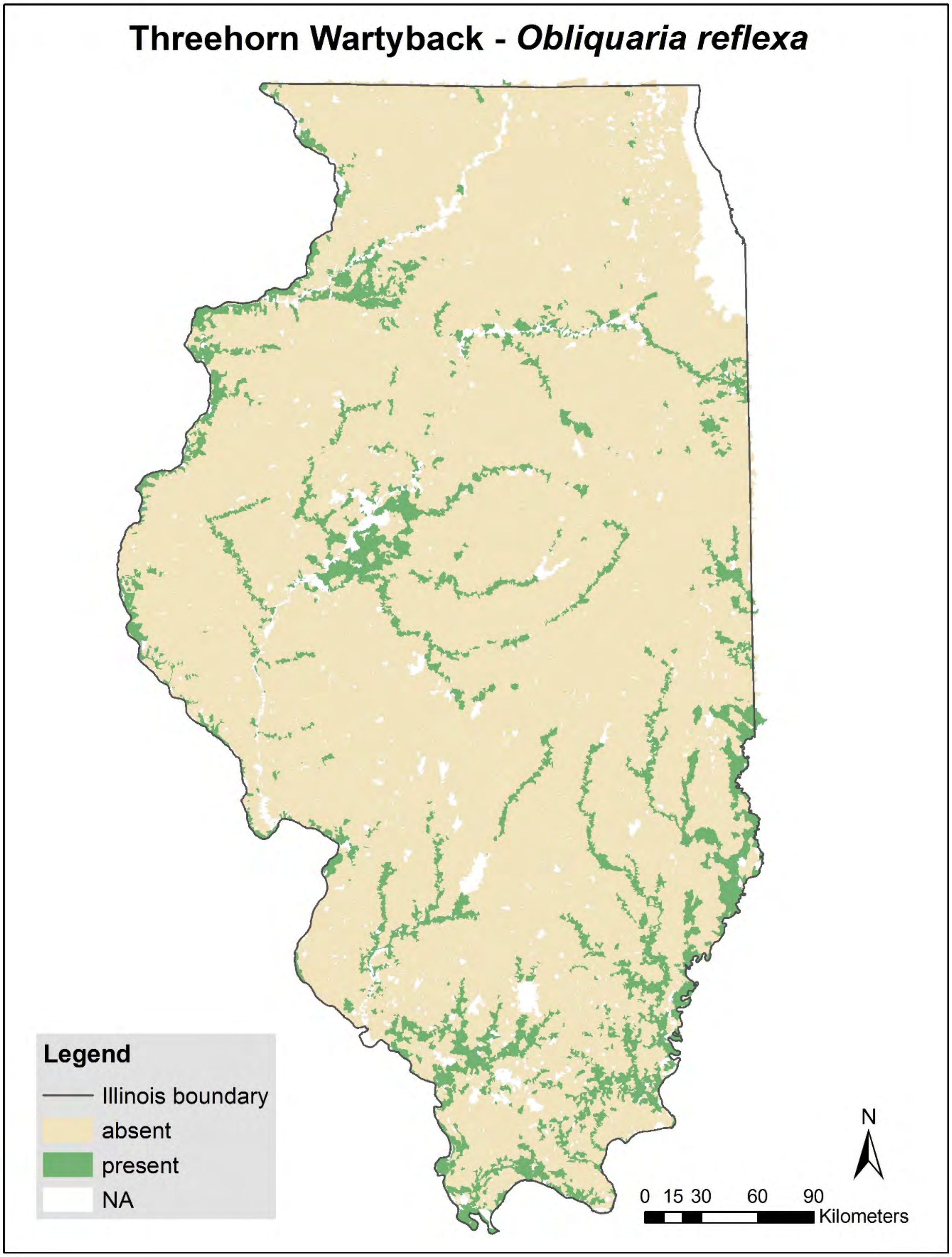

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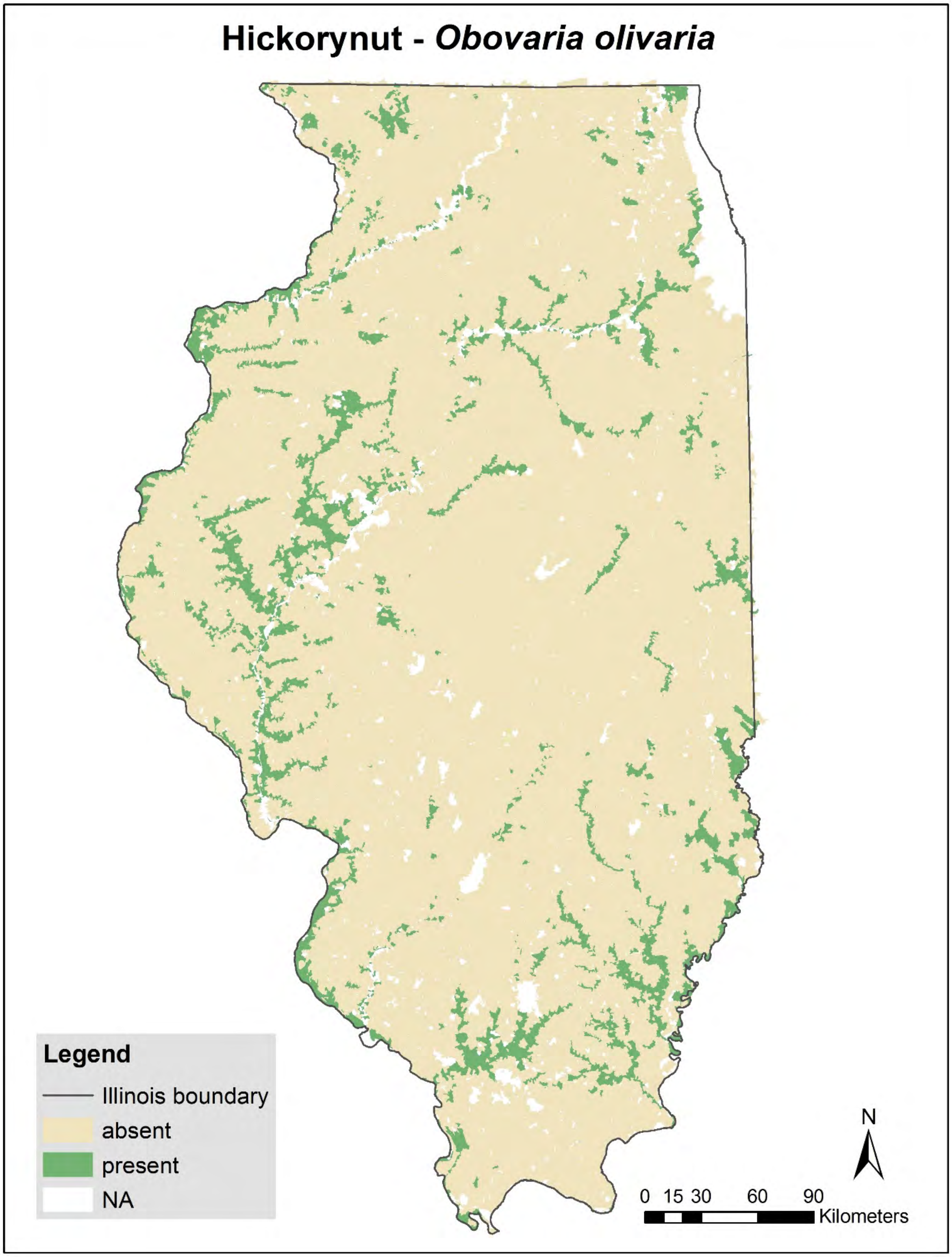

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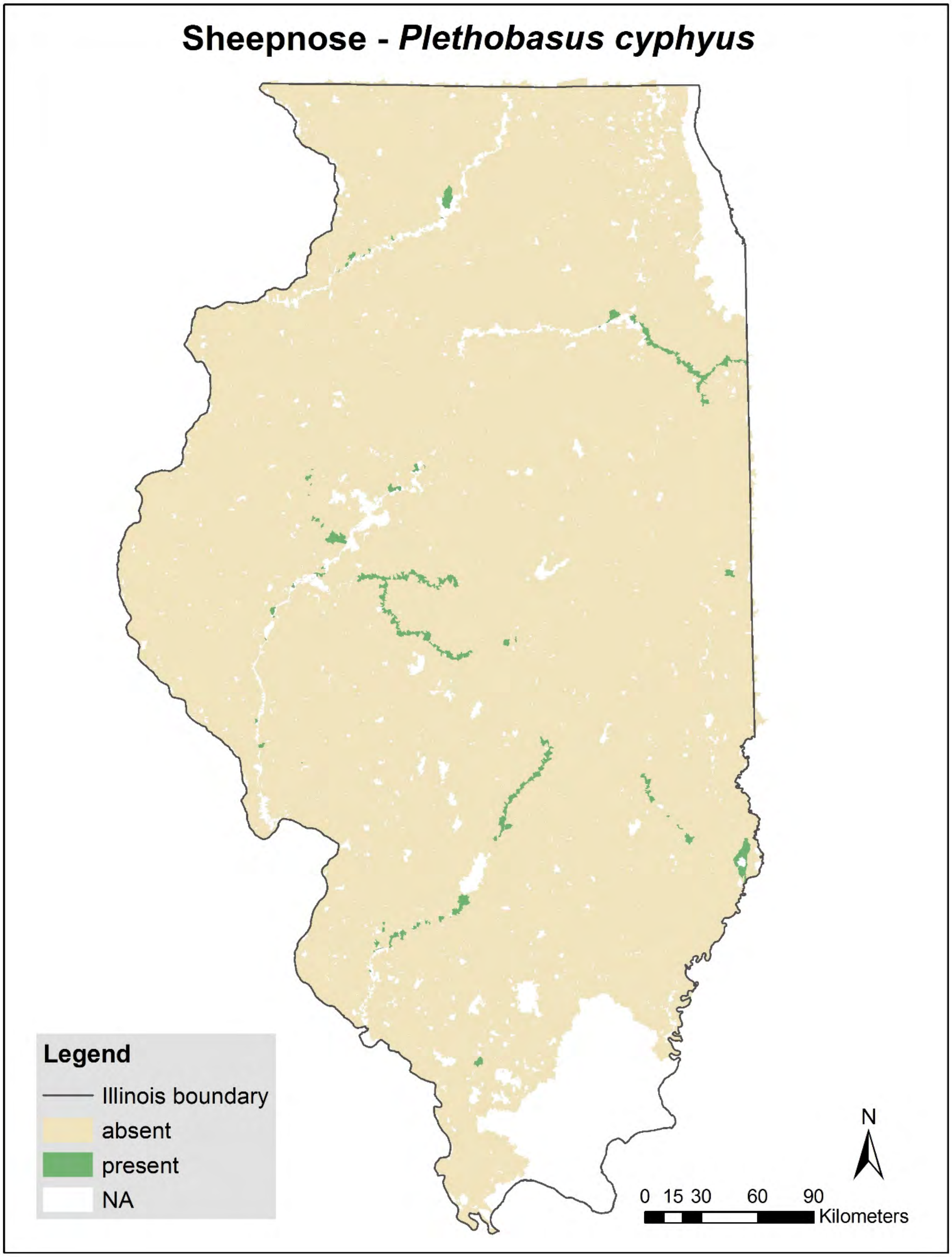

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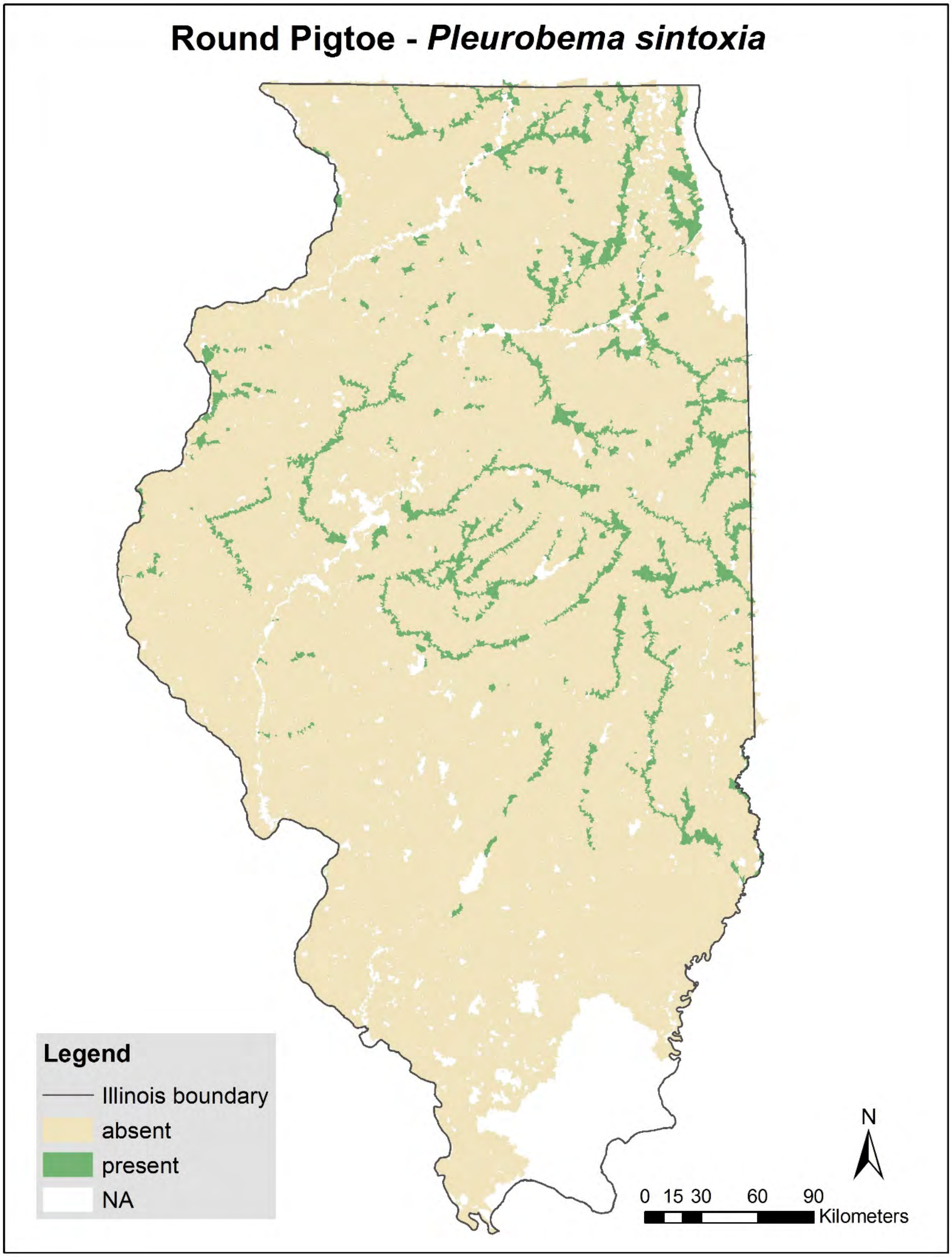

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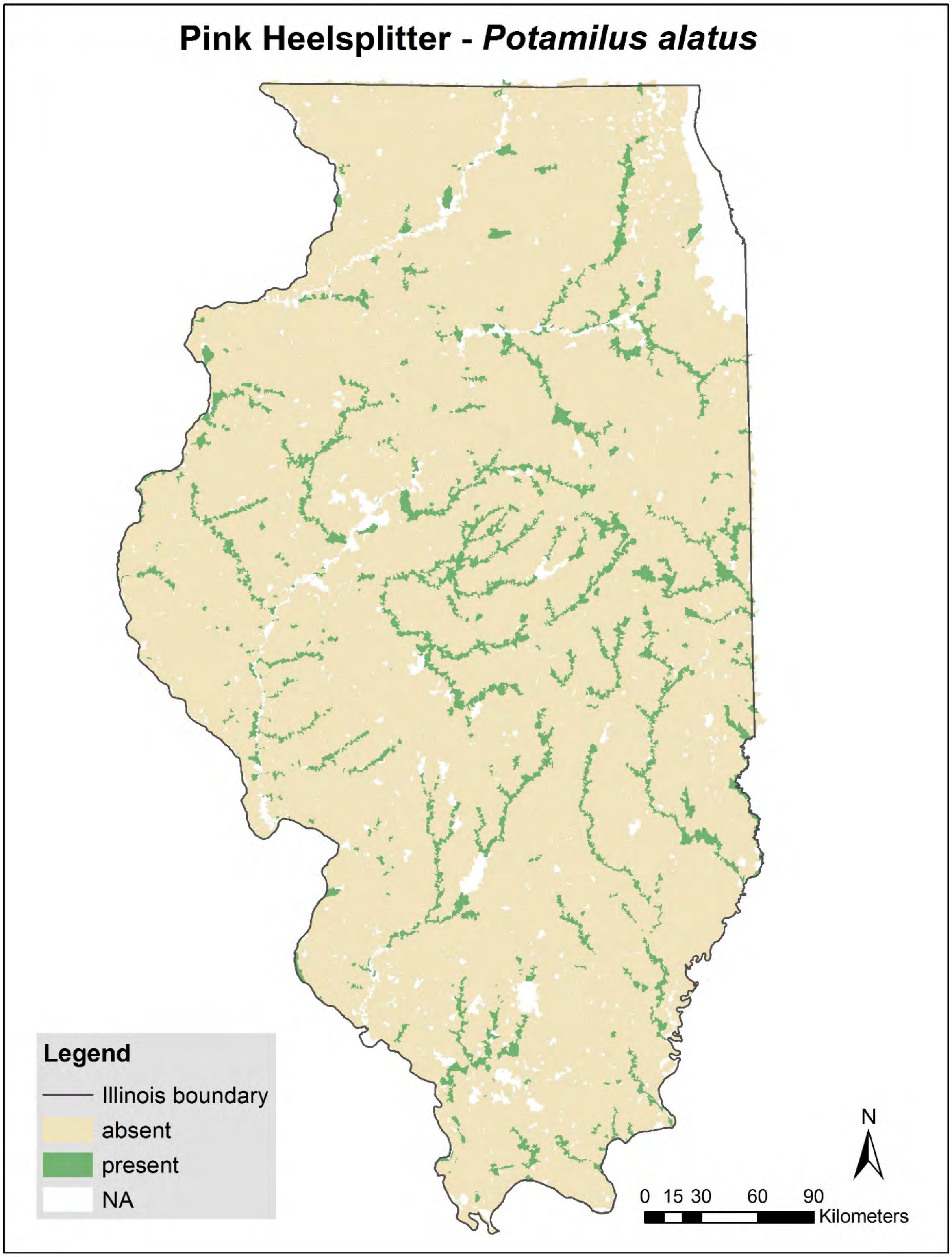

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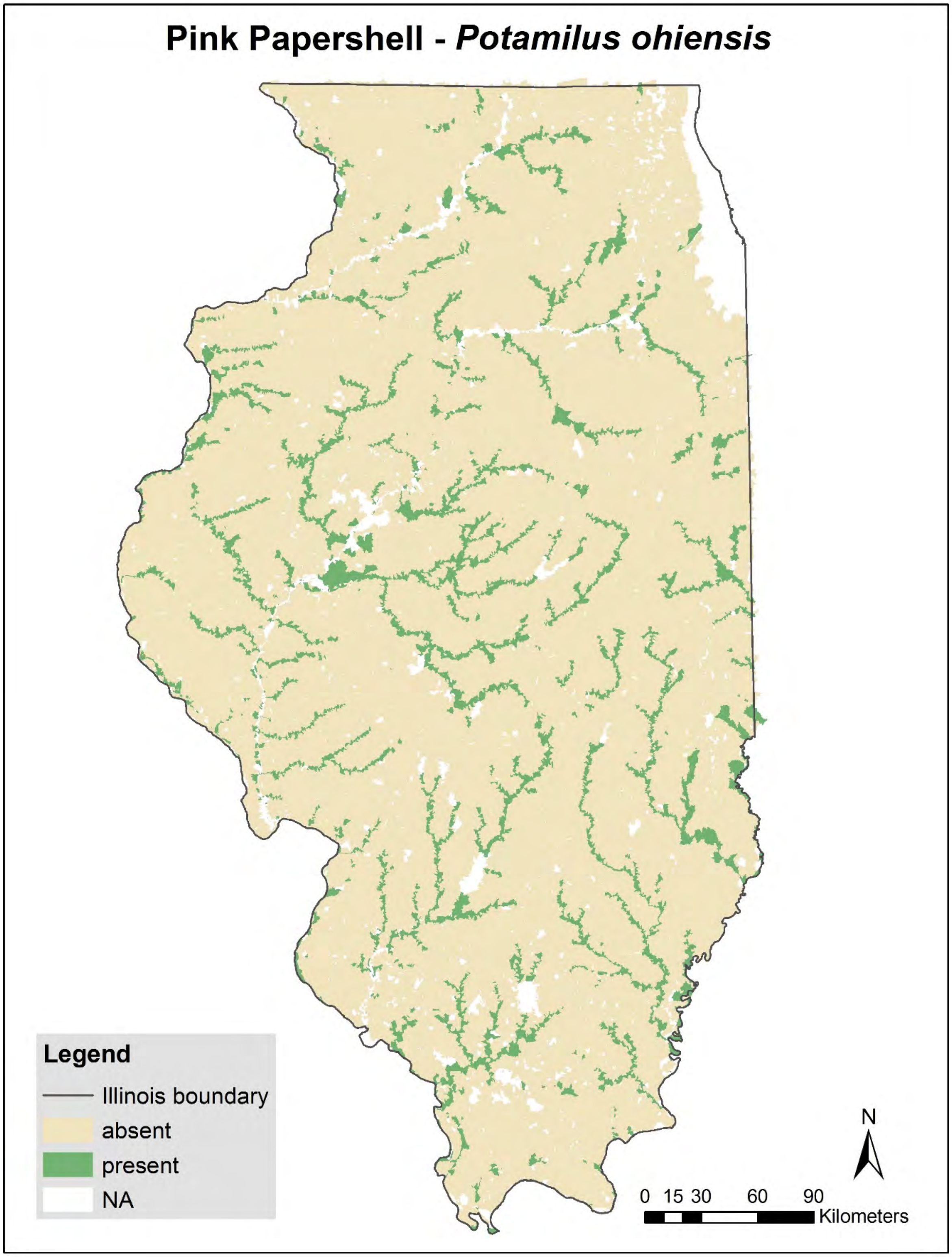

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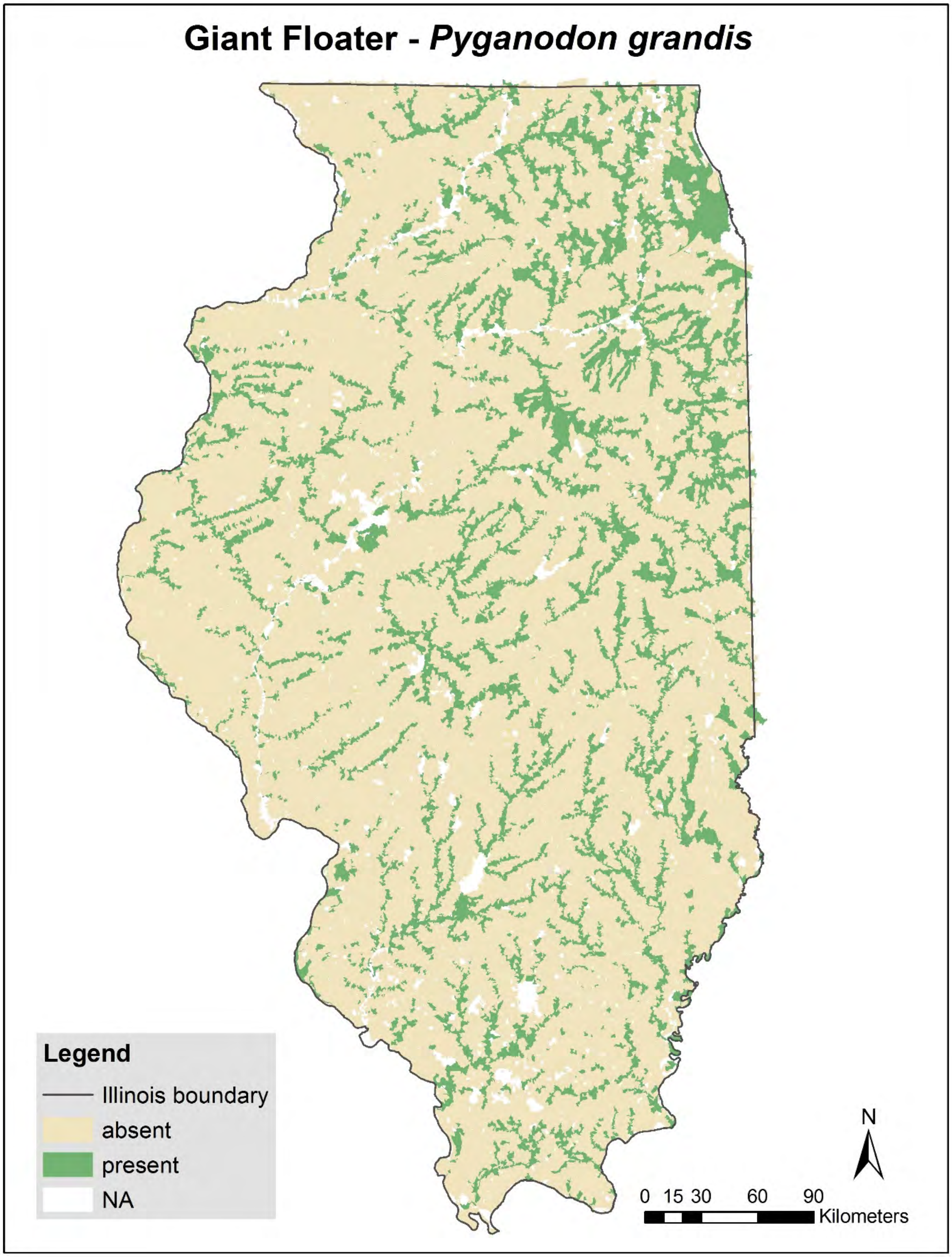

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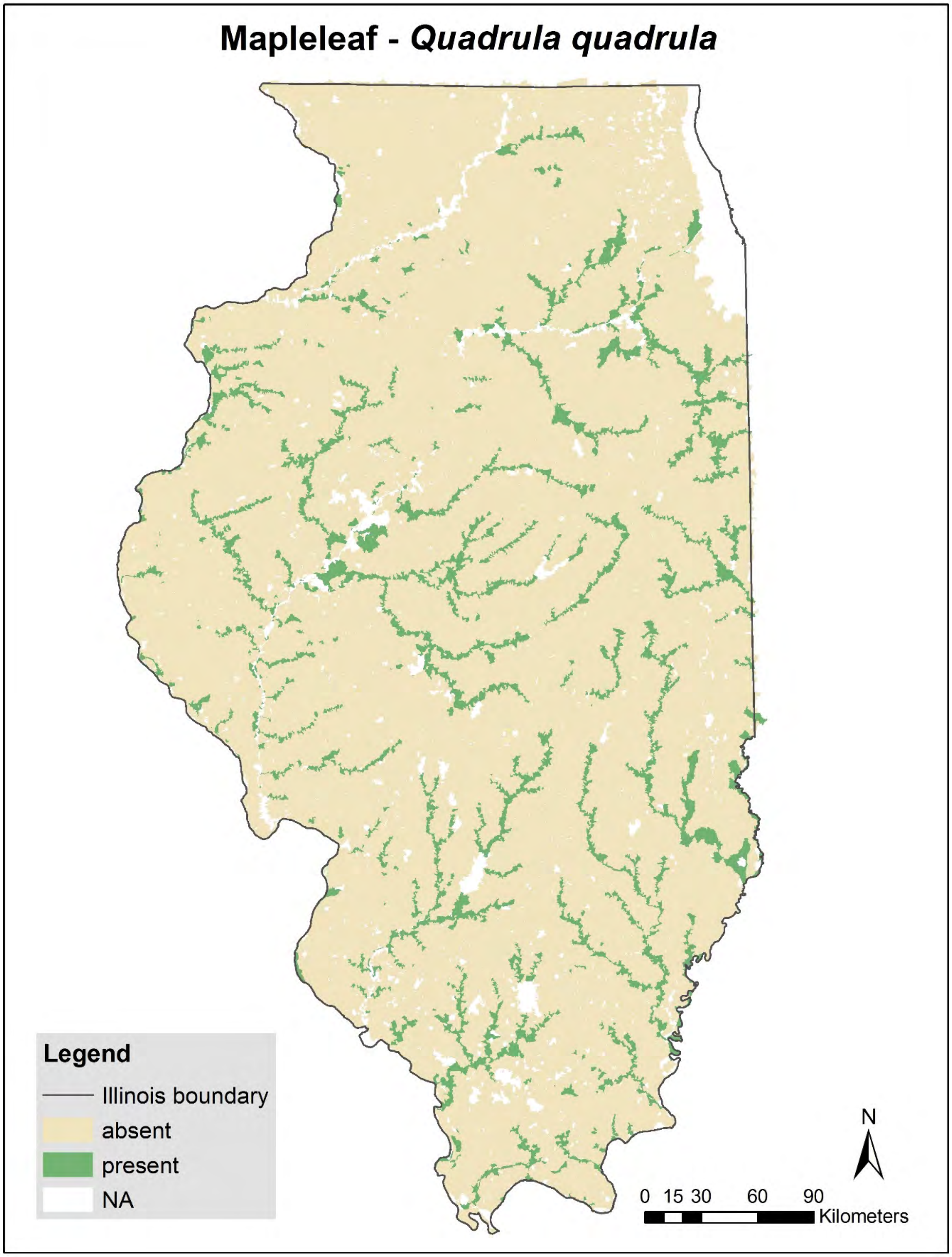

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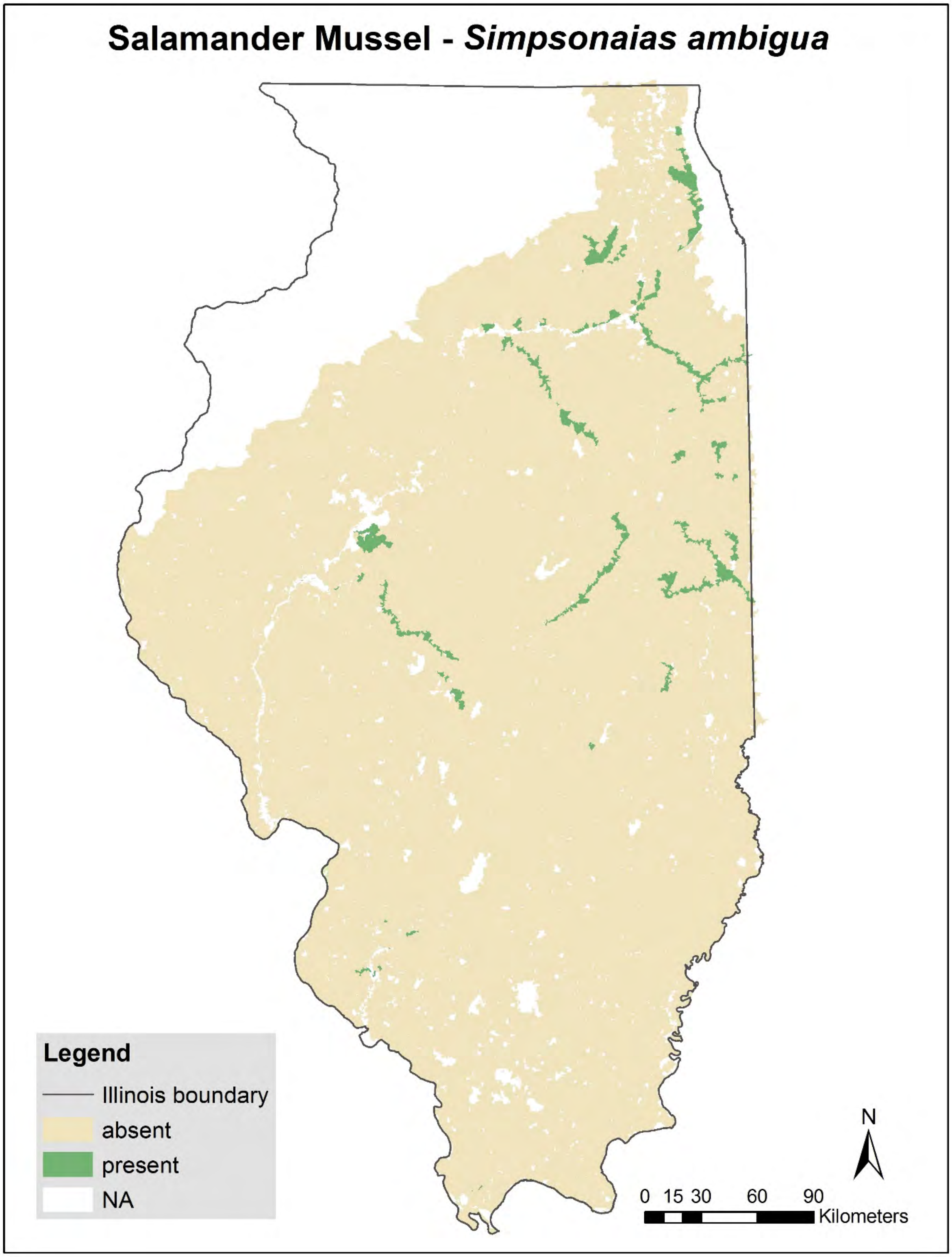

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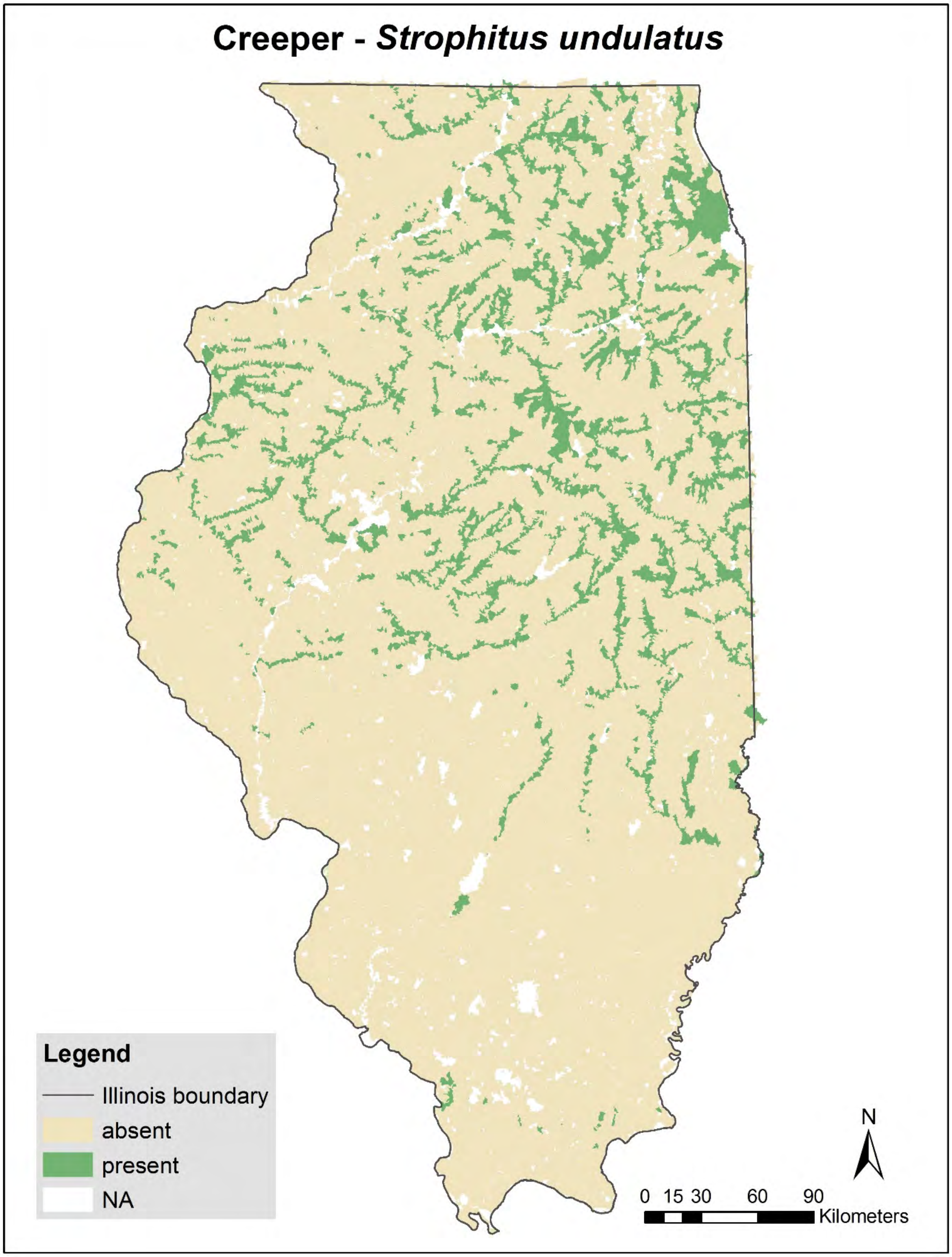

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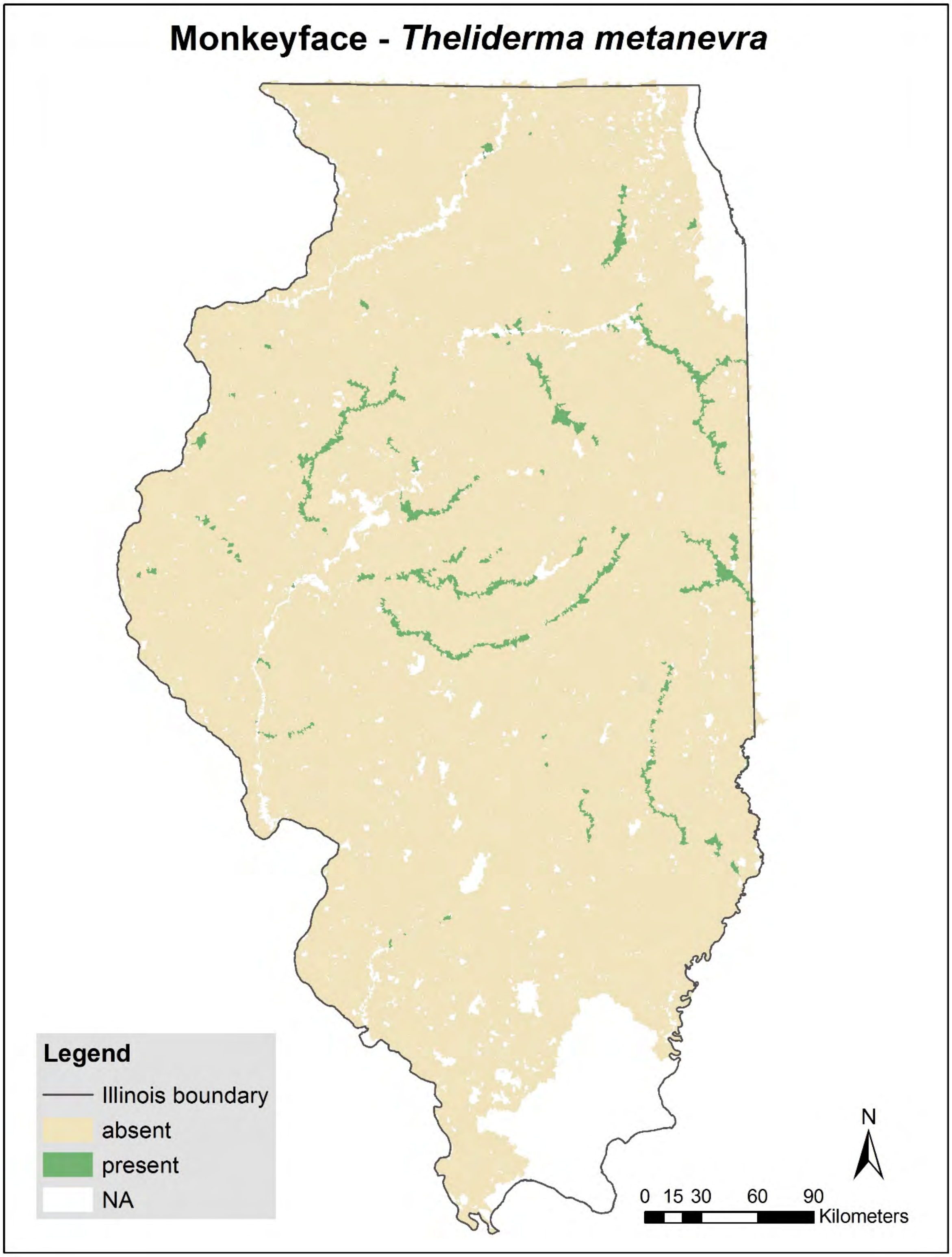

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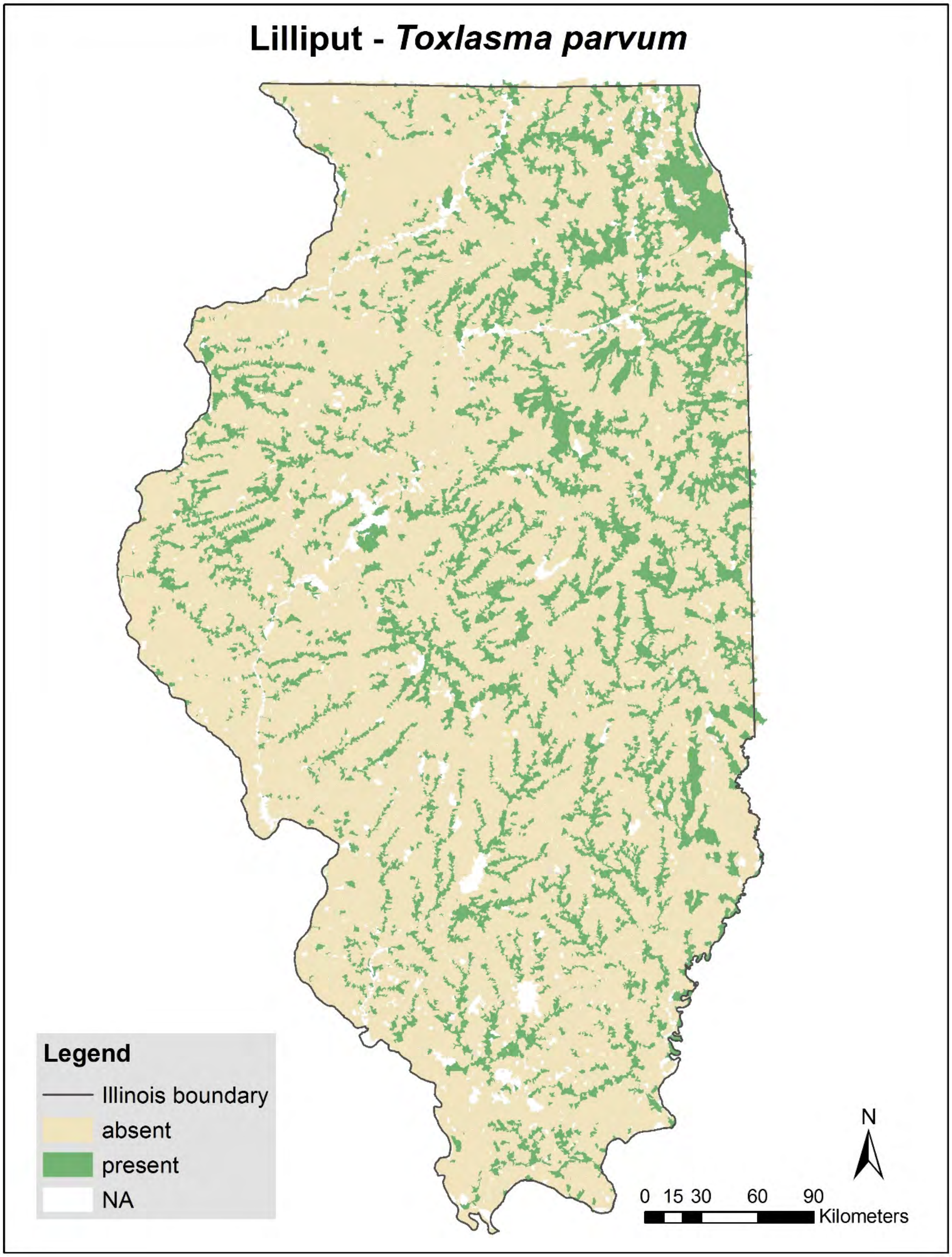

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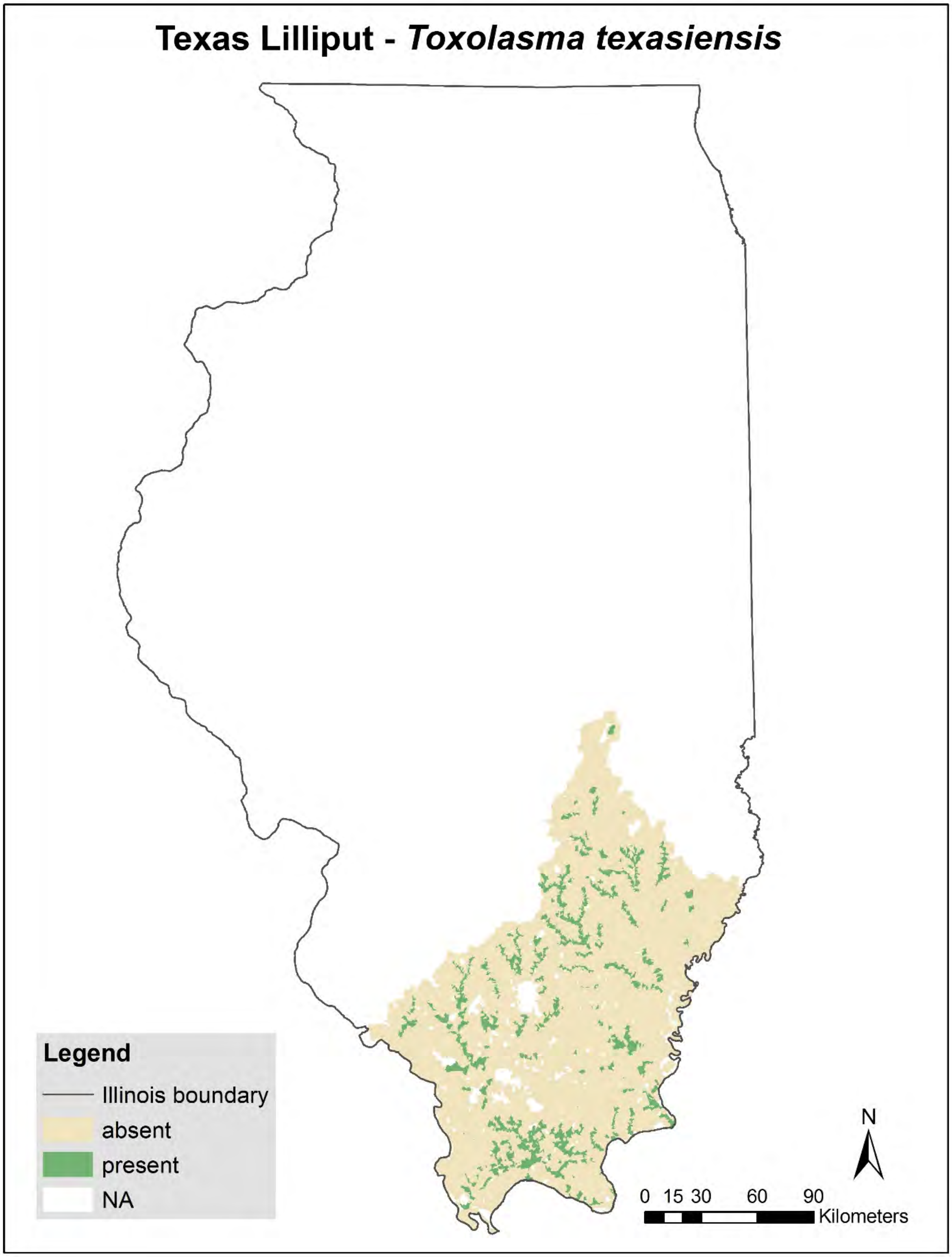

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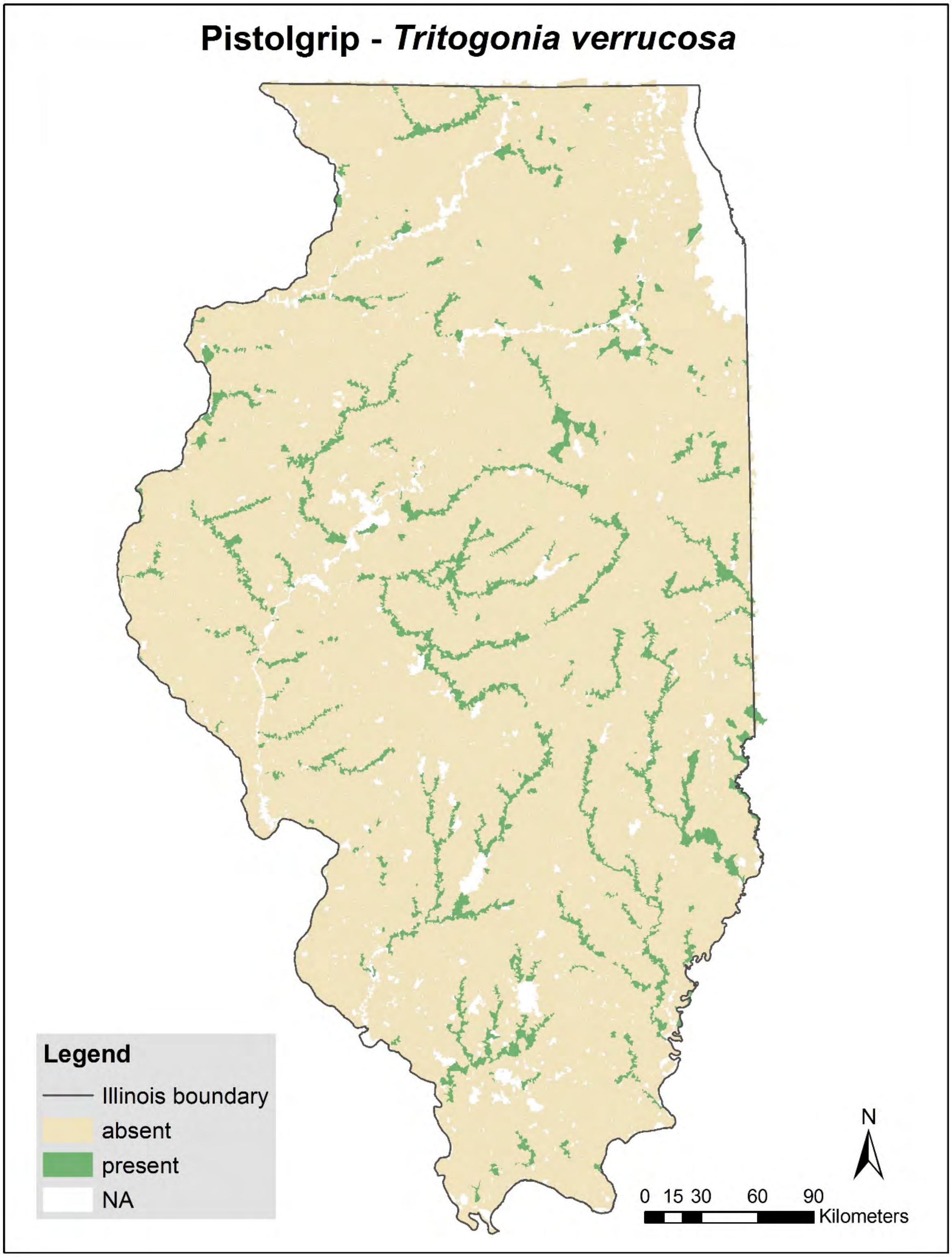

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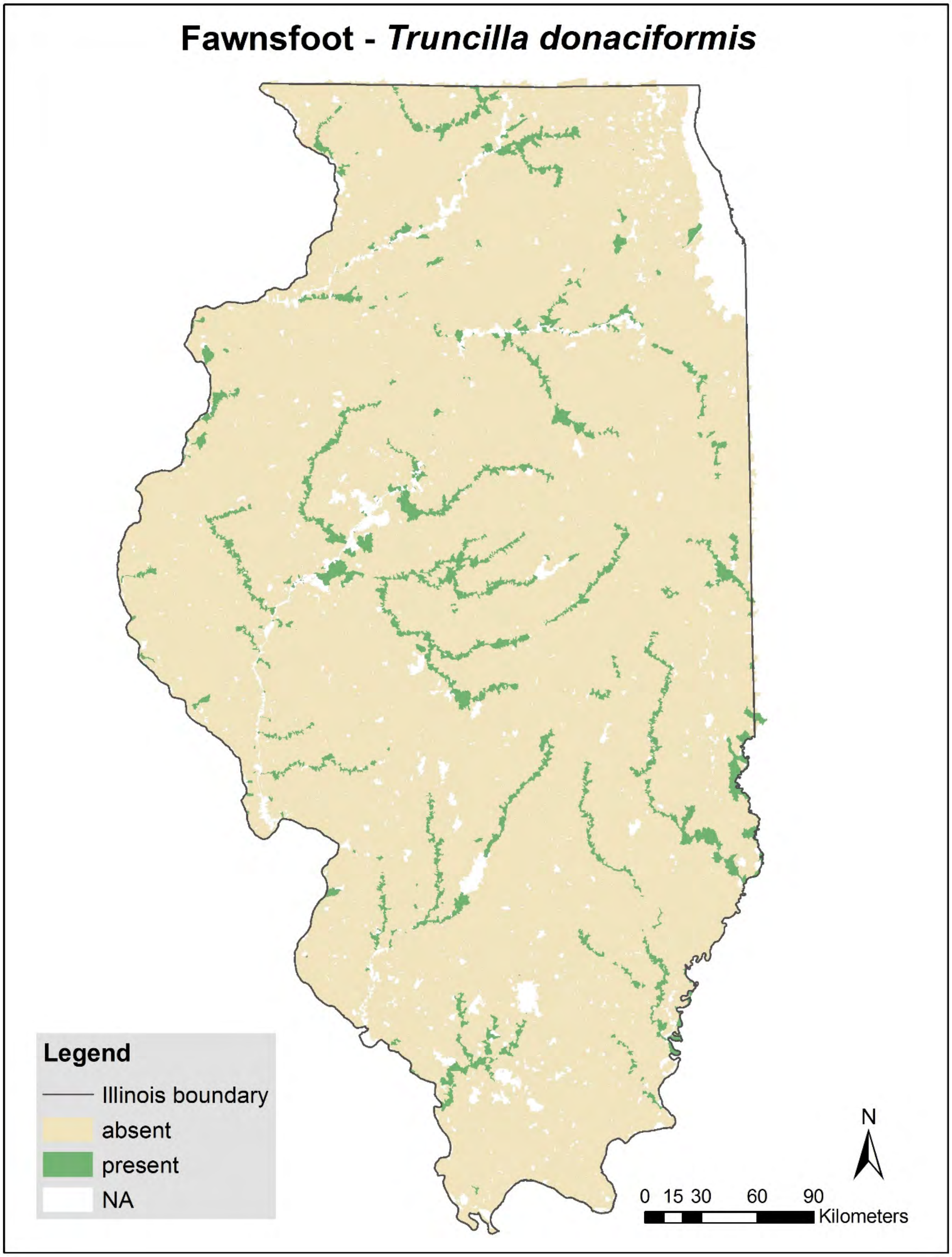

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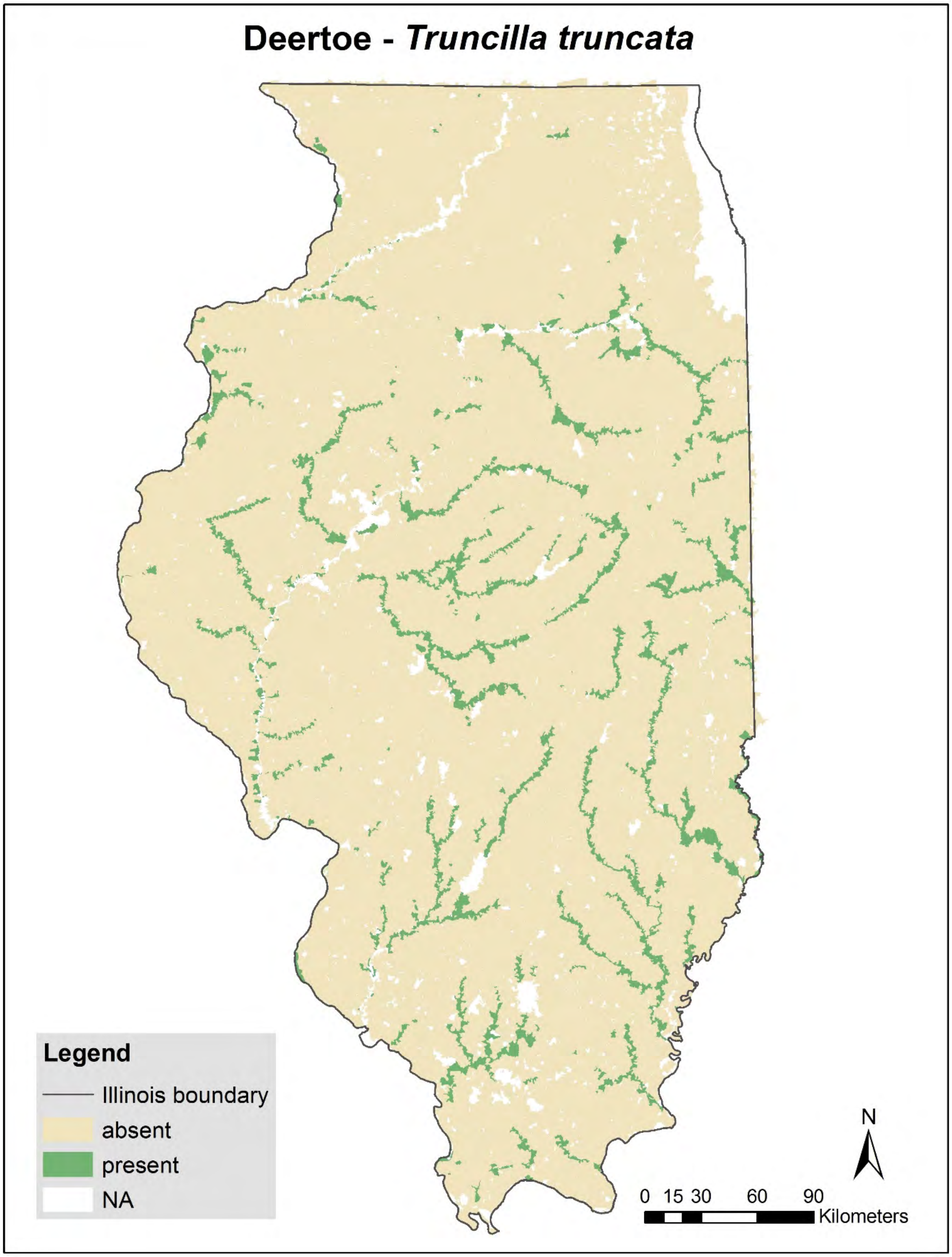

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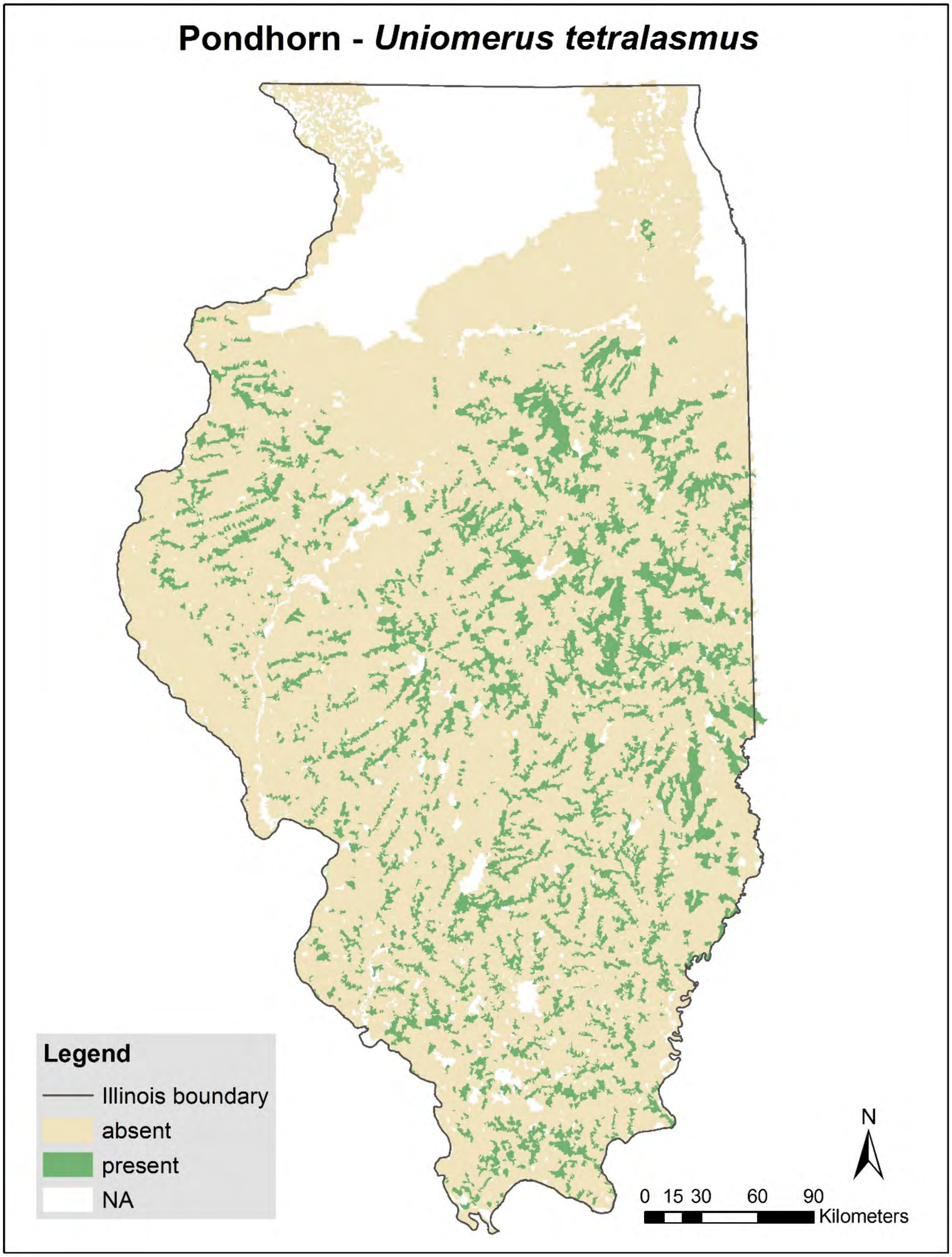

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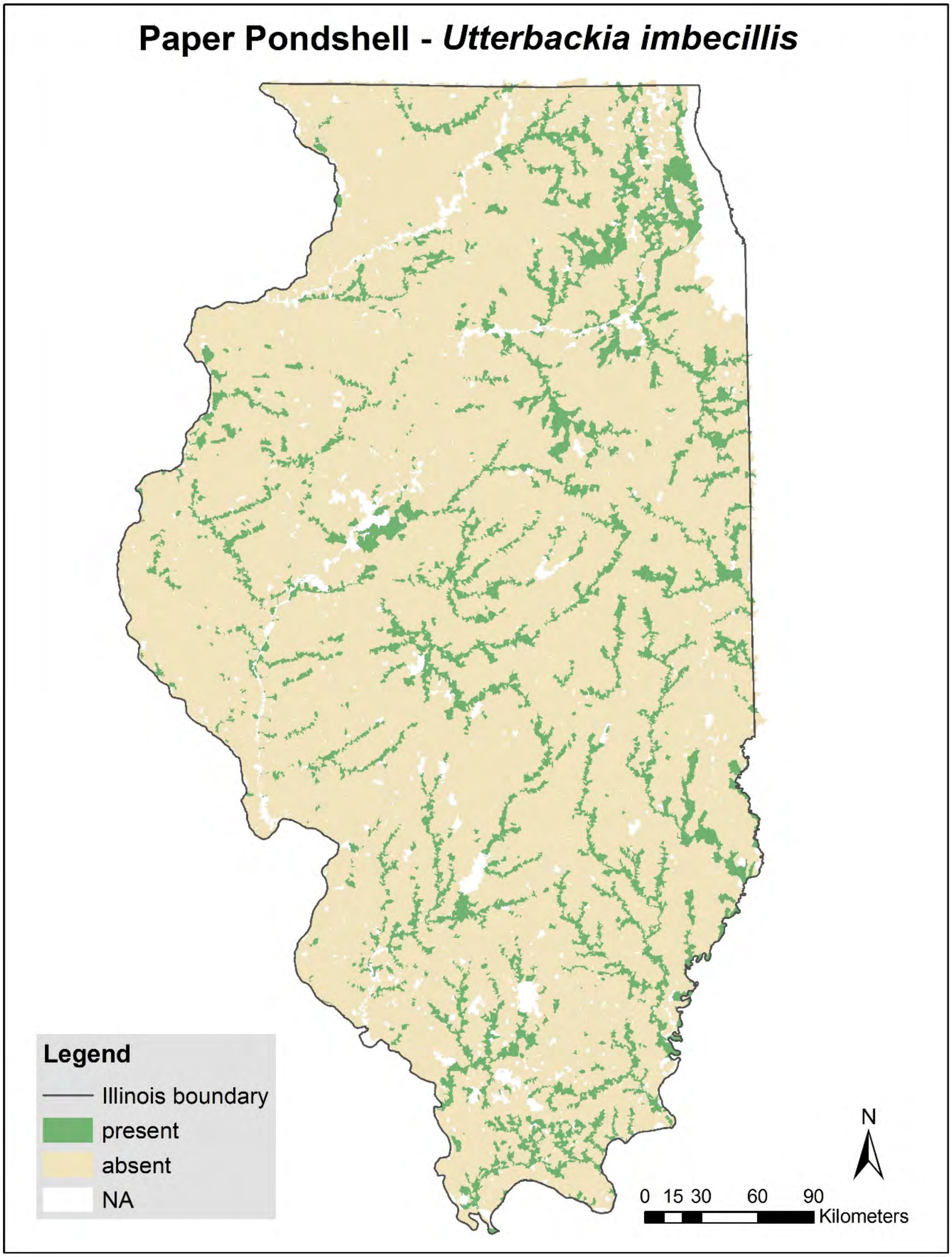

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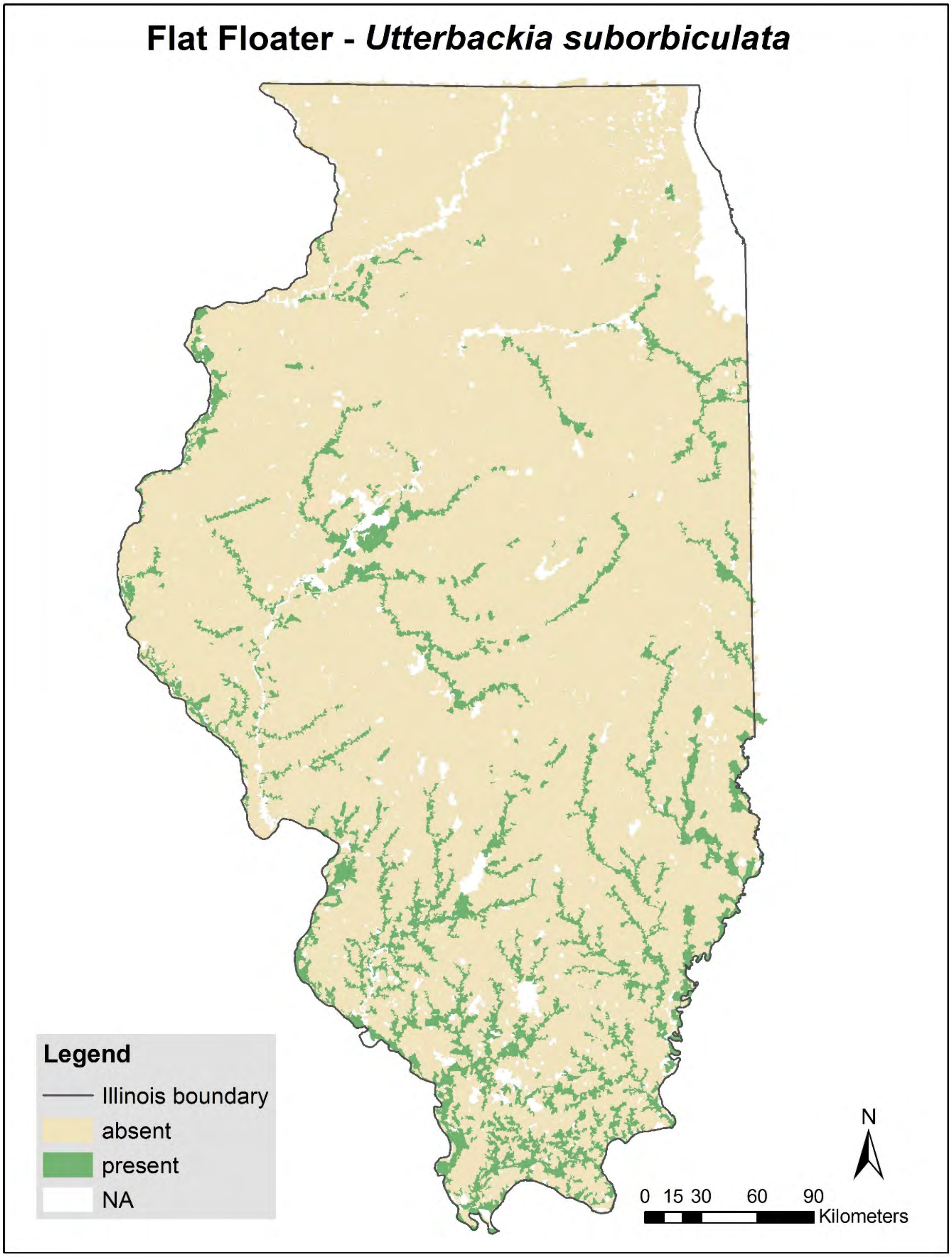

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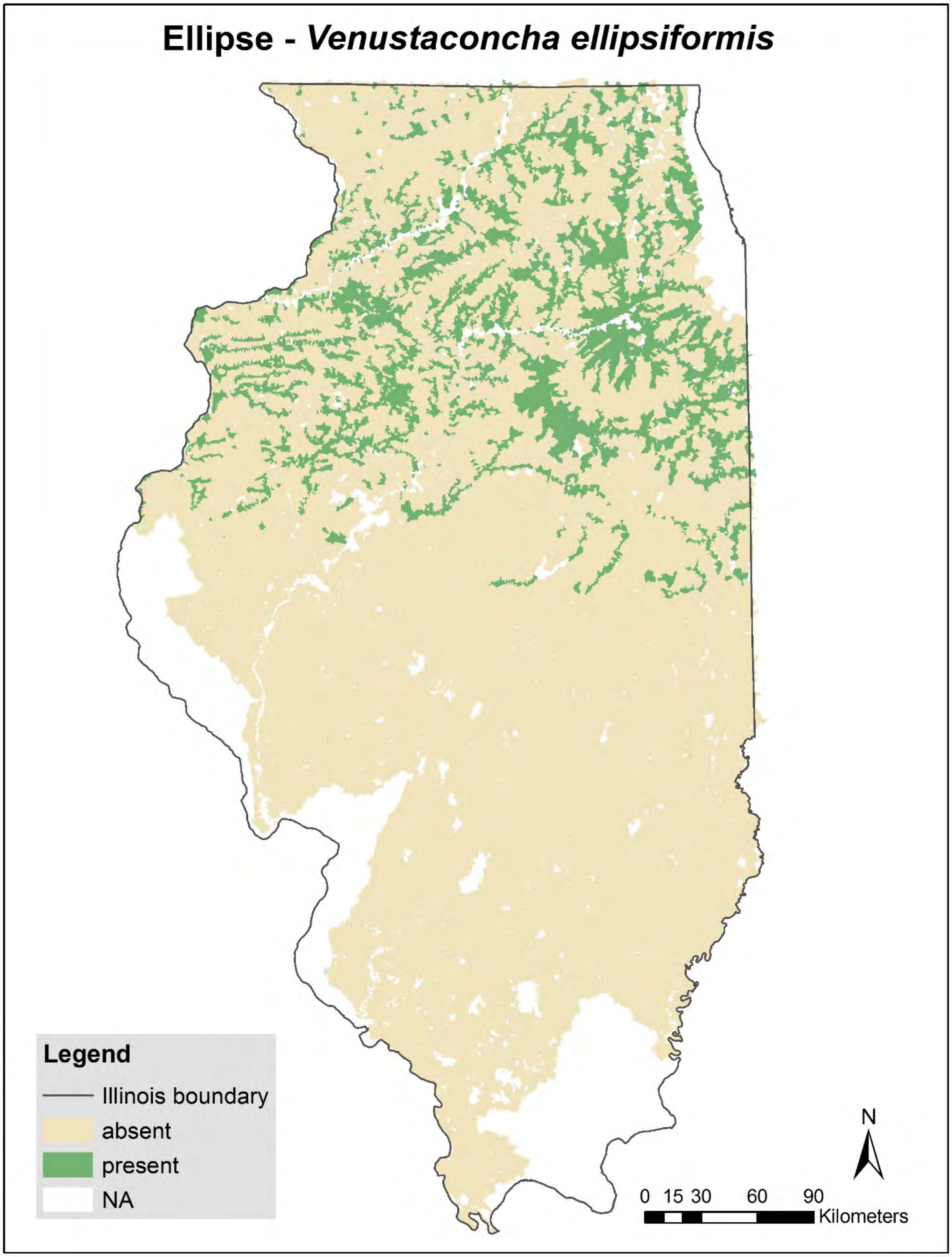

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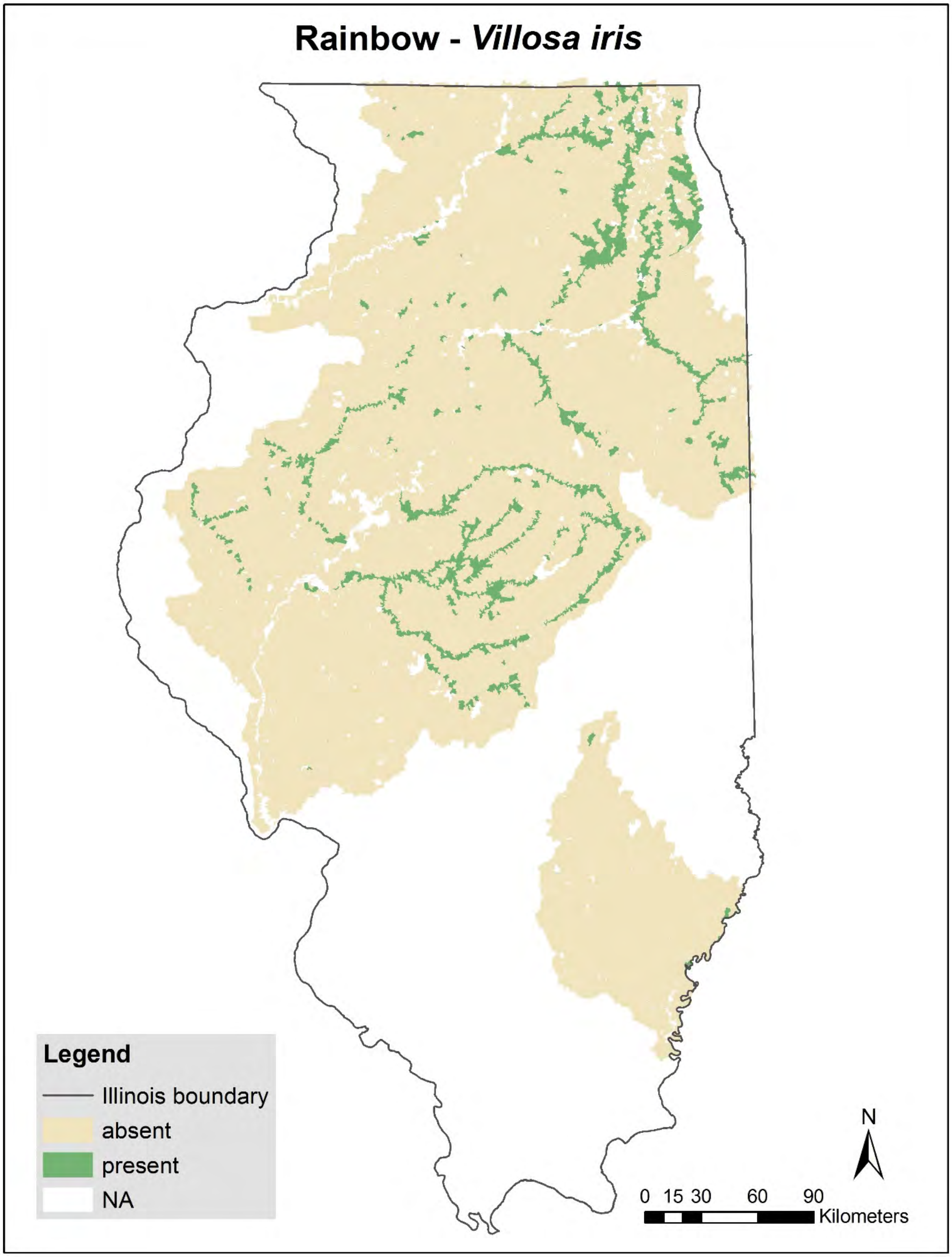

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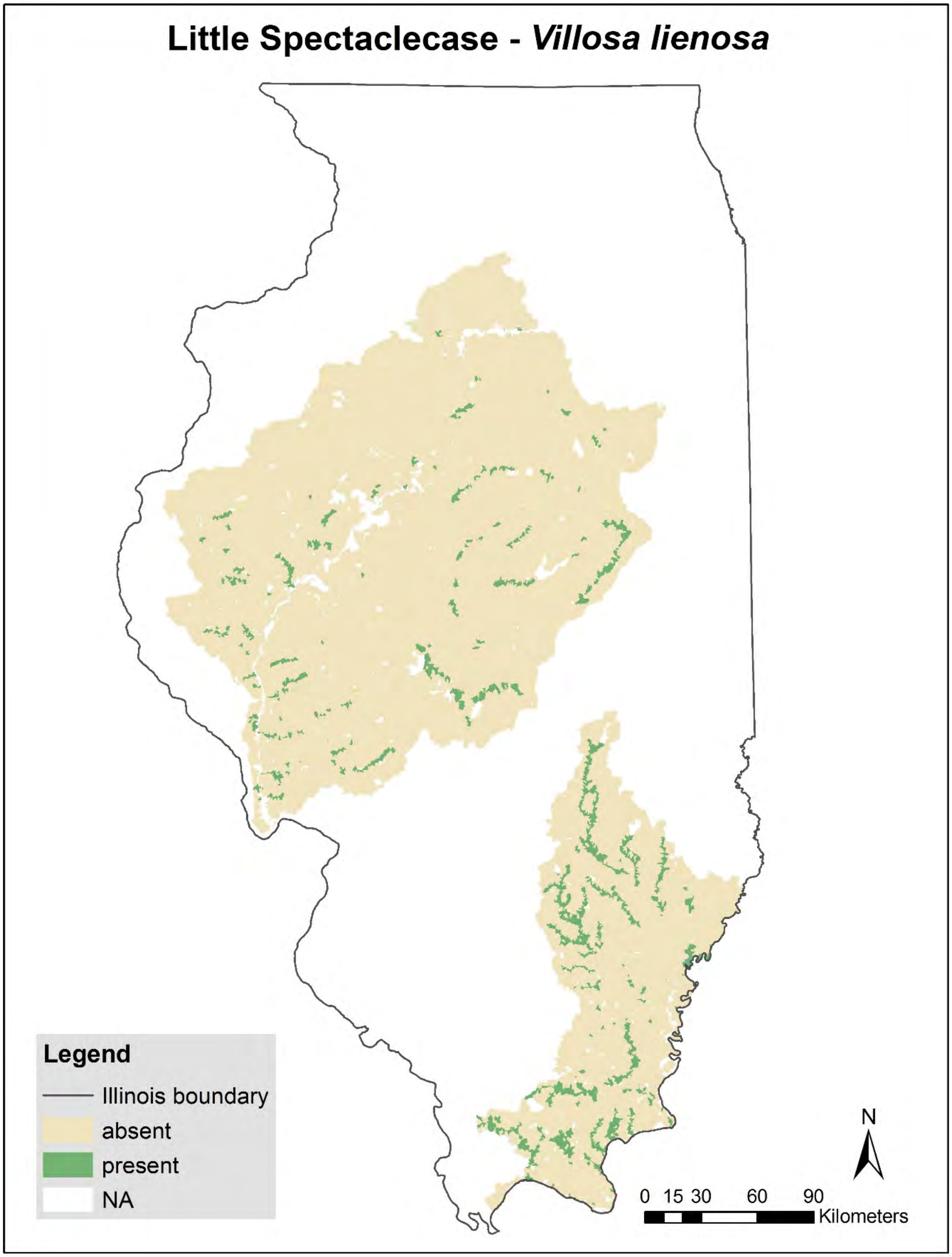

**Appendix 6:** Modeling historic distributions of Illinois's freshwater mussels using Maximum Entropy.

**Appendix 7:** Reconstructing the natural distribution of individual mussel species and species diversity in wadeable streams of Illinois, USA with reference to stream bioassessment.

# Reconstructing the natural distribution of individual unionid mussel species and species diversity in wadeable streams of Illinois, USA with reference to stream bioassessment

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**Abstract:** Freshwater mussels are considered one of the most imperiled aquatic species group in the United States. One of the challenges in effectively protecting and restoring mussel biodiversity is a lack of understanding of their natural distributions at relevant spatial scales. Without this information, it is difficult to assess the current status of individual species and overall biodiversity, or to evaluate restoration success. In the present study, we compiled records for 45 mussel species in Illinois wadeable streams and a range of natural environmental variables describing climate, geology, soil, land-cover, and watershed topography. We used reaches (segments between 2 neighboring tributaries) as the basic spatial unit of the stream network for modeling species distributions with Maxent. We applied these models statewide to all identified wadeable reaches. Stacking the predictions of individual models yielded an estimate of species richness for each reach. The estimates were compared with observed richness from 2 sets of independent sites; 17 sites sampled multiple times over the past 50-100 years, and 18 sites intensively sampled in 2009-2010. The latter set was considered to represent much more impaired mussel assemblages. These sets of sites lost an average of 25% and 46%, respectively, of species expected under natural conditions. Observed occupancy of individual species decreased by 27% and 35%, respectively, from expected natural values. We also found that listed species more frequently suffered heavy occupancy loss than non-listed species. Surprisingly, mussel species loss estimated was negatively correlated with 2 existing indices of biological integrity. These results, together with maps of natural distributions for individual species and for species richness will assist with mussel biodiversity conservation and for the development and use of mussel-based biological indicators in stream assessment.

**Key words**: species distribution, Illinois streams, Maxent modeling, biodiversity loss, historic records, freshwater mussels

Freshwater mussels (Unionidae) play an important role in stream ecosystems and provide many ecological services, including organic matter decomposition, nutrient recycling, and water purification (Vaughn et al. 2004, Howard and Cuffey 2006, Vaughn 2010, Chowdhury et al. 2015). Yet, they are among the most imperiled groups of animals in the world (Williams et al. 1996, Lydeard et al. 2004, IUCN 2015). A range of human disturbances have been identified to contribute to the decline, including habitat loss and degradation, water pollution, and fish-host loss (Downing et al. 2010, Lopes-Lima et al. 2015). There is a clear and urgent need for more effective conservation and restoration of freshwater mussels to support these ecosystem services. A better understanding of their historical and current spatial distributions are critical for success of these efforts.

Knowledge about the natural distribution of mussel species and local species diversity is needed to assess the conservation status of species and set targets for restoration of impaired streams. A small number of stream sites have been closely monitored over many decades (e.g., Metcalf-Smith et al. 1998, Hughes and Parmalee 1999, Angelo et al. 2009, Karatayev et al. 2012), but the vast majority of stream reaches have never been sampled or only sampled occasionally. The natural ranges of individual species are therefore normally drawn at basin or major watershed scales (e.g., NatureServe, www.explorer.natureserve.org). These coarse distribution maps are useful, but insufficient to serve the 2 objectives above or many other management or research needs. Reconstructing natural distributions of native species at a fine spatial resolution by modeling based on historic species records could overcome this challenge. This approach also provides an alternative for establishing reference conditions to assess stream health (Labay et al. 2013, 2015, Growns et al. 2013). Biological indicators have been widely used for stream management across the world (Karr and Chu 1998, Wright et al. 2000, Hawkins 2006, USEPA 2006). A key step to developing a biological indicator is to establish reference conditions based on minimally-disturbed sites (Stoddard et al. 2006). However, there are often not enough such sites available in developed regions, such as the Midwestern US. Predicting the natural distributions of mussel species would allow development of mussel-based biological indicators. Freshwater mussels have complex life histories, long life spans, and appear to be particularly sensitive to many human impacts (Grabarkiewicz and Davis 2008), such as un-ionized ammonia (Strayer and Malcom 2012). However, mussel assemblages have rarely been used for bioassessment (Grabarkiewicz and Davis 2008) and are potentially under-protected when assessments are based on other taxonomic groups (e.g., fish and macroinvertebrates). There is a clear need to examine how historic changes in mussel species diversity at fine spatial scales (e.g., site level) is related to existing indicators, such as the fish index of biological integrity (IBI).

Many modeling methods are available to predict species distribution (Pearson et al. 2011). Historical species records are typically presence-only, and for this type of species data Maxent modeling has been repeatedly shown to be as robust as and often more robust than other alternatives (Philips and Dudik 2008, Elith et al. 2011), and remains to be most robust method to predict species occurrence over space and time (Bateman et al. 2016, Petitpierre et al. 2016, Searcy and Shaffer 2016). Several studies have used Maxent to examine the distributions of specific freshwater mussels (e.g., Wilson et al. 2011, Lois et al. 2015, Campbell and Hilderbrand 2016). However, we are unaware of any efforts to systematically model a large suite of mussel species to re-construct local species diversity. Widely-available GIS-based environmental data allow species modeling at fine spatial scales. The reach, defined as a confluence-to-confluence segment (Brenden et al. 2006), is a scale highly relevant to stream management (Wang et al. 2012), and has been increasingly accepted for use in species modeling (Lyons et al. 2010, McKenna et al. 2013, Cao et al. 2015) and other landscape-based studies of streams and rivers.

In the present study, we used Maxent to model the natural (pre-European settlement) distributions of 45 mussel species in wadeable streams of Illinois, USA, based on a range of natural environmental variables (climate, geology, soil, and historic land-cover). To estimate the number of species in a reach, we stacked the binary prediction of individual species for each spatial unit as in several other studies (Pineda and Lobo 2009, 2012, Schmidt-Lebuhn et al. 2012, Cao et al. 2013, Pouteau et al. 2015). The predictions of species occurrences across sites were also used to estimate species-occupancy and its change (Guillera-Arrita et al. 2015, Hawkins and Yuan 2016, Ko et al. 2016). We then applied the model predictions to 2 separate datasets, 1 from a recent intensive survey, and another based on historically well-sampled sites to address 4 questions: 1) how has species richness (SR) changed in these 2 sets of sites from the natural expectation, 2) how do the occupancies of individual mussel species differ from their natural expectations, 3) have the species listed as endangered or threatened by governmental agencies been subjected to more occupancy loss than others, and 4) how are the estimated changes in the local species richness related to fish and macroinvertebrate IBIs? The answers to these questions will increase our understanding of the current status of both individual species and local assemblage and help to effectively protect mussel biodiversity.

## Data and methods

### Natural environmental variables

To model the natural species distribution, all predictors need to be natural environmental variables resistant to human alternation and accessible at the reach scale. For this reason, we excluded fish hosts from the predictor list, in spite of their known importance (e.g., Haag and Warren 1998, Vaughn and Taylor 2000). We adopted the environmental variables used by Cao et al. (2016) for modeling fish distributions in wadeable streams of Illinois, USA except those for land-use and spatial connectivity (e.g., distance to dams). These variables were derived by Great-Lakes Aquatic Gap Analysis Project (Brenden et al. 2006, Steen et al. 2008, McKenna et al. 2013), describing climate, geology, soil, and watershed topography. The environmental variables are summarized at the watershed and riparian-zone scales for each reach. We also summarized land-covers of 1800s (Szafoni et al. 2005), such as prairie, forests, and marsh at both scales. A cluster analysis based on Pearson correlation was conducted to identify data redundancy, and highly-correlated groups of variables were established from which a single variable was chosen from each group either because it is more biological meaningful or at random (Cao et al. 2016). As a result, 39 natural environmental variables were selected for modeling mussel distribution (Table 1). In the study region, 46,443 reaches were identified by Cao et al. (2016) as wadeable or likely wadeable and used as the modeling domain in the present study.

**Mussel collection data**

We compiled 31,599 species records from the mussel collection database of the Illinois Natural History Survey, that include site duplicates, invasive species, and a small number of ambiguous locations or species. After removing those unqualified data, we assigned all records to specific stream reaches leaving 17,881 reach-unique records from 77 native species. These retained records are widely spread across the study region (Fig. 1).

In Maxent modeling, a set of spatial units where a species has not been observed (i.e., background units), is required. Several studies recommend constraining background units to the area accessible to the species modeled (Phillips et al. 2009, Elith 2010). We compiled the occurrence of all 77 species in USGS Hydrological Code 6 (HUC6) watersheds. If a species was ever observed in the HUC6 watershed, the entire watershed was considered to be accessible to the species and was included in the background selection. However, certain species were only observed in 1 or 2 small HUC6 watersheds where the total number of reaches is much smaller than the standard background size (10,000 units) normally used in Maxent modeling. Some other species were not able to be appropriately modeled because they were recorded only at a few wadeable streams within the study region. As a result, we restricted our modeling to 45 species with >10 reach-unique records and >9,000 background reaches available (Table 2).

**Model Calibration**

We built Maxent models for 45 species using the package Maxent (Phillips et al. 2014) (v3.3.3.k https://www.cs.princeton.edu/~schapire/maxent/). Although AICc has been recommended to choose Maxent models for different levels of regularization or ß-value (Warrant and Serfeit 2011), AICc-based models were also reported to over-predict the distribution of most species and overall SR (Cao et al. 2013). We chose to implement Maxent using the default settings, including ß-value (1), the number of background units (10,000), and the number of features set based on the number of reach-unique records except for 2 species (*Lampsilis hydiana* and *Toxolasma texasiensis*), which had slightly lower numbers of background reaches available (9,381 and 9,323, respectively). For these species, all background reaches were used. For all other species, the background reaches were randomly chosen from all reaches that fell into the assumed range of the species. We recorded Area Under Curve (AUC) for each species model.

However, several recent studies sharply criticized AUC as being a poor criterion for model performance (Lobo et al. 2008, Peterson et al. 2008, Jimenz-Valverde 2012). We therefore did not split species data for AUC-based validation (see Warrant and Serfeit 2011, Labay et al. 2013). Use of all records for calibration allowed us to model many non-common species and include them in species-richness estimation. Instead, we indirectly tested the model predictions by comparing the estimates of species loss between 2 separate sets of sites considered to be biologically impaired to different levels (see details below).

We applied each model to the rest of the reaches in all accessible watersheds (applicable reaches). We transformed the output of Maxent predictions for the applicable reaches into species presence-absence based on a threshold defined for Equal Sensitivity and Specificity, as recommended by several studies (Liu et al. 2005, Jemenez-Valverde and Lobo 2007, Cao et al. 2013). We stacked up the binary prediction of each modeled species to estimate the number of species expected in each reach, as in several previous studies (Pineda and Lobo 2009, 2012, Cao et al. 2013).

**Model Applications**

*Historical sampling sites.* - After reviewing detailed collection information, we chose 17 wadeable sites that were sampled 6-15 times from 1870-1955 as the first dataset (Historic Sites) for model application (Appendix 1). These sites tended to support diverse mussel faunas as collections are traditionally focused on taxonomy and species inventory. SR at the 17 sites ranged from 10 to 27 (mean = 20.5, SD = 6.0) and was assumed to be nearly complete due to the high numbers of collection visits. All 45 species modeled were recorded at these sites. Mussel fauna in the Midwestern US were subject to a variety of human impacts, such as dredging, over-harvesting, farming, deforestation, and damming even before 1900, although the exact impacts are poorly documented (Haag 2012). Nevertheless, species list compiled for these historic sites, containing some species that were later extirpated, should represent partly-impaired mussel assemblages.

*Recent survey sites.*- A second dataset included 18 wadeable sites sampled during 2009-2010 (e.g., Recent Sites) (Appendix 2). The watersheds of these sites are dominated by agricultural lands. In particular, 16 of them are in central-eastern Illinois, a region with highly productive row-crop farming and heavy use of fertilizers (Davis et al. 2010). Sixteen person-hour searches at these sites led to a nearly complete species list (Huang et al. 2011) with SR ranging from 6 to 19 (mean = 11.1, SD = 4.0). Thirty-three of the 45 species modeled were recorded at the sites. In the Midwestern US, massive use of fertilizers, herbicides, and pesticides started around the early 1950s, and the worst water-quality degradation occurred in the 1960s. In the past few decades, despite water quality generally improving after the Clean Water Act implementation, the delayed effects of systematic habitat degradation coupled with non-point sources of pollution, habitat fragmentation, and exotic species invasion have led to continuous and rapid decline of mussel diversity and abundance in most streams (Downing et al. 2010, Haag 2012). It is therefore reasonable to assume that the mussel species lists at these sites characterize mussel assemblages that were impacted much more severely by human disturbance than at the 17 historical sites.

*Estimating loss of reach species diversity and species occupancy.* – We first calculated a ratio [observed richness/expected richness], that is often referred to as O/E in stream assessment (Hawkins 2006, USEPA 2006) for each of the 2 datasets described above. We then estimated proportional species loss as [1 – O/E]. The proportional occupancy loss of a specific species was calculated as [1 – (observed occurrence / expected occurrence)] (Hawkins and Yuan 2016). We hypothesized that the recent sites would suffer from heavier losses in both species diversity and species occupancy. A confirmation of this hypothesis would show that the estimation of SR based on individual Maxent models is accurate enough to detect major differences in the impairment of mussel assemblages. However, because neither dataset was based on randomly-selected sites, we could not assess the mussel diversity changes across the whole study region. Instead, we used the 2 datasets as an example of how to apply the prediction of Maxent models to site-specific and species-specific assessment based on intensive mussel surveys. The historical sites were not sampled consistently over time and the occupancy change for individual species are thus difficult to assess. Therefore, we compared the occupancy loss of 43 species recorded at the recent sites in relation to their conservation status in Illinois.

*Relationship between mussel O/E and existing multimetric indices*. – We also examined the correlation between 2 existing biological indicators commonly used in Illinois, fish IBI (Smogor 2002) and benthic IBI (IL-EPA 2010), and assessed whether mussel-based O/E provided any new information on stream conditions. Data for the 2 indicators were obtained from Illinois Environmental Protection Agency.

## Results

The Maxent models for the 45 mussel species yielded AUC-value of 0.88-0.99 (Table 3). The number of occupied reaches predicted was significantly correlated with the number of occupied reaches recorded (average $r$ = 0.64, $p$ <0.01), although there are great differences among species. The model predicted *Toxolasma parvum* as the most widely-distributed species historically, occupying 15.4% of all wadeable reaches in the study region, followed by *Pyganodon grandis* (14.2%) and *Uniomerus tetralasmus* (13.6%). In comparison, the most common species in the collection data were *Pyganodon grandis, Lasmigona complanata,* and *Lampsilis cardium.* Three species, *Fusconaia ebena*, *Obovaria reflexa*, and *Utterbackia suborbiculata* were rare in the surveys, but were predicted to be relatively common under natural conditions, occupying 7.1-10.4% of the reaches (Table 2).

Under natural conditions, most species were predicted to occupy relatively large streams and be widely distributed (Fig. 2a-b), but some species appear naturally rare or local (Fig. 2c-d). The number of species predicted in a reach ranged from 0 to 38 (3 on average). The hotspots of mussel richness are concentrated in larger streams, particularly in central and eastern Illinois (Fig. 3). Most streams near the Mississippi River in the west, the far south (Shawnee Hills) and northwestern corner (Driftless Area) of Illinois are associated with low SR.

Based on the predicted richness, species loss was evaluated for the recent and historic sites. All recent sites, except 1, lost species, an average of 11.8 with 21 as the maximum (Fig. 4). The O/E ratio was smaller than 1 at all recent sites but 1, ranging from 0.25 to 1.15 with an average of 0.54. In other words, on average 46% of the native species were lost across these recent sites. In comparison, the historic sites lost an average of 6.5 species per site, but up to a maximum of 16. Species losses at the recent sites were significantly higher than those at the historic sites (*T*-test, $p$ <0.05, Table 4). The O/E ratio at the historic sites was 0.75 on average (0.43 – 1.08), which is 25% species loss. The predictions of the models thus clearly differentiated 2 levels of biological impairment represented by the 2 datasets. In addition, the mussel O/E values derived for the recent sites were negatively correlated with both fish and macroinvertebrate IBIs ($r$ = -0.22 and – 0.51, respectively) used by IL-EPA (Fig. 5), while the 2 existing indices are positively correlated ($r$ = 0.47, $p$ = 0.1). This result strongly suggests that the mussel O/E index provides novel information about stream biological conditions and the existing IBIs do not protect mussel assemblages.

For species occupancy, the vast majority of species in both datasets suffered losses (Fig. 6). At the recent sites, only 1 species (*Villosa lienosa*) was more common than expected (7 vs. 2 sites). On average, occupancy decreased by 5.1 reaches per species at the 18 recent sites (28%). At the historic sites, 43 of 45 modeled species had reduced occupancy, although 2 singleton species (*Lampsilis hydiana*, *Toxolasma texasiensis*) were not predicted. As at the recent sites, *Villosa lienosa* was more commonly observed than predicted. The occupancy loss at the recent sites (35%) was significantly higher than at the historic sites (27%) (*T*-test, $p$<0.01). Again, the result indicates the usefulness of the model predictions.

We further examined species-specific occupancy changes at the recent sites in relation to their conservation status (Appendix 3). Of 11 species with >90% occupancy loss, 5 are listed as endangered or threatened in Illinois. However, 6 were non-listed species, such as *Actinonaias ligamentina, Quadrula metanevra*, and *Utterbackia suborbiculata*, with *Q. metanevra* being an Illinois Species in Greatest Need of Conservation. In contrast, 1 listed species, *Villosa lienosa* was actually observed in more sites than expected. Another listed species, *Cyclonaias tuberculata*, also suffered from a smaller loss (67%) than 14 non-listed species. Five very common species (*Fusconaia flava, Lampsilis siliquoidea, L. cardium, L. complanata, and Pleuobema sintoxia*) only suffered from <7% occupancy loss, indicating their high sustainable distribution ranges.

# Discussion

The need for freshwater mussel conservation and restoration is well recognized (Williams et al. 1993, Strayer and Dodgeon 2010, Haag 2012). The natural distribution of individual species and species diversity provides a benchmark for assessing the effects of historic human disturbances and future climate change. In the present study, we re-constructed the ranges of 45 mussel species in wadeable streams in Illinois. The predictions have a number of important implications for mussel biodiversity conservation.

A key step for species conservation is to assess the status of a species in a region or nation. Assigning a conservation status or listing of species are typically based on species rarity, temporal trends in abundance or range, and existing or future threats (Stein et al. 2000, Moyle et al. 2011, 2013). However, temporal trends are often difficult to determine due to the lack of long-term monitoring data from a large number of sites. The benchmark based on the natural distributions of mussel species in the study region we developed is useful in refining the existing status assignment in the study region. For example, *Villosa lienosa,* is considered rare and listed as threatened in Illinois (Illinois Endangered Species Protection Board 2015), but this species occurred more often than expected in both recent and historic sites, suggesting that it may not be as threatened as first perceived. Douglass and Stodola (2014) reached a similar conclusion in their review of mussel conservation status. In contrast, several non-listed species, including *Actinonaias ligamentina*, and *Utterbackia suborbiculata* appeared to have suffered from heavy occupancy loss across the recent sites. Although these species are not as rare as the listed ones, their declining trends are alarming and further investigations are needed. For local species diversity, the natural spatial pattern predicted (Fig. 3) is somewhat similar to what was found based on a recent survey (Cao et al. 2015), with hotspots largely concentrated on large streams and lower diversity in the southern and northwestern part of the region. However, hotspot losses are also evident in many streams. For example, mussel assemblages in the Fox and DuPage rivers in north-eastern Illinois (west Chicago) were predicted to be among the most diverse, but not observed to be in the recent survey (Cao et al. 2015). The exact loss for the region, unfortunately, is difficult to quantify in our analysis because the sampling effort in the recent survey is not adequate to accurately estimate SR.

The natural species distribution we constructed here is also useful to set restoration targets for individual species, particularly ones listed. Two Illinois endangered species (*Plethobasus cyphyus*, Federally Endangered, and *Simpsonaias ambigua*) are extremely rare and their predicted ranges also seem very limited, with < 500 reaches suitable even under natural conditions. The restoration goal of these species therefore should never be high. In comparison, 2 other threatened species (*Villosa iris* and *F. ebena*) are predicted to be more common, with >1,300 and > 3,200 reaches suitable, offering much more room for restoration. The locations of suitable reaches as predicted in this study can guide future efforts designed for finding new populations of a listed species or prioritizing habitat restoration for a specific listed species.

One of the most important applications of natural distribution maps is to assess stream biological condition based on mussel communities. Biological indicators based on macro-invertebrate, fish and algal assemblages have been commonly used by environmental agencies (Karr and Chu 1999, USEPA 2006). Despite mussels occasionally being included in some biotic indices (e.g., Kerans and Karr 1994, Daniel et al. 2014), only a few efforts have been made to develop mussel-assemblage based indicators (Hoggarth and Goodman 2007, Grabarkiewicz and Davis 2008, Dunn et al. 2012), and none seem to have been used in practice. However, the negative correlations we observed between mussel O/E index and existing indices imply that mussel assemblages are unlikely to be protected in the area assessed based on existing fish or macroinvertebrate indicators. Mussel species often prefer different types of habitats than fish and other benthic groups (Haag 2012, Cao et al. 2015, 2016), and have exceptional sensitivity to certain stressors (Haag and Warren 2008, Strayer and Malcom 2012, Shea et al. 2013). For example, coal mining led to 65% decline in mussel SR in a Kentucky stream, but only minor loss in fish and aquatic insect diversity (Poly 1997, Haag 2012). A similar result was reported in the Embarrass River, Illinois (Haag 2012). These observations and our findings highlight the need for developing mussel-based indicators that reflect keys stressors to mussel assemblages.

However, developing and applying an O/E index based on predicted natural distributions of individual species, is not free of challenges. First, because total species detection is assumed in estimation of expected SR (E) based on Maxent models, a reliable species inventory at a site is needed to accurately estimate species loss. A low sampling effort (e.g., < 4-person-hour search) likely misses some or many species and thus overestimates species loss. Intensive sampling, such as 16-person-hour search, may be required to capture all or most species at many sites (Huang et al. 2011). However, if the goal is to rank the biological state of streams or the occupancy of a species, or to identify the main stressors, some lower sampling efforts (e.g., 8-person-hour search) may be sufficient because SR for this sampling effort is highly correlated with the estimate of the true SR (Huang et al. 2011). A greater challenge is to assess the accuracy of E estimates *per se*. One may assess the accuracy using independent and presence-absence data from intensive sampling of minimally-altered streams, assuming the long-term natural changes are insignificant (hard to argue for under changing climate). However, such streams do not occur in our study region or in many others, and this was the main factor motivating the present study. SR estimates based on stacking individual Maxent species models have been shown to be accurate in several empirical studies (Pineda and Lobo 2009, 2012, but see Guillera-Arrita et al. 2015 for simulation). Cao et al. (2013) reported that SR estimates were strongly correlated with the assumed true value, but associated with considerable across-site variability. Nevertheless, the detection of significant differences in SR and occupancy loss between the 2 sets of stream sites (Table 4) indirectly validated the reliability of the predictions by the Maxent models. The heavy loss of reach species diversity across our 18 recent sites (46%) also agrees with many long-term mussel studies. For example, 40 mussel species were recorded in the Red River (a tributary of the Cumberland River in Kentucky and Tennessee) in 1966-69, but only 17 were found in 1987 (58% loss) (Haag 2012). Angelo et al. (2009) also found mussel species declined by 25% across 30 stream sites in Kansas from the historic records. A similar result was reported for 10 Great Lakes drainages in Canada (Metcalf-Smith et al. 1998). As historic collections typically started after some impairment had already occurred (25% loss estimated in the present study), the true species loss at the reach scale may be higher. Both sets of data also did not include any species-poor or urban streams. The true species loss in the study region probably is much higher than what we observed here. A robust evaluation of SR changes, as well as species occupancy loss, would require intensively sampling some large number of randomly-selected sites across the study region.

## Concluding remarks

We modeled the natural distributions of 45 mussel species in all wadeable streams of Illinois based on comprehensive historic collections and a range of natural environmental variables. Using the model predictions, we estimated the species richness expected under natural conditions for every wadeable stream reach and the number of reaches likely occupied by each species under natural conditions in the study region. The natural hotspots of species richness were concentrated in larger streams and central-eastern Illinois. By comparing the expectations with observations (O/E) in both species richness and occupancy, we found 46% loss in species richness and 35% loss in occupancy at the recent sites; the loss at the historic sites were less severe, 28% and 27%, respectively. Most listed and several non-listed species appeared to have suffered heavier occupancy losses. The value of O/E in mussel species richness was negatively correlated with 2 existing IBI indices, indicating the need for a mussel-based index. There are challenges in fully validating and utilizing the prediction of natural mussel distributions. However, Maxent modeling for mussel species and the derived O/E index adds an additional tool for protection of unionid mussel biodiversity and assessment of stream conditions.

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## Captions

Fig. 1. Locations of mussel records and the two sets of sampling sites in wadeable streams, Illinois, USA.

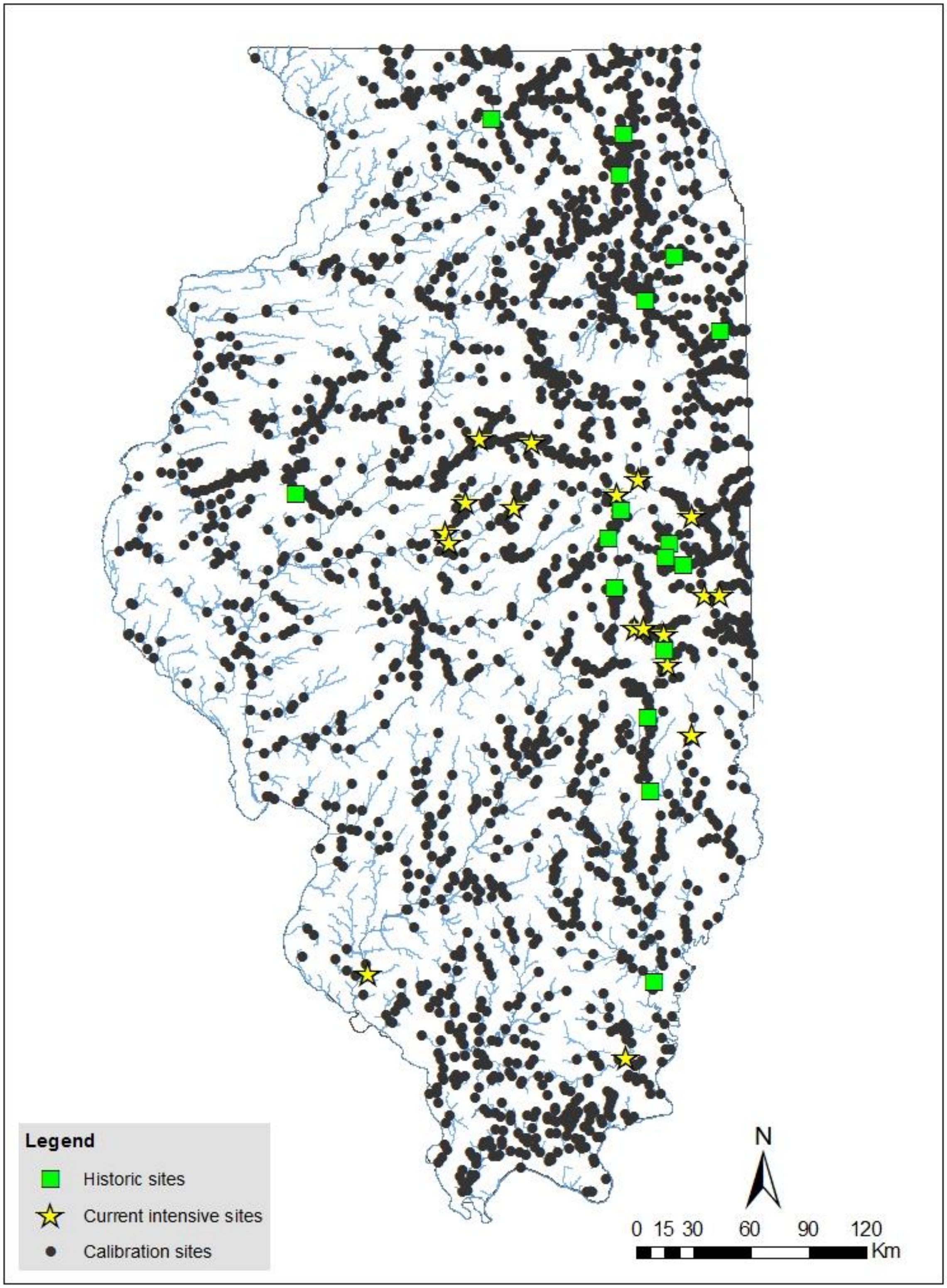
Fig. 2. Examples of historic distributions of mussel species in wadeable streams, Illinois, USA, showing disparate spatial patterns.

Fig. 3. Spatial patterns of mussel species richness estimated based on stacking of the predictions of individual Maxent models for 45 species in wadeable streams of Illinois, USA.

Fig. 4. Comparing the numbers of mussel species observed and predicted at 17 historically well-sampled sites and 18 recently-sampled sites in Illinois, USA (dotted line for 1:1 ratio).

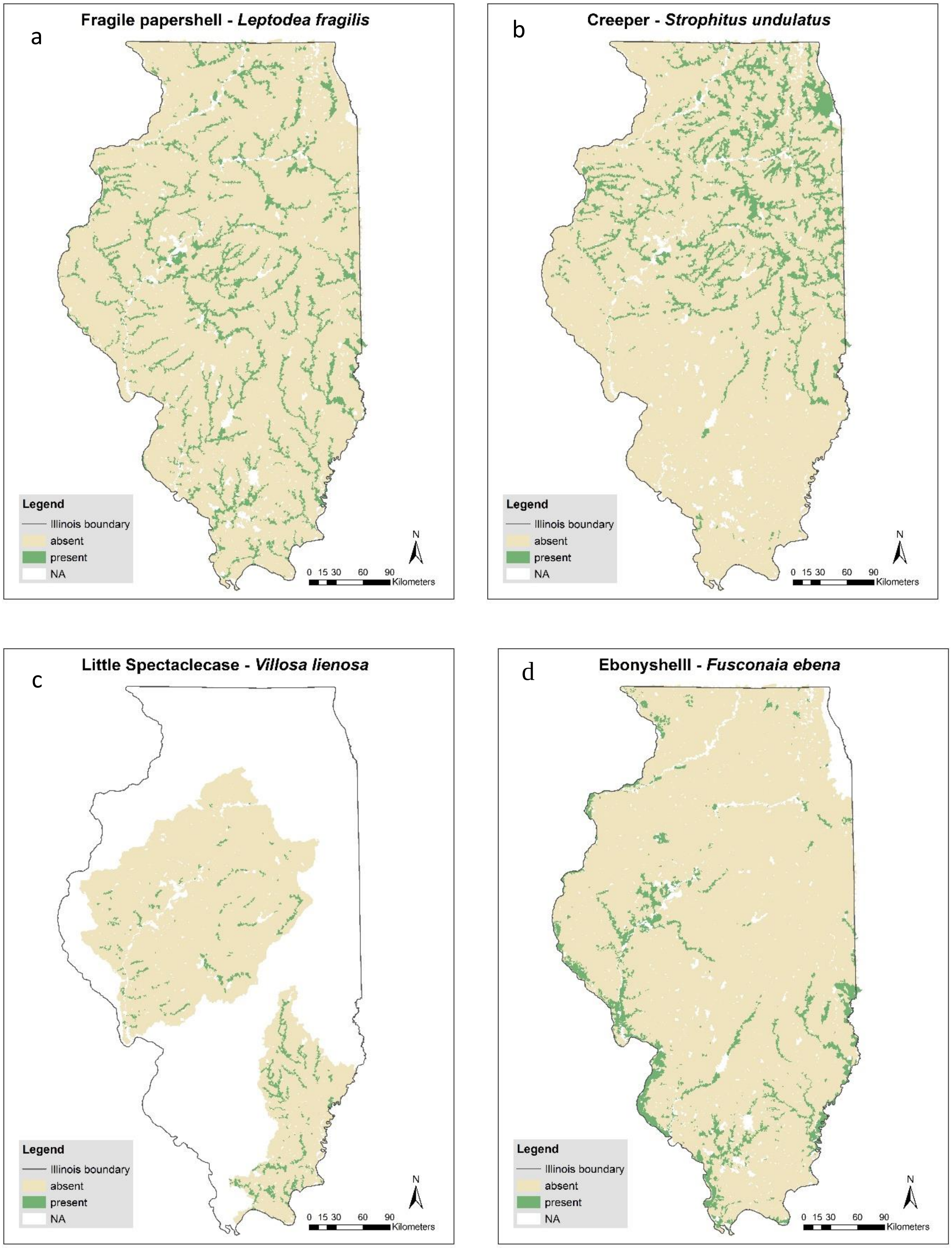
Fig. 5. Correlations between mussel O/E index and two IBI indices (fish- and macroinvertebrate-base) at 18 recent sites in wadeable streams of Illinois (solid line for a linear fitting).

Fig. 6. Comparing the numbers of occupied reaches observed and predicted for modeled species at 17 historically well-sampled sites and recently thoroughly-sampled sites in Illinois, USA (dotted line for 1:1 ratio).



Legend
Historic sites
Current intensive sites
Calibration sites
N
0 15 30 60 90 120
Km


Fig. 1



Fragile papershell - *Leptodea fragilis*
a
Legend
Illinois boundary
absent
present
NA
0 15 30 60 90
Kilometers
N
Creeper - *Strophitus undulatus*
b
Legend
Illinois boundary
absent
present
NA
0 15 30 60 90
Kilometers
N
Little Spectaclecase - *Villosa lienosa*
c
Legend
Illinois boundary
absent
present
NA
0 15 30 60 90
Kilometers
N
Ebonyshelll - *Fusconaia ebena*
d
Legend
Illinois boundary
absent
present
NA
0 15 30 60 90
Kilometers
N


Fig. 2.

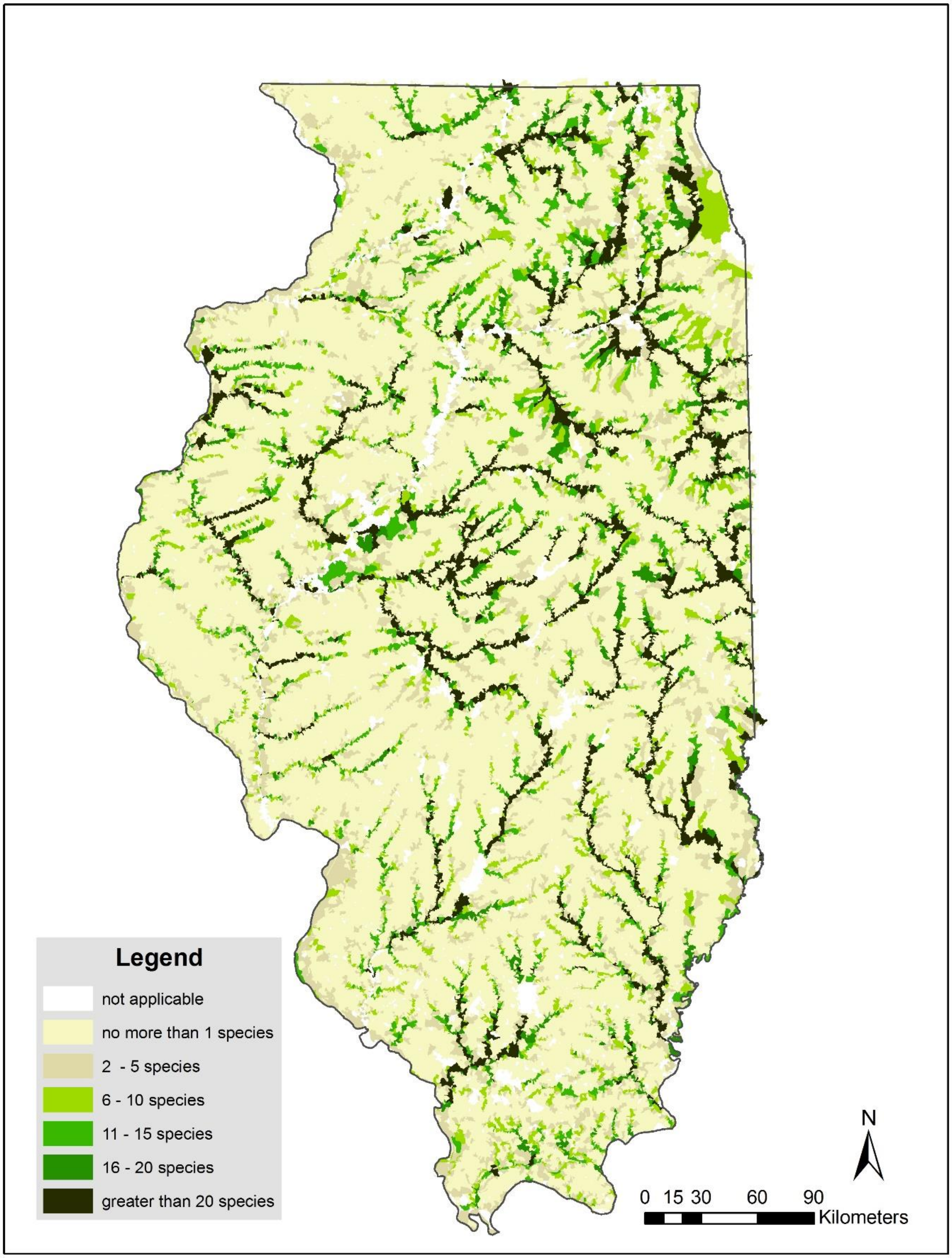
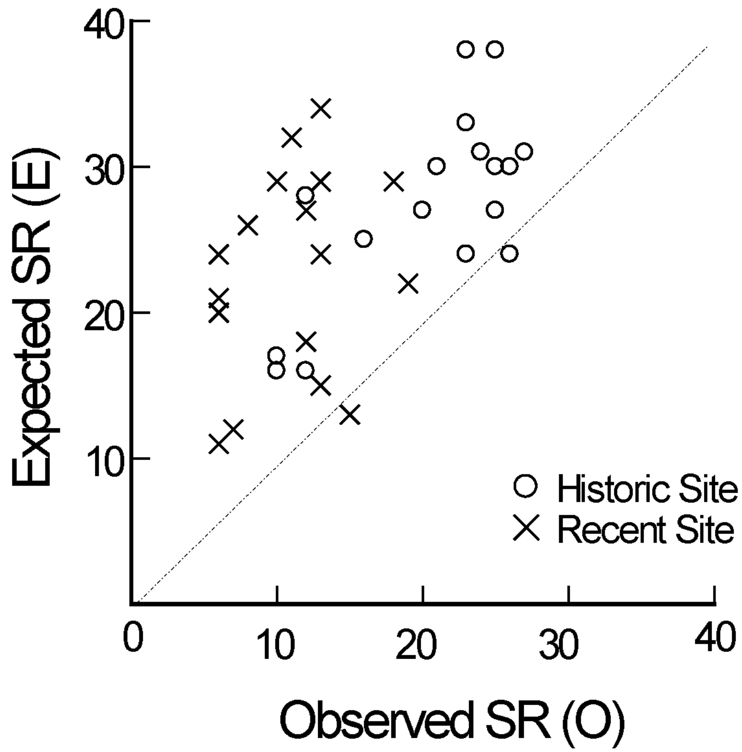

Legend
not applicable
no more than 1 species
2 - 5 species
6 - 10 species
11 - 15 species
16 - 20 species
greater than 20 species
N
0 15 30 60 90
Kilometers

Fig. 3



40
30
20
10
Expected SR (E)
0
10
20
30
40
Observed SR (O)
Historic Site
Recent Site


Fig. 4

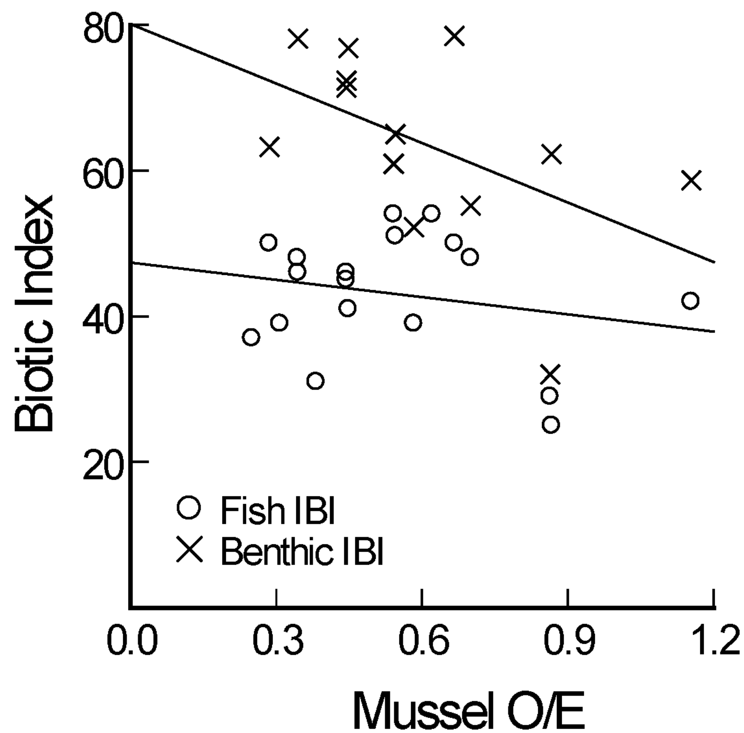

80
60
40
20
Biotic Index
Fish IBI
Benthic IBI
0.0
0.3
0.6
0.9
1.2
Mussel O/E

Fig. 5

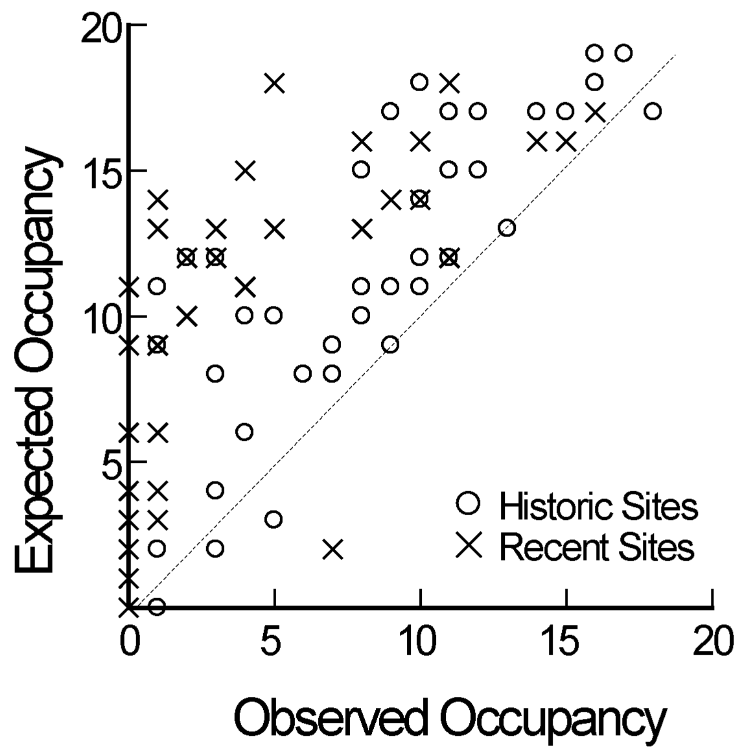

20
15
10
5
0
5
10
15
20
Expected Occupancy
Observed Occupancy
Historic Sites
Recent Sites

Fig. 6

Table 1. Thirty-nine natural environmental variables used for Maxent modeling of mussel distributions in wadeable streams of Illinois, USA (WT = the total watershed, W = the area directly draining into a reach, i.e., a confluence-to-confluence stream segment).

| Variables | | Description |
|---|---|---|
| Geology | | |
| | Chan_BR50 | channel bedrock depth<15.24m (50f) |
| | Chan_BR100 | channel bedrock depth >15.24m and <30.48m (100f) |
| | Chan_BRG100 | Channel bedrock depth > 30.48m (100 f) |
| | WT_Alluv | % of WT for alluvium (deposit) |
| | WT_CMorai | % of WT for coarse moraine (deposit) |
| | WT_Collu | % of WT for colluviums (deposit) |
| | WT_Dune | % of WT for dune (deposit) |
| | WT_Fine | % of WT for all-form-fine (deposit) |
| | WT_ICont | % of WT for ice contact (deposit) |
| | WT_Lacus | % of WT for lacustrine (deposit) |
| | WT_Loess | % of WT for loess (deposit) |
| | WT_MMora | % of WT for medium moraine (deposit) |
| | WT_OWash | % of WT for outwash (deposit) |
| | WT_PMuck | % of WT for peat-muck (deposit) |
| | WT_Rocky | % WT for bedrock-colluvium (deposit) |
| | WT_Sand | % WT for sand (bedrock) |
| | WT_Shale | % WT for shale (bedrock) |
| Climate | | |
| | WT_GDD | Growth-degree-days (WT) |
| Stream size & Topography | | |
| | Order | stream Order (Shreve) |
| | Downorder | order of downstream reach |
| | Link | number of upstream 1st-order streams |
| | Dlink | link of downstream reach |
| | Sinuosity | (channel length of a reach)/(downstream distance) |
| | CH_Grad | Elevation change (m)/channel length (m) |
| | WT_Slope | ArcInfo SLOPE command: arctangent(rise/run) × 57.296 |
| Soil | | |
| | W_Darcy | Average Darcy Number in (W) |
| | WT_Perm | Average Soil Permeability (WT) |
| | WT_Darcy | Average Darcy Number (WT) |
| Historic Land-covers | | |
| | WT_Water | % WT for water |
| | WT_Cultural land | % of WT for Cultural land |
| | WT_Bottomland | % of WT for bottomland |
| | WT_Prairie | % of WT for prairie |
| | WT_Topo_Geo | % of WT for topographic or Geographic land (e.g., bluff, hill, and ravines) |
| | WT_Slough | % of WT for slough |
| | WT_Wet_Prairie | % of WT for wet-prairie |
| | WT_Barrens | % of WT for barrens |
| | WT_Marsh | % of WT for marsh |
| | WT_Swamp | % of WT for swamp |
| | WT_Other_Wetland | % of WT for other-wetland |

Table 2. Data splitting for modeling 45 mussel species in wadeable streams of Illinois, USA.

| Species | Domain | Training | Background | Applicable |
|---|---|---|---|---|
| *Actinonaias ligamentina* | 46317 | 305 | 10000 | 36012 |
| *Alasmidonta marginata* | 40904 | 316 | 10000 | 30588 |
| *Alasmidonta viridis* | 43780 | 233 | 10000 | 33547 |
| *Amblema plicata* | 46317 | 799 | 10000 | 35518 |
| *Anodontoides ferussacianus* | 43567 | 761 | 10000 | 32806 |
| *Arcidens confragosus* | 43567 | 110 | 10000 | 33457 |
| *Cyclonaias tuberculata* | 43780 | 92 | 10000 | 33688 |
| *Elliptio dilatata* | 46443 | 284 | 10000 | 36159 |
| *Fusconaia ebena* | 46317 | 14 | 10000 | 36303 |
| *Fusconaia flava* | 46443 | 746 | 10000 | 35697 |
| *Lampsilis cardium* | 46317 | 891 | 10000 | 35426 |
| *Lampsilis hydiana* | 9427 | 46 | 9381 | 0 |
| *Lampsilis siliquoidea* | 46443 | 883 | 10000 | 35560 |
| *Lampsilis teres* | 46317 | 382 | 10000 | 35935 |
| *Lasmigona complanata* | 46317 | 1075 | 10000 | 35242 |
| *Lasmigona compressa* | 43780 | 335 | 10000 | 33445 |
| *Lasmigona costata* | 43780 | 265 | 10000 | 33515 |
| *Leptodea fragilis* | 46443 | 705 | 10000 | 35738 |
| *Ligumia recta* | 43780 | 124 | 10000 | 33656 |
| *Ligumia subrostrata* | 45986 | 226 | 10000 | 35760 |
| *Megalonaias nervosa* | 46317 | 127 | 10000 | 36190 |
| *Obliquaria reflexa* | 46317 | 87 | 10000 | 36230 |
| *Obovaria olivaria* | 46317 | 10 | 10000 | 36307 |
| *Plethobasus cyphyus* | 43780 | 25 | 10000 | 33755 |
| *Pleurobema sintoxia* | 43780 | 348 | 10000 | 33432 |
| *Potamilus alatus* | 46317 | 260 | 10000 | 36057 |
| *Potamilus ohiensis* | 46317 | 335 | 10000 | 35982 |
| *Pyganodon grandis* | 46443 | 1212 | 10000 | 35231 |
| *Quadrula nodulata* | 46317 | 61 | 10000 | 36256 |
| *Quadrula pustulosa* | 46317 | 528 | 10000 | 35789 |
| *Quadrula quadrula* | 46317 | 568 | 10000 | 35749 |
| *Quadrula metanevra* | 43780 | 88 | 10000 | 33692 |
| *Simpsonaias ambigua* | 38578 | 15 | 10000 | 28563 |
| *Strophitus undulatus* | 46443 | 738 | 10000 | 35705 |
| *Toxolasma parvum* | 46443 | 657 | 10000 | 35786 |
| *Toxolasma texasiensis* | 9427 | 104 | 9323 | 0 |
| *Tritogonia verrucosa* | 46317 | 319 | 10000 | 35998 |
| *Truncilla donaciformis* | 46317 | 155 | 10000 | 36162 |
| *Truncilla truncata* | 46317 | 235 | 10000 | 36082 |
| *Uniomerus tetralasmus* | 41432 | 356 | 10000 | 31076 |
| *Utterbackia imbecillis* | 46317 | 316 | 10000 | 36001 |
| *Utterbackia suborbiculata* | 46317 | 45 | 10000 | 36272 |
| *Venustaconcha ellipsiformis* | 40904 | 318 | 10000 | 30586 |
| *Villosa iris* | 26054 | 46 | 10000 | 16008 |
| *Villosa lienosa* | 20673 | 18 | 10000 | 10655 |

Table 3.Model AUC –values, the number of occupied reaches observed or predicted, and the percent occupancy predicted (* = endangered or threatened in Illinois).

| Species | AUC | Observed | Predicted | Occupancy (%) |
|---|---|---|---|---|
| *Actinonaias ligamentina* | 0.97 | 319 | 2428 | 5.24 |
| *Alasmidonta marginata* | 0.97 | 328 | 1712 | 4.19 |
| *Alasmidonta viridis** | 0.97 | 236 | 3033 | 6.93 |
| *Amblema plicata* | 0.93 | 820 | 4345 | 9.38 |
| *Anodontoides ferussacianus* | 0.93 | 771 | 4533 | 10.40 |
| *Arcidens confragosus* | 0.98 | 116 | 1825 | 4.19 |
| *Cyclonaias tuberculata** | 0.99 | 102 | 1028 | 2.35 |
| *Elliptio dilatata** | 0.97 | 299 | 2624 | 5.65 |
| *Fusconaia ebena** | 0.98 | 20 | 3283 | 7.09 |
| *Fusconaia flava* | 0.94 | 768 | 3474 | 7.48 |
| *Lampsilis cardium* | 0.93 | 910 | 3921 | 8.47 |
| *Lampsilis hydiana* | 0.97 | 47 | 1024 | 10.86 |
| *Lampsilis siliquoidea* | 0.92 | 901 | 4507 | 9.70 |
| *Lampsilis teres* | 0.96 | 391 | 3617 | 7.81 |
| *Lasmigona complanata* | 0.91 | 1095 | 4827 | 10.42 |
| *Lasmigona compressa* | 0.96 | 338 | 3221 | 7.36 |
| *Lasmigona costata* | 0.98 | 279 | 1752 | 4.00 |
| *Leptodea fragilis* | 0.93 | 721 | 4583 | 9.87 |
| *Ligumia recta** | 0.99 | 135 | 988 | 2.26 |
| *Ligumia subrostrata* | 0.95 | 227 | 4624 | 10.06 |
| *Megalonaias nervosa* | 0.99 | 134 | 2168 | 4.68 |
| *Obliquaria reflexa* | 0.99 | 93 | 4185 | 9.04 |
| *Obovaria olivaria* | 0.96 | 12 | 4549 | 9.82 |
| *Plethobasus cyphyus** | 0.99 | 31 | 290 | 0.66 |
| *Pleurobema sintoxia* | 0.97 | 364 | 2132 | 4.87 |
| *Potamilus alatus* | 0.97 | 270 | 2959 | 6.39 |
| *Potamilus ohiensis* | 0.96 | 349 | 3962 | 8.55 |
| *Pyganodon grandis* | 0.88 | 1233 | 6597 | 14.20 |
| *Quadrula nodulata* | 0.99 | 66 | 1681 | 3.63 |
| *Quadrula pustulosa* | 0.95 | 547 | 3024 | 6.53 |
| *Quadrula quadrula* | 0.94 | 581 | 3729 | 8.05 |
| *Quadrula metanevra* | 0.99 | 97 | 801 | 1.83 |
| *Simpsonaias ambigua** | 0.99 | 18 | 458 | 1.19 |
| *Strophitus undulata* | 0.94 | 756 | 3678 | 7.92 |
| *Toxolasma parvum* | 0.90 | 669 | 7144 | 15.38 |
| *Toxolasma texasiensis* | 0.97 | 105 | 976 | 10.35 |
| *Tritogonia verrucosa* | 0.97 | 333 | 2648 | 5.72 |
| *Truncilla donaciformis* | 0.98 | 168 | 2044 | 4.41 |
| *Truncilla truncata* | 0.98 | 248 | 2536 | 5.48 |
| *Uniomerus tetralasmus* | 0.92 | 360 | 5630 | 13.59 |
| *Utterbackia imbecillis* | 0.94 | 329 | 4841 | 10.45 |
| *Utterbackia suborbiculata** | 0.97 | 47 | 4806 | 10.38 |
| *Venustaconcha ellipsiformis* | 0.97 | 329 | 4482 | 10.96 |
| *Villosa iris** | 0.99 | 52 | 1316 | 5.05 |
| *Villosa lienosa** | 0.99 | 23 | 1092 | 5.28 |

Table 4. Loss of species richness and occupancy in 18 recently-sampled sites and 17 historic sites, estimated based on Maxent-model predictions.

| | Species richness | | Number of reaches occupied | |
|---|---|---|---|---|
| | Recent sites | Historic sites | Recent sites | Historic sites |
| Mean | 11.8 | 6.5 | 5.07 | 3.13 |
| Median | 14.5 | 6.5 | 5 | 2 |
| Max | 21.0 | 16.0 | 13 | 10 |
| Min | -2.0 | -2.0 | -5 | -2 |
| Paired *T*-test | $p < 0.05$ | | $p < 0.01$ | |