Identifying Regional Priority Areas for Focusing Conservation Actions in Streams and Grasslands: Conservation Planning

Timothy D. Lambert,
Leon C. Hinz Jr.,
and Yong Cao

Illinois Natural History Survey
Prairie Research Institute
University of Illinois

31 August 2016

INHS Technical Report 2016 (31)
(Final Report for T-94-R-1)

Prepared for: Illinois Department of Natural Resources
Office of Resource Conservation
State Wildlife Grant Program

Unrestricted: for immediate online release.

Prairie Research Institute, University of Illinois at Urbana Champaign
Mark R. Ryan, Executive Director

Illinois Natural History Survey
Leellen F. Solter, Interim Director
1816 South Oak Street
Champaign, IL 61820
217-333-6830

Final Report

Project Title:

Identifying Regional Priority Areas for Focusing Conservation Actions in Streams and Grasslands:

Conservation Planning

Project Number:

T-94-R-1

Contractor information:

University of Illinois at Urbana/Champaign

Prairie Research Institute

Illinois Natural History Survey

1816 South Oak Street

Champaign, IL 61820

Principle Investigators:

Yong Cao, Ph.D.

yongcao@illinois.edu

Leon C. Hinz Jr., Ph.D.

leonhinz@illinois.edu

IDNR Project Manager:

Ann Marie Holtrop

Ann.Holtrop@illinois.gov

Prepared by:

Timothy D. Lambert, Leon C. Hinz Jr. and Yong Cao, INHS

EXECUTIVE SUMMARY

In the United States, many resources devoted to conservation are routed through states, but animal and plant populations do not conform to state boundaries. Consequently, neighboring states can enhance their collective conservation impact by coordinating natural resources management. In order to support managers as they review and revise state Wildlife Action Plans in Illinois, Indiana, Michigan, and Wisconsin, this project identified regional conservation priorities for streams and grasslands of the Upper Midwest. Specifically, we (1) selected stream and grassland species of common conservation interest to partnering states, (2) modeled and mapped regional distributions of these species, and (3) used predicted species occurrences to identify regional conservation focal areas.

We focused on 31 native grassland and stream species: eight birds, 10 freshwater mussels, 12 fish, and one salamander. The birds, mussels, salamander, and one fish were listed as Species of Greatest Conservation Need (SGCNs) by at least two participating states (Table 1). The remaining 11 fish were reproductive hosts for the selected freshwater mussels (Table 2). With the help of state Departments of Natural Resources, Natural Heritage programs, and other project partners (Table 3 and *Acknowledgments*), we compiled comprehensive occurrence data for all 31 species. We also downloaded environmental data for streams and grasslands across the Upper Midwest.

We used the assembled species and environmental data to develop regional distribution models for all selected aquatic species and five of the selected grassland birds. The most reliable models were obtained from species with widespread survey data (e.g., fish, birds), although some rare species remained data-limited. It was more difficult to model species with presence-only observations (i.e., no absences recorded; e.g., Mudpuppy) or with surveys whose design or data availability differed among states (e.g., mussels).

Predicted species distributions were used to identify regional focal areas for stream and grassland conservation. We used Marxan, a spatially explicit conservation planning software, to design reserve systems that most efficiently protect 10% of the regional populations of all selected SGCNs, which were mostly grassland birds and freshwater mussels. Marxan solutions that addressed these regional conservation priorities emphasized the importance of grassland protection in Illinois and Wisconsin and streams protection in Illinois, Indiana, and Michigan. Proposed focal areas often overlapped with Illinois and Wisconsin Conservation Opportunity Areas, Illinois State Acres For wildlife Enhancement (SAFE) Areas, and Chicago Wilderness's Green Infrastructure Vision, but this project also points out new areas where conservation initiatives are likely to be effective. Relative to prior efforts, this project's proposed grassland and stream reserve designs expand coverage to all of Illinois, Indiana, Michigan, and Wisconsin.

The regional conservation priority maps for streams and grasslands can be used by natural resource managers to ensure that individual state conservation strategies contribute meaningfully to regional goals. State managers can also take a species-specific approach, identifying likely population hotspots within their state by referring to the included high-resolution maps of predicted species distributions. Conservation focal areas spanning state borders highlight opportunities where neighboring states might cooperate to more effectively manage shared natural resources. In summary, by modeling the spatial distributions of selected stream and grassland species, this project provides a regional perspective for conservation in the Upper Midwest.

INTRODUCTION

Wildlife Action Plan Coordinators from Illinois, Indiana, Michigan, and Wisconsin jointly discussed the need for regional prioritization of conservation actions while reviewing and revising their state Wildlife Action Plans in 2013. These discussions resulted in the development of an agreement to work toward such regional prioritizations for grassland and stream systems. The project discussed in this report is part of this larger effort and builds upon work conducted under a separate grant (X-3-R-1) to the Illinois Department of Natural Resources from the Upper Midwest Great Lakes Landscape Conservation Cooperative (UMGL-LCC). The UMGL-LCC funded portion of the project allowed us to coordinate with our partners, assemble species location data and begin the development of the species distribution models. The second phase of the project was designed to complete the species distribution modeling and develop recommendations for regional conservation prioritization. These efforts were funded with an Illinois State Wildlife Grant (T-94-R-1). Activities undertaken under both phases of the project are reported in this document.

Tens of thousands of species location records have been accumulated from the study region in the past few decades from a variety of general and directed survey efforts. This point-based information provides extremely valuable data for prioritizing conservation efforts, however, it does not identify all locations that a species occupies, which are required for rigorous prioritization processes, such as Marxan. Species modeling is a practical and accepted avenue to estimate species distributions at relevant spatial scales. In this study, we first modeled the distributions of selected species of regional conservation interest at a fine spatial scale and then used these predictions as the key input for Marxan modeling to identify and rank individual spatial units for conservation priority.

JOB 1. REGIONAL SPECIES DISTRIBUTION MODELS

Job 1. Integrate regional species distribution models and associated data with regional geospatial databases for conservation planning and modeling.

With the assistance of our regional partners we will integrate information on existing state conservation priorities, COAs, and species distribution models developed from our companion project into our GIS infrastructure. These data will be used to inform the conservation planning in subsequent jobs.

Species selection

We used State Wildlife Action Plans to identify candidate species that were listed as Species of Greatest Conservation Need (SGCNs) by multiple partnering states. In consultation with taxonomic experts, we focused on species whose persistence was tied to the health of grassland and stream ecosystems. The candidate species included eight grassland birds (Bobolink, Dickcissel, Eastern Meadowlark, Grasshopper Sparrow, Henslow's Sparrow, Northern Harrier, Short-eared Owl, and Upland Sandpiper), ten freshwater mussels (Ellipse, Fat Pocketbook, Kidneyshell, Purple Lilliput, Purple Wartyback, Rainbow, Salamander Mussel, Sheepnose, Slippershell, and Snuffbox), one fish (Black Redhorse), and one salamander (Mudpuppy) (Table 1).

We also selected a number of the mussels' reproductive hosts for species distribution modeling. Using tables of mussel-host relationships compiled by INHS researchers (Douglass and Stodola 2014), we identified a dozen hosts that collectively represented an average of 62% of each candidate mussel's documented host species. The selected hosts included the Mudpuppy along with 11 non-threatened fish: Blackside Darter, Brook Stickleback, Channel Catfish, Freshwater Drum, Green Sunfish, Johnny Darter, Logperch, Longear Sunfish, Mottled Sculpin, Rainbow Darter, and Striped Shiner (Table 2).

Species data

Georeferenced data on species presence and abundance were contributed by state partners from across the study region (Table 3). These data included records from recent projects on Illinois mussels (Douglass and Stodola 2014) and fish (Metzke et al. 2012) as well as centralized data sources such as Natural Heritage databases, Herp Atlases, and museum collections.

For grassland birds, we downloaded point survey counts from the North American Breeding Bird Survey (BBS) (Pardieck et al. 2016). The BBS is carried out each June by skilled volunteer birders, who perform 3-minute roadside point counts at 50 stops evenly spaced along 24.5-mile routes. The study is long-term (1966-present) and large-scale (thousands of routes across the continent). Previous analysis of BBS data has provided considerable insight regarding temporal trends and spatial patterns of breeding bird populations (e.g., Sauer and Linke 2011). For this study of Upper Midwest grassland bird distributions, the BBS dataset was selected because it provided consistent methodology and ample coverage. In the four focal states, 336 routes were surveyed at least once between 2000 and 2014: 102 in Illinois, 56 in Indiana, 89 in Michigan, and 89 in Wisconsin. The prevalence of candidate species at survey stops averaged 13% but varied widely, ranging from 0.01% (Short-eared Owl) to 46% (Eastern Meadowlark) (Table 4).

For fish, quantitative survey data were contributed by the Illinois, Michigan, and Wisconsin Departments of Natural Resources and the Indiana Department of Environmental Management. Agencies used a variety of survey methods. We restricted our analyses to electrofishing, which included backpack electrofishing, boat (boom) electrofishing, longline electrofishing, electric seining, and electrofishing with a towed unit (e.g., stream shocker, tote barge, canoe, sport canoe). We aggregated data from all four states by consolidating survey data fields (e.g., method, effort, species) into a common format. In total, the assembled database included more than 28,000 electrofishing surveys for the period 1990-2014, with the majority (78%) coming from Wisconsin. There were >1000 surveys associated with every state (Table 5).

For freshwater mussels, we obtained quantitative survey data from the Illinois Natural History Survey and Indiana Department of Natural Resources and georeferenced occurrence records from the Illinois Natural Heritage Database, Michigan Natural Features Inventory, and Wisconsin Natural Heritage Program. Survey protocols differed among states. For example, Illinois, Indiana, and Michigan all used constant-effort surveys, but effort was defined by time (person-hours) in Illinois and Indiana and by area (m^2) in Michigan. Null records (i.e., species absences) were only available for Illinois and Indiana. To reduce geographic bias and other complications that occur when combining data sources and types, we reduced all information to a common format: presence-only records. All states contributed >100 unique freshwater mussel species records: Illinois (405), Indiana (495), Michigan (333), and Wisconsin (174) (Table 6).

Mudpuppy occurrence records were obtained from the Illinois Natural Heritage Database, Illinois State University, INHS Amphibian and Reptile Collection, Non-INHS Illinois Herp Database, Indiana DNR, Michigan Herp Atlas, Wisconsin Herp Atlas, and VertNet. A few records were attributed to local sampling that targeted Mudpuppies, but—in contrast to the other candidate taxa—there were no large-scale sampling efforts. Instead, most records represented incidental encounters that included bycatch from electrofishing and recreational angling. Of the four partner states, Michigan had by far the most Mudpuppy records, most of which were provided by the Michigan Herp Atlas (Table 6). All Mudpuppy data were obtained in the form of presence-only records.

Geographic and environmental data

This project focuses on grassland and stream fauna of four states: Illinois, Indiana, Michigan, and Wisconsin. To better understand conservation decisions made near state borders, we buffered this four-state region by 50 km for all environmental data acquisition. This expanded study area was maintained during the species distribution modeling and conservation planning phases of the project. Model predictions within this buffer were geographic extrapolations because no species data was collected here; however, we reasoned that the same species-environment relationships were likely to hold in both the core states and the buffer zone because the extrapolated buffer was relatively narrow and directly adjacent to the core states. Indeed, comparisons of species distribution maps between this project and other sources (e.g., grassland bird occurrence maps provided by eBird [www.ebird.org] and created May 6, 2016) indicated close concordance and no appreciable loss of prediction accuracy in the extrapolated buffer zone.

Grasslands

Previous modeling studies have identified a set of environmental factors that are closely tied to spatial variation in grassland bird abundance, including land cover attributes as well as annual and spring/summer climate normals (Thogmartin et al. 2006). We selected 19 environmental predictors that captured most of these important factors (Table 7). Fifteen of the selected predictors were land cover variables obtained from the 2011 National Land Cover Database (NLCD) at 30-m resolution (Homer et al. 2015), while the remaining four were 30-year (1981-2010) climate normals obtained from the PRISM Climate Group at 800-m resolution (PRISM Climate Group 2015).

Previous studies have evaluated spatial patterns in BBS counts at the resolution of 24.5-mile routes: counts were summed across each route's 50 stops and then regressed against route-scale environmental variables (e.g., Thogmartin et al., 2006). We opted to attempt a finer scale resolution by using the full 50-stop point count data. The resulting higher resolution species distribution and conservation planning maps promise to be both extensive enough to guide regional prioritizations and detailed enough to help initiate local conservation action. Although the BBS does not currently provide the locations of individual survey stops, route shapefiles (directional vectors) are available. From these shapefiles we interpolated the locations of each route's ordered stops by placing 50 equidistant points along it. This procedure was unreliable for a few routes that had multiple shapefile arcs or non-standard lengths; these non-standard routes, which comprised <5% of all routes, were dropped from the dataset. Efforts by the BBS to expand the set of survey stops with published GPS coordinates would facilitate future spatial data analyses.

In order to assign values of environmental variables to each point count location, we used ArcGIS software to calculate the percent land cover and area-weighted average climate across a region surrounding the survey stop. We defined this surrounding area in two ways. First, to help determine the optimal spatial resolution for species distribution models, we used circular buffers. We tested 8 different spatial scales, with buffer radii increasing logarithmically (by a factor of 2) from 100 m to 12.8 km. Preliminary models of avian abundance (random-forests regression, Breiman 2001) indicated that a radius of 800 m was close to optimal for all species.

Calculating environmental predictors for circular buffers centered about point locations was spatially accurate but computationally expensive; it was possible to do this for the 16,800 BBS survey stops, but expanding to include a fine-scale grid of points across the entire study region would have been computationally prohibitive. Therefore for the final predictive models we instead opted for a raster-based approach. We chose a 1600 x 1600-m resolution for several reasons: cells were similar in size to the optimal circular buffers that had radii of 800 m; the resulting grid of 257,865 cells was computationally manageable given the available software computing power; and the resolution was appropriate for regional management prioritizations. Environmental predictors were calculated for each cell, and BBS stops were assigned the predictor values of the cell in which they were located.

Streams

We used confluence-to-confluence stream reaches defined by the National Hydrography Dataset (NHDPlusV1) as the spatial resolution for aquatic modeling because they have been associated with large numbers of environmental variables across the study region. We concentrated on human disturbance indices available from the National Fish Habitat Partnership (http://ecosystems.usgs.gov/fishhabitat/nfhap_download.jsp) and natural watershed characteristics (e.g., geology, climate, topography, stream size, and land cover) available from the National Hydrography Dataset (NHDPlusV1). From these compiled data sources, we identified a total of 81 candidate environmental variables (Table 8). We eliminated 17 of these variables because they exhibited little variation across the study region, with their modes comprising >95% of stream reaches. To reduce collinearity among the remaining 64 variables, we performed hierarchical agglomerative clustering (Fig. 1). From each cluster—defined such that within-group Pearson's r was >0.7 (Dormann et al. 2013)—we selected a single variable, arriving at a final list of 42 reach-scale predictors.

Species distribution models

Using the assembled species and environmental data, we modeled and mapped regional species distributions across the Upper Midwest. The modeling method varied according to the types of data available. For species that had associated survey data (birds and fish), we used random forests classification to model presence/absence and random forests regression to model relative abundance. Random forests, a machine learning method, performs exceptionally well on complex datasets with many predictor variables and a measured categorical or quantitative response (Breiman 2001). However, freshwater mussels and the Mudpuppy could not be modeled in the same way because our collected data on these species was in the form of presence-only records; they lacked region-wide survey data (i.e., a multi-valued response variable). For these species, we used another machine learning technique, the maximum entropy method (Maxent). Maxent's superior discrimination of species ranges when no species absence information is available have contributed to its popularity as a modeling approach for presence-only data (Phillips et al. 2006).

Both modeling methods were implemented using the statistical software R (version 3.0.3; R Core Team 2014). For Maxent we used R package *dismo* (version 1.0-12; Hijmans et al. 2015), and for random forests regression, *randomForest* (version 4.6-10; Liaw and Wiener 2002). We used *maptools* (version 0.8-34; Bivand and Lewin-Koh 2015), *rgdal* (version 0.9-2; Bivand et al. 2015), and *sp* (version 1.0-17; Pebesma et al. 2005, Bivand et al. 2013) to handle spatial data and generate maps.

Grasslands

For each BBS survey stop in the study region, all point counts from 2000-2014 were averaged to obtain a single location-specific species count. Within this 15-year time window, 76% of routes had ten or more surveys, and <10% of routes had fewer than five surveys. These time-averaged counts were then square root transformed and regressed against the 19 land-cover and climate predictors. The non-independence of survey stops within a route violates the assumptions of classical statistical methods, but random forests performs reliably even when such spatial autocorrelation occurs (Evans et al. 2011).

We completed species distribution models for five grassland bird species: Upland Sandpiper, Bobolink, Eastern Meadowlark, Grasshopper Sparrow, and Dickcissel. For these species, random forests regression pseudo-R^2 values ranged from 0.16 to 0.51 (Table 9). We did not produce models for Northern Harrier, Short-eared Owl, or Henslow's Sparrow because of insufficient data (<50 detections) or poor model performance (pseudo-R^2 < 0.12). Further analysis of Northern Harrier and Short-eared Owl that are winter or year-round residents across much of the study region by including non-BBS data—e.g., from Natural Heritage programs and eBird—could improve model performance for these species.

For each of the five modeled species, we mapped predicted relative abundance across the study region at 1600x1600-m resolution (Fig. 2a-e).

Streams

The 12 candidate fish species were modeled using random forests classification and regression. With ArcGIS, each survey was linked to its closest NHDPlusV1 stream reach and its associated set of environmental variables. Species presence/absence and counts were then modeled using the selected set of 42 environmental predictors. We also added a 43rd predictor—the survey's day of the year—in order to account for seasonality. To isolate the geographic variation in species counts that was of interest to spatial conservation planning, temporal variability was eliminated by normalizing all predictions of fish presence and relative abundance to the summer solstice (172nd day of the year), a time when fish surveys are common and many of the selected mussel species release larvae. Prior to analysis, species counts were log transformed. Across the 12 species, error rates of classification models for out-of-bag sites (not used for model calibration) averaged 0.10 (range 0.02-0.20) while pseudo-R^2 values for regression models averaged 0.48 (range 0.32-0.72) (Table 10).

Freshwater mussels and the Mudpuppy were modeled based on presence-only records. Species records with point location information were snapped to their nearest stream reach in a Geographic Information System (GIS). When two or more reaches occurred within 100 m of a location, we manually assigned the record to the most likely reach—usually the larger of the two unless contradicted by the record's metadata.

Many freshwater mussel records of occurrence from state Natural Heritage programs documented the estimated areal extent of a population. In addition, most Mudpuppy records we obtained had been generalized to square mile blocks. Assigning a species presence to all stream reaches falling within these documented areas would inflate the importance of that record and possibly also introduce false presences. Omitting areal records was not an option because point records alone did not provide sufficient regional data coverage or density. Hence we opted to assign each areal record to the largest stream reach falling entirely or partially within the documented area, a process which we deemed least likely to introduce false occurrences. In total, we assembled 1675 unique reach-scale records for the ten freshwater mussel and one salamander species (Table 6). The number of unique reaches in which species were recorded ranged from 23 (Fat Pocketbook) to 283 (Slippershell).

We used Maxent to generate species distribution models for the ten freshwater mussels and the Mudpuppy. Ten thousand reaches from across the study region were randomly selected for the background dataset. Model AUC values ranged from 0.967 to 0.998 (Table 6). Based on a threshold of equal sensitivity and specificity, recommended by Cao et al. 2013, we used the Maxent models to predict species presence/absence in all of the study region's 185,364 stream reaches. To facilitate visualization of species distributions, we aggregated reach-scale presence/absence predictions to obtain species prevalence (i.e., the proportion of occupied reaches) within the study region's 7920 12-digit Hydrologic Units. We used these aggregated HUC12-scale predictions to construct distribution maps for each of the 23 aquatic species: 12 fish, 10 freshwater mussels, and one salamander (Figure 3a-w).

Job 2. Identify at least two regional conservation focal areas for grasslands and two for streams using the identified conservation priorities, including selected species distribution models, with a Marxan modeling approach.

In an effort to identify regional conservation focal areas for grasslands and streams, we used the predicted species distributions developed in Job 1 as inputs to Marxan software (Ball et al. 2009, Watts et al. 2009). At its core, Marxan is an optimization algorithm designed to solve a minimum set problem: Given a list of conservation targets, what is the least costly reserve network (i.e., the minimum set of planning units) that can adequately protect them? The software produces conservation areas by optimizing the aggregation of individual planning units to meet the desired conservation targets. It is flexible enough to allow the user to enforce including planning units within existing protected areas, minimize fragmentation of planning units, or include a cost for each planning unit that can be minimized (e.g., cost of purchasing the land or obtaining an easement).

Grasslands

We set conservation targets for each of the five modeled grassland bird species at 10% of the regional breeding populations (Table 11). Ten percent was chosen primarily because this value yielded regional reserve solutions of a reasonable size—large enough to expand beyond existing protected areas yet small enough to effectively focus conservation efforts. Future studies could benefit from identifying whether protecting 10% of regional populations is a biologically desirable target, and whether this target should vary by species. Relative population size was approximated as the product of land area and predicted survey counts. The regional extent of the species distribution models—i.e., all of Illinois, Indiana, Michigan, and Wisconsin, plus a 50-km buffer—determined the geographic domain of the Marxan analysis. To maximize spatial resolution, we defined each 1600x1600-m grid cell (the resolution of the species distribution models) as a separate planning unit. All planning units were assigned the same cost.

To reduce the fragmentation of reserve solutions, we utilized Marxan's boundary functionality. This feature allows a penalty to be assigned to the boundaries between pairs of planning units, and these penalties are incurred if the proposed reserve solution includes one of the planning units but not the other. Usually a planning unit's boundary penalty is defined to be directly proportional to its edge length. However, when using a grid of square planning units, setting boundary penalties equal to edge length favors rectangular Marxan reserve solutions. This geometric bias occurs because reserve edges oriented at (90k)°, where k is any integer, align with the planning units and incur the lowest cost per straight-edge length (i.e., length as measured in a straight line and not along the contour of planning unit boundaries). Some conservation projects have used hexagonal planning units to reduce this problem (e.g., Becker et al. 2010). We devised an alternative solution that retained the square planning unit grid but weighted boundaries such that reserve edges at (90k)° and (90k + 45)° both cost the same per unit length. The final solution assigned boundary penalties to a planning unit's adjacent cells (i.e., those sharing an edge) as well as cells diagonal to it (i.e., those sharing a vertex but no edges), with adjacent cells weighted $\frac{7}{-2+3\sqrt{2}} = 3.12$ times more heavily than diagonal cells. This adjustment significantly reduced the orientation bias of Marxan reserve solutions. To prevent bias for or against cells on the edge of the modeled extent, we followed the recommendations of Game and Grantham (2008) and defined missing bordering cells to incur an irremovable penalty equal to half the usual boundary penalty.

Marxan uses simulated annealing, an optimization algorithm that starts with a random selection of planning units and goes through a number of iterations, removing and replacing planning units to arrive at an optimal solution. Any given Marxan solution will be different than a previous solution because of different random starting points. We used 100 Marxan runs for each of the analyses we conducted and summed the number of times a given planning unit was part of a solution, yielding a measure of its irreplaceability.

Conservation planners often improve the efficiency of reserve additions by strategically building upon the network of existing protected areas. Correspondingly, we included a Marxan analysis that locked existing reserves into its solution (Fig. 4a). We used protected areas listed by the U.S. Protected Areas Database (PAD-US; U.S. Geological Survey 2012), restricted to lands categorized as GAP Statuses 1-3 (i.e., not GAP Status 4 – "no known mandate for protection"). A planning unit was considered protected if its centroid fell within a protected area; this resolution adequately represented regional patterns, but fine-scale reserve geometries should be considered prior to local land acquisition. In the grasslands Marxan analysis that locked PAD-US reserves into the solution's reserve system (Fig. 4a), unprotected planning units that were surrounded by protected areas incurred an especially large boundary penalty and were therefore included in the solution even if they did not contribute substantially to meeting the grassland bird conservation targets. This effect is especially apparent in northern Michigan and Wisconsin. To help bring focus to most important grassland areas, we also produced a separate analysis that did not lock in existing protected areas (Fig. 4b). The results of these two Marxan analyses complement one another, allowing managers to identify key grassland bird conservation opportunity areas and how best to link these areas with existing protected areas.

Based on the Marxan analysis (Fig. 4b), we identified two key regional conservation focal areas for grasslands:

1. **Southern Illinois**: A large swath of southern Illinois in the vicinity of Carlyle Lake is home to major regional populations of Eastern Meadowlark, Grasshopper Sparrow, and Dickcissel.
2. **Southwestern Wisconsin**: Parts of southwestern Wisconsin and nearby lands in Illinois and Iowa host regionally significant populations of Upland Sandpiper and Eastern Meadowlark as well as moderate populations of the other three modeled grassland birds.

We also defined two focal areas that were smaller in extent:

3. **Central Wisconsin**: Central Wisconsin contains excellent habitat for Bobolink and also hosts moderate numbers of Eastern Meadowlark.
4. **Door Peninsula**: The Door Peninsula, Wisconsin, separates Green Bay from Lake Michigan. Like the Central Wisconsin focal area, the Door Peninsula focal area hosts strong populations of Bobolink and moderate numbers of Eastern Meadowlark.

In addition, smaller priority areas were located in northeastern Michigan (for Bobolink, Upland Sandpiper, and Grasshopper Sparrow), central Illinois (for Eastern Meadowlark, Dickcissel, and Upland Sandpiper), and southern Indiana (for Eastern Meadowlark, Grasshopper Sparrow, and Dickcissel).

Streams

For the streams component, we focused on 12 of the candidate aquatic species: Black Redhorse, Mudpuppy, and the 10 freshwater mussels. We did not include 11 non-threatened fish that acted as the mussels' reproductive hosts because all were common and it was difficult to determine whether the spatial extent of their populations actually limited mussel reproduction. Using the output from species distribution models, we measured a species' regional population extent in terms of the length of streams in which it was predicted to be present. We set each species' conservation target at 10% of its predicted regional population, bounded between 500 and 2000 kilometers (Table 12).

Because stream physical and biological conditions are highly dependent upon the condition of tributaries and upstream watersheds, basin-wide initiatives are critical to freshwater conservation. Therefore, to identify connected regional freshwater conservation areas, we defined planning units to be subbasins (8-digit Hydrologic Units—HUC8s—defined by the USGS). Because by design these planning units are inherently large and connected, we did not include boundary penalties. If future studies wish to differentiate conservation priorities at the finer scale of watersheds (HUC10s), subwatershed (HUC12s), or stream reaches, they should consider manipulating Marxan's boundary penalty to ensure longitudinal freshwater connectivity (see Hermoso et al. 2011, 2012).

The HUC8-scale stream conservation priorities generated using Marxan revealed four key regional conservation focal areas for streams (Fig. 5):

1. **Wabash**: Centered about southeastern Illinois and southwestern Indiana, the core contains three HUC-8 watersheds: the Lower Wabash (irreplaceability score of 100), Highland-Pigeon (99), and Lower White (80). Peripheral watersheds include the Middle Wabash-Busseron (44) and Lower Ohio-Little Pigeon (39).
2. **Tippecanoe**: Includes the Tippecanoe (94) and Middle Wabash-Deer (70) watersheds of Indiana.
3. **Upper Illinois**: The Upper Illinois (84) and Lower Fox (56) watersheds of Illinois.
4. **Flotrack-Haw**: The Flotrack-Haw (66) watershed of Indiana.

In addition, two Michigan focal areas contained at least one watershed with an irreplaceability score ≥49:

5. **Pine**: The Pine (56) watershed.
6. **Huron**: Huron (49) and Detroit (20) watersheds.

Job 3. Assess current status of Conservation Opportunity Areas at conserving grassland and stream SGNC regionally and identify where gaps exist.

Currently Illinois and Wisconsin have designated Conservation Opportunity Areas within their State Action Plans although Indiana and Michigan do not. Regionally, Chicago Wilderness has a Green Infrastructure Plan that covers portions of each of the four states. In order to assess the efficacy of existing COA and Green Infrastructure plans at conserving project SGCNs in grassland and streams, we compared these conservation planning areas with the conservation focal areas identified in Job 2. The focal areas defined here overlap significantly with existing Conservation Opportunity Areas but also suggest additional areas where stream and grassland conservation efforts might be most effectively targeted.

Illinois: Illinois' Prairie Ridge Landscape COA and the proposed Southern Till Plains Grassland SAFE Areas in Illinois overlap significantly with the eastern portion of this project's Southern Illinois grassland focal area, and Grand Prairie SAFE Areas are often included among the smaller scattered priority areas where Marxan identified high grassland conservation irreplaceability. However, areas west of Carlyle Lake, which comprise the substantial western wing of this project's Southern Illinois grassland focal area, are not currently identified as high priority conservation areas. For streams, this project's Wabash focal area largely corresponds to the Wabash COA, indicating additional support for the conservation importance of this watershed. This project's Upper Illinois focal area is partly encompassed by the Lower Fox COA.

Indiana: Indiana appears to have rich potential for conservation of freshwater mussels, as indicated by this project's Wabash, Tippecanoe, and Flotrack-Haw focal areas. These focal areas may help state managers to formulate an official Conservation Opportunity Area map. Although this project did not identify any large regional focal areas for the selected grassland species in Indiana, the state does contain a few localized grassland areas that could contribute to regional conservation goals.

Michigan: This project identified regional focal areas for streams in central (Pine focal area) and southeastern (Huron focal area) Michigan along with several localized grassland priority areas in northeastern Michigan.

Wisconsin: This project's grassland focal areas in Wisconsin do not clearly match up with the state's existing Conservation Opportunity Areas. Hence the proposed Door Peninsula and Southwestern and Central Wisconsin focal areas might be important additions to the state's existing conservation priorities. This project did not identify any stream conservation focal areas in Wisconsin that contributed substantially to meeting regional goals for the selected freshwater mussels.

The focal areas for streams and grasslands defined in this project can help Illinois and Wisconsin to refine their COAs and allow Michigan and Indiana to define them. The regional analyses also provide an opportunity for all partnering states to consider how COAs or focal areas align across state boundaries. To facilitate this process, electronic ArcGIS shapefiles of predicted species distributions and Marxan reserve solutions have been submitted to Illinois DNR for distribution to project partners and conservation managers.

JOB 4. FINAL REPORT AND MAPS

Job 4. Complete final report and provide species distribution and conservation focal area maps to partner states for inclusion into revised State Wildlife Action Plans.

We completed this final report and the maps contained within it. In addition, for both grassland and aquatic project components, we have prepared geospatial files for distribution to partner states. These files include the full results of species distribution models and landscape conservation planning.

ACKNOWLEDGEMENTS

Funding: This work is funded by the Illinois Department of Natural Resources (State Wildlife Grant T-94-R-1) and the Upper Midwest and Great Lakes Landscape Conservation Cooperative (X-3-R-1).

People: Specifically, we gratefully acknowledge the assistance provided by Peter Badra, T.J. Benson, Tara Bergeson, Julie Bleser, Angelo Capparella, Arthur Cooper, Amy Derosier, Sarah Douglass, Brant Fisher, Ann Holtrop, Terrell Hyde, Julie Kempf, Tara Kieninger, LisieKitchel, Shari Koslowski, John Lyons, Brian Metzke, David Mifsud, Chris Phillips, Lori Sargent, Edward Schools, Stacey Sobat, Alison Stodola, Chris Taylor, Jodi Vandermyde, Kevin Wehrly, Phil Willink, and Amanda Wuestefeld.

REFERENCES

Ball, I.R., H.P. Possingham, and M. Watts. 2009. Marxan and relatives: Software for spatial conservation prioritization. Chapter 14: Pages 185-195 in Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press, Oxford, UK.

Becker, C. G., R. D. Loyola, C. F. B. Haddad, and K. R. Zamudio. 2010. Integrating species life-history traits and patterns of deforestation in amphibian conservation planning. Diversity and Distributions 16:10–19.

Bivand, R., and N. Lewin-Koh. 2015. maptools: Tools for Reading and Handling Spatial Objects. R package version 0.8-34. http://CRAN.R-project.org/package=maptools

Bivand, R., T. Keitt and B. Rowlingson. 2015. rgdal: Bindings for the Geospatial Data Abstraction Library. R package version 0.9-2. http://CRAN.R-project.org/package=rgdal

Bivand, R.S., E. Pebesma and V. Gomez-Rubio, 2013. Applied spatial data analysis with R, Second edition. Springer, NY. http://www.asdar-book.org/

Breiman, L. 2001. Random Forests. *Machine Learning*, *45*, 5–32.

Cao, Y., R.E DeWalt, J.L Robinson, T. Tweddale, L. Hinz, M. Pessino. 2013. Using Maxent to model the historic distributions of stonefly species in Illinois streams: the effects of regularization and threshold selections. Ecological Modelling 259, 30-39

Dormann, C. F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J. R. G. Marquéz, B. Gruber, B. Lafourcade, P. J. Leitão, T. Münkemüller, C. Mcclean, P. E. Osborne, B. Reineking, B. Schröder, A. K. Skidmore, D. Zurell, and S. Lautenbach. 2013. Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. Ecography 36:027–046.

Douglass, S.A. and A.P. Stodola. 2014. Status revision and update for Illinois' freshwater mussel Species in Greatest Need of Conservation. Illinois Natural History Survey Technical Report 2014 (47). 156 pp.

DeWalt, R.E., Y. Cao, L. Hinz and T. Tweddale. 2009. Modelling of historical stonefly distributions using museum specimens. Aquatic Insects 31(suppl. 1): 253-267.

Esselman, P.C., D. M. Infante, L. Wang, D. Wu, A.R. Cooper and W.W. Taylor. 2011. An Index of Cumulative Disturbance to River Fish Habitats of the Conterminous United States from Landscape Anthropogenic Activities. Ecological Restoration 29: 133-151.

Evans, J. S., M. A. Murphy, Z. A. Holden, and S. A. Cushman. 2011. Modeling Species Distribution and Change Using Random Forest. Pages 139–159 *in* C. A. Drew, Y. F. Wiersma, and F. Huettmann (editors). Predictive Species and Habitat Modeling in Landscape Ecology: Concepts and Applications. Springer.

Game, E. T. and H. S. Grantham. 2008. Marxan User Manual: For Marxan version 1.8.10. University of Queensland, St. Lucia, Queensland, Australia, and Pacific Marine Analysis and Research Association, Vancouver, British Columbia, Canada.

Hermoso, V., S. Linke, J. Prenda, and H. P. Possingham. 2011. Addressing longitudinal connectivity in the systematic conservation planning of fresh waters. Freshwater Biology 56:57–70.

Hermoso, V., M. J. Kennard, and S. Linke. 2012. Integrating multidirectional connectivity requirements in systematic conservation planning for freshwater systems. Diversity and Distributions 18:448–458.

Hijmans, R.J., S. Phillips, J. Leathwick and J. Elith. 2015. dismo: Species Distribution Modeling. R package version 1.0-12. http://CRAN.R-project.org/package=dismo

Homer, C.G., Dewitz, J.A., Yang, L., Jin, S., Danielson, P., Xian, G., Coulston, J., Herold, N.D., Wickham, J.D., and Megown, K., 2015, Completion of the 2011 National Land Cover Database for the conterminous United States-Representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing*, v. 81, no. 5, p. 345-354.

Liaw, A. and M. Wiener. 2002. Classification and Regression by randomForest. R News 2(3), 18-22.

Metzke, B.A., L.C. Hinz Jr. and A.C. Hulin. 2012. Status revision and Update for Illinois' Fish Species in Greatest Need of Conservation. Illinois Natural History Survey Technical Report 2012 (9). 179 pp.

Pardieck, K.L., D.J. Ziolkowski Jr., M.-A.R. Hudson, and K. Campbell. 2016. North American Breeding Bird Survey Dataset 1966 - 2015, version 2015.0. U.S. Geological Survey, Patuxent Wildlife Research Center. <www.pwrc.usgs.gov/BBS/RawData/>; doi:10.5066/F71R6NK8.

Pebesma, E.J., and R.S. Bivand. 2005. Classes and methods for spatial data in R. R News 5 (2), http://cran.r-project.org/doc/Rnews/.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modeling **190**:231-259.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 1 Mar 2016.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Sauer, J. R., and W. A. Link. 2011. Analysis of the North American Breeding Bird Survey Using Hierarchical Models. The Auk 128(1):87–98.

Thogmartin, W. E., M. G. Knutson, and J. R. Sauer. 2006. Predicting regional abundance of rare grassland birds with a hierarchical spatial count model. The Condor 108:25–46.

U.S. Geological Survey, Gap Analysis Program (GAP). November 2012. Protected Areas Database of the United States (PAD-US), version 1.3 Combined Feature Class.

Watts, M.E, I.R. Ball, R.R. Stewart, C.J. Klein, K. Wilson, C. Steinback, R. Lourival, L. Kircher, and H.P. Possingham. 2009. Marxan with Zones: software for optimal conservation based land- and sea-use zoning, Environmental Modelling & Software (2009), doi:10.1016/j.envsoft.2009.06.005.

Table 1. Candidate Focal Species. Candidate Focal Species and their state conservation statuses: Species of Greatest Conservation need (SGCN), State Threatened (ST), and State Endangered (SE). All ST and SE species are also SGCN.

Common name	Scientific name	Status			
		IL	IN	MI	WI
Birds					
Bobolink	*Dolichonyx oryzivorus*	SGCN		SGCN	SGCN
Dickcissel	*Spiza americana*	SGCN		SGCN	SGCN
Eastern Meadowlark	*Sturnella magna*			SGCN	SGCN
Grasshopper Sparrow	*Ammodramus savannarum*	SGCN		SGCN	SGCN
Henslow's Sparrow	*Ammodramus henslowii*	ST	SE	SE	ST
Northern Harrier	*Circus cyaneus*	SE	SE	SGCN	SGCN
Short-eared Owl	*Asio flammeus*	SE	SE	SE	SGCN
Upland Sandpiper	*Bartramia longicauda*	SE	SE	SGCN	ST
Fish					
Black Redhorse	*Moxostoma duquesnei*	SGCN		SGCN	SE
Freshwater mussels					
Ellipse	*Venustaconcha ellipsiformis*	SGCN	SGCN	SGCN	ST
Fat Pocketbook	*Potamilus capax*	SE	SE		SGCN
Kidneyshell	*Ptychobranchus fasciolaris*	SE	SGCN	SGCN	
Purple Lilliput	*Toxolasma lividus*	SE	SGCN	SE	
Purple Wartyback	*Cyclonaias tuberculata*	SE		ST	SE
Rainbow	*Villosa iris*	SE		SGCN	SE
Salamander Mussel	*Simpsonaias ambigua*	SE	SGCN	SE	ST
Sheepnose	*Plethobasus cyphyus*	SE	SE		SE
Slippershell	*Alasmidonta viridis*	SGCN		ST	ST
Snuffbox	*Epioblasma triquetra*	SE	SE	SE	SE
Salamanders					
Mudpuppy	*Necturus maculosus*	SGCN	SGCN	SGCN	SGCN

Table 2. Mussel-host relationships. Fish and salamander species that serve as reproductive hosts for one or more of the ten focal freshwater mussels. Check marks indicate a documented mussel-host relationship (Douglass and Stodola 2014).

			Mussel Species										
	Scientific name	**Common name**	*Alasmidonta viridis*	*Cyclonaias tuberculata*	*Epioblasma triquetra*	*Plethobasus cyphyus*	*Potamilus capax*	*Ptychobranchus fasciolaris*	*Simpsonaias ambigua*	*Toxolasma lividum*	*Venustaconcha ellipsiformis*	*Villosa iris*	Number of mussels hosted
Fish													
	Aplodinotus grunniens	Freshwater Drum					✓						1
	Cottus bairdi	Mottled Sculpin	✓-		✓						✓	✓	4
	Culaea inconstans	Brook Stickleback						✓			✓		2
	Etheostoma caeruleum	Rainbow Darter						✓			✓	✓	3
	Etheostoma nigrum	Johnny Darter	✓-								✓		2
	Ictalurus punctatus	Channel Catfish		✓									1
	Lepomis cyanellus	Green Sunfish								✓		✓	2
	Lepomis megalotis	Longear Sunfish								✓			1
	Luxilus chrysocephalus	Striped Shiner				✓						✓	2
	Percina caprodes	Logperch			✓						✓		2
	Percina maculata	Blackside Darter			✓						✓		2
Salamander													
	Necturus maculosus	Mudpuppy							✓				1
	# of modeled hosts		2	1	3	1	1	2	1	2	6	4	
	Total # listed hosts		3	4	6	27	1	3	1	2	13	7	

Table 3. Project partners and data contributors.

Project partners and data contributors
Species data
Illinois Department of Natural Resources
Illinois Natural Heritage Database
Illinois Natural History Survey
INHS Amphibian and Reptile Collection
Non-INHS Illinois Herp Database
Indiana Department of Environmental Management
Indiana Department of Natural Resources
Michigan Department of Natural Resources
Michigan Herp Atlas
Michigan Natural Features Inventory
North American Breeding Bird Survey (BBS)
Wisconsin Department of Natural Resources
Wisconsin Natural Heritage Program
Wisconsin Herp Atlas
Environmental data
National Fish Habitat Partnership
National Land Cover Dataset (NLCD)
National Hydrography Dataset (NHDPlusV1)
PRISM Climate Group, Oregon State University
U.S. Geological Survey

Table 4. Grassland bird data used for modeling. Number of survey stops where species were detected at least once during the BBS surveys 2000-2014. Prevalence was calculated as the proportion of stops with at least one detection during this time period.

Common name	Scientific name	Illinois		Indiana		Michigan		Wisconsin		All states	
		# stops	Prevalence	# stops	Prevalence	# stops	Prevalence	# stops	Prevalence	# stops	Prevalence
Bobolink	*Dolichonyx oryzivorus*	181	3.5%	164	5.9%	546	12.3%	1365	30.7%	2256	13.4%
Dickcissel	*Spiza americana*	3200	62.7%	736	26.3%	62	1.4%	856	19.2%	4854	28.9%
Eastern Meadowlark	*Sturnella magna*	3696	72.5%	1632	58.3%	825	18.5%	1640	36.9%	7793	46.4%
Grasshopper Sparrow	*Ammodramus savannarum*	768	15.1%	344	12.3%	147	3.3%	207	4.7%	1466	8.7%
Henslow's Sparrow	*Ammodramus henslowii*	30	0.6%	47	1.7%	22	0.5%	68	1.5%	167	1.0%
Northern Harrier	*Circus cyaneus*	42	0.8%	15	0.5%	79	1.8%	291	6.5%	427	2.5%
Short-eared Owl	*Asio flammeus*	0	0.0%	0	0.0%	1	0.0%	1	0.0%	2	0.0%
Upland Sandpiper	*Bartramia longicauda*	90	1.8%	13	0.5%	96	2.2%	119	2.7%	318	1.9%
All surveys		5100		2800		4450		4450		16800	

Table 5. Fish data used for modeling. Number of survey events in which a species was detected. Prevalence was calculated as the proportion of surveys in which the species was detected.

Common name	Scientific name	Illinois		Indiana		Michigan		Wisconsin		All states	
		# records	Prevalence	# records	Prevalence	# records	Prevalence	# records	Prevalence	# records	Prevalence
Black Redhorse	*Moxostoma duquesnei*	269	8%	288	17%	13	1%	9	0%	579	2%
Blackside Darter	*Percina maculata*	558	16%	184	11%	234	21%	1924	9%	2900	10%
Brook Stickleback	*Culea inconstans*	19	1%	5	0%	146	13%	5257	24%	5427	19%
Channel Catfish	*Ictaluris punctatus*	1347	39%	240	14%	35	3%	1176	5%	2798	10%
Freshwater Drum	*Aplodinotus grunniens*	986	29%	154	9%	21	2%	974	4%	2135	8%
Green Sunfish	*Lepomis cyanellus*	2164	63%	1205	69%	334	30%	2879	13%	6582	23%
Johnny Darter	*Etheostoma nigrum*	1278	37%	951	55%	446	40%	6272	29%	8947	32%
Logperch	*Percina caprodes*	299	9%	264	15%	101	9%	1318	6%	1982	7%
Longear Sunfish	*Lepomis megalotus*	1325	39%	834	48%	33	3%	74	0%	2266	8%
Mottled Sculpin	*Cottus bairdi*	35	1%	345	20%	330	29%	4099	19%	4809	17%
Rainbow Darter	*Etheostoma caeruleum*	222	6%	478	27%	180	16%	638	3%	1518	5%
Striped Shiner	*Luxilus chrysocephalus*	967	28%	639	37%	17	2%	2	0%	1625	6%
All surveys		3421		1741		1122		21774		28058	

Table 6. Species records and model performance for freshwater mussels and Mudpuppy. The number of unique stream reaches in which each freshwater mussel and salamander species was detected. Maxent's Area Under the Curve (AUC) values ranged from 0.967 to 0.998.

Scientific name	Common name	# records					Maxent
		IL	IN	MI	WI	All states	AUC
Alasmidonta viridis	Slippershell	104	49	97	33	283	0.967
Cyclonaias tuberculata	Purple Wartyback	59	108	36	20	223	0.985
Epioblasma triquetra	Snuffbox	7	5	31	7	50	0.990
Plethobasus cyphyus	Sheepnose	8	28	0	8	44	0.996
Potamilus capax	Fat Pocketbook	6	17	0	0	23	0.998
Ptychobranchus fasciolaris	Kidneyshell	12	102	20	0	134	0.990
Simpsonaias ambigua	Salamander Mussel	9	11	3	53	76	0.991
Toxolasma lividus	Purple Lilliput	20	34	3	0	57	0.995
Venustaconcha ellipsiformis	Ellipse	164	36	43	39	282	0.974
Villosa iris	Rainbow	16	105	100	14	235	0.980
Necturus maculosus	Mudpuppy	24	15	218	11	268	0.969

Table 7. Predictors included in the modeling of grassland birds.

Variable name	**Description**
VALUE_11_perc	Percent open water
VALUE_21_perc	Percent developed, open space
VALUE_22_perc	Percent developed, low intensity
VALUE_23_perc	Percent developed, medium intensity
VALUE_24_perc	Percent developed, high intensity
VALUE_31_perc	Percent barren land (rock/sand/clay)
VALUE_41_perc	Percent deciduous forest
VALUE_42_perc	Percent evergreen forest
VALUE_43_perc	Percent fixed forest
VALUE_52_perc	Percent shrub/scrub
VALUE_71_perc	Percent grassland/herbaceous
VALUE_81_perc	Percent pasture/hay
VALUE_82_perc	Percent cultivated crops
VALUE_90_perc	Percent woody wetlands
VALUE_95_perc	Percent emergent herbaceous wetlands
ppt_Jun	Average June precipitation
ppt_annual	Average annual precipitation
temp_Jun	Average June temperature
temp_annual	Average annual temperature

Table 8. Predictors used for aquatic species modeling. Descriptions of 81 candidate predictor variables obtained from the National Fish Habitat Database (NFHD), National Land Cover Database (NLCD), NRCS State Soil Geographic (STATSGO) Database, and the National Hydrography Dataset Plus Version 1 (NHDPlusV1).

Variable type	Selected	Variable name	Source	Description
Disturbance	✓	L_URBANL	NFHD	% of local catchment defined as developed, open space and low intensity
	✓	L_URBANM	NFHD	% of local catchment defined as developed, medium intensity
	✓	L_URBANH	NFHD	% of local catchment defined as developed, high intensity
		L_PASTURE	NFHD	% of local catchment defined as pasture/hay
		L_CROPS	NFHD	% of local catchment defined as cultivated crops
		L_POPDENS	NFHD	Mean population density within local catchment (units = Individuals/km2)
	✓	L_ROADCR_dens	NFHD	Density of road crossings within local catchment (number/area)
		L_ROADLEN_dens	NFHD	Density of roads within local catchment in meters (length/area)
		L_DAMS	NFHD	Number of dams within local catchment
		L_MINES	NFHD	Number of mines or mineral processing plants within local catchment
		L_TRI	NFHD	Number of TRI sites within local catchment; Toxics Release Inventory (TRI) Program
		L_NPDES	NFHD	Number of NPDES sites within local catchment; National Pollutant Discharge Elimination System (NPDES) Majors from the Permit Compliance System (PCS)
		L_CERC	NFHD	Number of SNPL sites within local catchment; Superfund National Priorities List (SNPL) from the Compensation and Liability Information System (CERCLIS)
	✓	N_URBANLC	NFHD	% of network catchment defined as developed, open space and low intensity
	✓	N_URBANMC	NFHD	% of network catchment defined as developed, medium intensity
	✓	N_URBANHC	NFHD	% of network catchment defined as developed, high intensity
	✓	N_PASTUREC	NFHD	% of network catchment defined as pasture/hay
	✓	N_CROPSC	NFHD	% of network catchment defined as cultivated crops
	✓	N_POPDENSC	NFHD	Mean population density within network catchment (units = Individuals/km2)
	✓	N_ROADCRC_dens	NFHD	Density of road crossings within network catchment (number/area)
	✓	N_ROADLENC_dens	NFHD	Density of roads within network catchment in meters (length/area)
		N_DAMSC	NFHD	Number of dams within network catchment
		N_MINESC	NFHD	Number of mines or mineral processing plants within network catchment
		N_TRIC	NFHD	Number of TRI sites within network catchment; Toxics Release Inventory (TRI) Program
		N_NPDESC	NFHD	Number of NPDES sites within network catchment; National Pollutant Discharge Elimination System (NPDES) Majors from the Permit Compliance System (PCS)
		N_CERCC	NFHD	Number of SNPL sites within network catchment; Superfund National Priorities List (SNPL) from the Compensation and Liability Information System (CERCLIS)
Land cover (local watershed)	✓	NLCD_11	NLCD	% of catchment area classified as Open Water in NLCD
		NLCD_12	NLCD	% of catchment area classified as Perennial Ice/Snow in NLCD
	✓	NLCD_21	NLCD	% of catchment area classified as Low Intensity Residential in NLCD
	✓	NLCD_22	NLCD	% of catchment area classified as High Intensity Residential in NLCD
		NLCD_23	NLCD	% of catchment area classified as Commercial/Industrial/Transportation in NLCD
		NLCD_31	NLCD	% of catchment area classified as Bare Rock/Sand/Clay in NLCD
		NLCD_32	NLCD	% of catchment area classified as Quarries/Strip Mines/Gravel Pits in NLCD
		NLCD_33	NLCD	% of catchment area classified as Transitional in NLCD
		NLCD_41	NLCD	% of catchment area classified as Deciduous Forest in NLCD
		NLCD_42	NLCD	% of catchment area classified as Evergreen Forest in NLCD
		NLCD_43	NLCD	% of catchment area classified as Mixed Forest in NLCD
		NLCD_51	NLCD	% of catchment area classified as Shrubland in NLCD
		NLCD_61	NLCD	% of catchment area classified as Orchards/Vineyards/Other in NLCD
		NLCD_71	NLCD	% of catchment area classified as Grasslands/Herbaceous in NLCD
		NLCD_81	NLCD	% of catchment area classified as Pasture/Hay in NLCD
		NLCD_82	NLCD	% of catchment area classified as Row Crops in NLCD
		NLCD_83	NLCD	% of catchment area classified as Small Grains in NLCD
		NLCD_84	NLCD	% of catchment area classified as Fallow in NLCD
		NLCD_85	NLCD	% of catchment area classified as Urban/Recreational Grasses in NLCD
	✓	NLCD_91	NLCD	% of catchment area classified as Woody Wetlands in NLCD
	✓	NLCD_92	NLCD	% of catchment area classified as Emergent Herbaceous Wetland in NLCD

Table 8. Predictors used for aquatic species modeling. Continued…

Variable type	Selected	Variable name	Source	Description
Land cover (total watershed)	✓	CUMNLCD_11	NLCD	% of cumulative drainage area classified as Open Water in NLCD
		CUMNLCD_12	NLCD	% of cumulative drainage area classified as Perennial Ice/Snow in NLCD
		CUMNLCD_21	NLCD	% of cumulative drainage area classified as Low Intensity Residential in NLCD
		CUMNLCD_22	NLCD	% of cumulative drainage area classified as High Intensity Residential in NLCD
		CUMNLCD_23	NLCD	% of cumulative drainage area classified as Commercial/ Industrial/Transportation in NLCD
	✓	CUMNLCD_31	NLCD	% of cumulative drainage area classified as Bare Rock/Sand/ Clay in NLCD
	✓	CUMNLCD_32	NLCD	% of cumulative drainage area classified as Quarries/Strip Mines/Gravel Pits in NLCD
	✓	CUMNLCD_33	NLCD	% of cumulative drainage area classified as Transitional in NLCD
	✓	CUMNLCD_41	NLCD	% of cumulative drainage area classified as Deciduous Forest in NLCDD
	✓	CUMNLCD_42	NLCD	% of cumulative drainage area classified as Evergreen Forest in NLCD
	✓	CUMNLCD_43	NLCD	% of cumulative drainage area classified as Mixed Forest in NLCD
		CUMNLCD_51	NLCD	% of cumulative drainage area classified as Shrubland in NLCD
		CUMNLCD_61	NLCD	% of cumulative drainage area classified as Orchards/Vineyards/ Other in NLCD
	✓	CUMNLCD_71	NLCD	% of cumulative drainage area classified as Grasslands/ Herbaceous in NLCD
	✓	CUMNLCD_81	NLCD	% of cumulative drainage area classified as Pasture/Hay in NLCD
		CUMNLCD_82	NLCD	% of cumulative drainage area classified as Row Crops in NLCD
	✓	CUMNLCD_83	NLCD	% of cumulative drainage area classified as Small Grains in NLCD
		CUMNLCD_84	NLCD	% of cumulative drainage area classified as Fallow in NLCD
	✓	CUMNLCD_85	NLCD	% of cumulative drainage area classified as Urban/Recreational Grasses in NLCD
	✓	CUMNLCD_91	NLCD	% of cumulative drainage area classified as Woody Wetlands in NLCD
	✓	CUMNLCD_92	NLCD	% of cumulative drainage area classified as Emergent Herbaceous Wetlands in NLCD
Surficial geology	✓	ROCKDEPL	STATSGO	Low value for the range in the total soil thickness examined (inches)
	✓	PERMAVE	STATSGO	Average value for the range in permeability
	✓	CLAYAVE	STATSGO	Average value of clay content (mean percent of catchment)
	✓	SILTAVE	STATSGO	Average value of silt (mean percent of catchment)
Watershed size	✓	L_AREASQKM	NFHD	area of the local catchment (km2)
	✓	N_AREASQKM	NFHD	area of the network catchment (km2)
	✓	LENGTHKM	NHDPlusV1	length of the flowline/reach (km)
	✓	MINELEVSMO	NHDPlusV1	Minimum elevation (smoothed) in meters
	✓	SLOPE	NHDPlusV1	Slope of flowline (m/m)
	✓	SO	NHDPlusV1	Strahler stream order
		SC	NHDPlusV1	Strahler stream calculation
Climate	✓	AREAWTMAP	NHDPlusV1	Area Weighted Mean Annual Precipitation at bottom of flowline in mm
	✓	AREAWTMAT	NHDPlusV1	Area Weighted Mean Annual Temperature at bottom of flowline in degree C * 10

Table 9. Grassland bird modeling effectiveness expressed as mtry and pseudo-R^2.

Species	Scientific name	mtry	pseudo-R^2
Upland Sandpiper	*Bartramia longicauda*	2	0.17
Bobolink	*Dolichonyx oryzivorus*	2	0.28
Eastern Meadowlark	*Sturnella magna*	2	0.41
Grasshopper Sparrow	*Ammodramus savannarum*	2	0.16
Dickcissel	*Spiza americana*	3	0.51

Table 10. Fish modeling effectiveness for presence and abundance models expressed as mtry and pseudo-R^2 and misclassifications.

		Presence				Abundance	
Fish Species	Modeled prevalence	mtry	OOB error	Misclassification of absences	Misclassification of presences	mtry	pseudo-R^2
Black Redhorse	0.04	9	0.02	0.01	0.42	15	0.53
Blackside Darter	0.11	4	0.09	0.03	0.59	8	0.37
Brook Stickleback	0.24	10	0.19	0.09	0.49	6	0.32
Channel Catfish	0.09	8	0.06	0.03	0.37	5	0.52
Freshwater Drum	0.07	7	0.04	0.02	0.33	7	0.60
Green Sunfish	0.25	9	0.14	0.09	0.31	12	0.50
Johnny Darter	0.34	9	0.20	0.12	0.37	7	0.43
Logperch	0.07	5	0.07	0.02	0.70	6	0.34
Longear Sunfish	0.19	4	0.06	0.04	0.15	12	0.73
Mottled Sculpin	0.20	8	0.14	0.06	0.48	6	0.40
Rainbow Darter	0.06	7	0.04	0.01	0.49	8	0.48
Striped Shiner	0.20	9	0.09	0.05	0.28	9	0.64
Average	0.16	7	0.10	0.05	0.41	8	0.49

Table 11. Grassland Conservation Targets. Marxan conservation targets for grassland birds, expressed as a relative population size captured by protected areas. Relative population sizes are expressed in terms of observed species density (predicted average count per BSS survey stop), multiplied by land area (square kilometers).

Bird Species Common name	Predicted relative population size	Target protected relative population size
Dickcissel	21385	2139
Grasshopper Sparrow	1241	124
Eastern Meadowlark	32681	3268
Bobolink	4453	445
Upland Sandpiper	79	8

Table 12. Aquatic Conservation Targets. Marxan conservation targets for aquatic focal species in streams, expressed as the protection of a target length of stream in which each species was predicted to occur.

Common name	Predicted length of stream occupied (km)	Target length of stream protected (km)
Fish		
Black redhorse	3203	500
Freshwater mussels		
Rainbow	12383	1238
Ellipse	15939	1594
Purple Lilliput	2600	500
Salamander Mussel	5983	598
Kidneyshell	4012	500
Fat Pocketbook	868	500
Sheepnose	2258	500
Snuffbox	3925	500
Purple Wartyback	7638	764
Slippershell	30725	2000
Salamander		
Mudpuppy	34740	2000

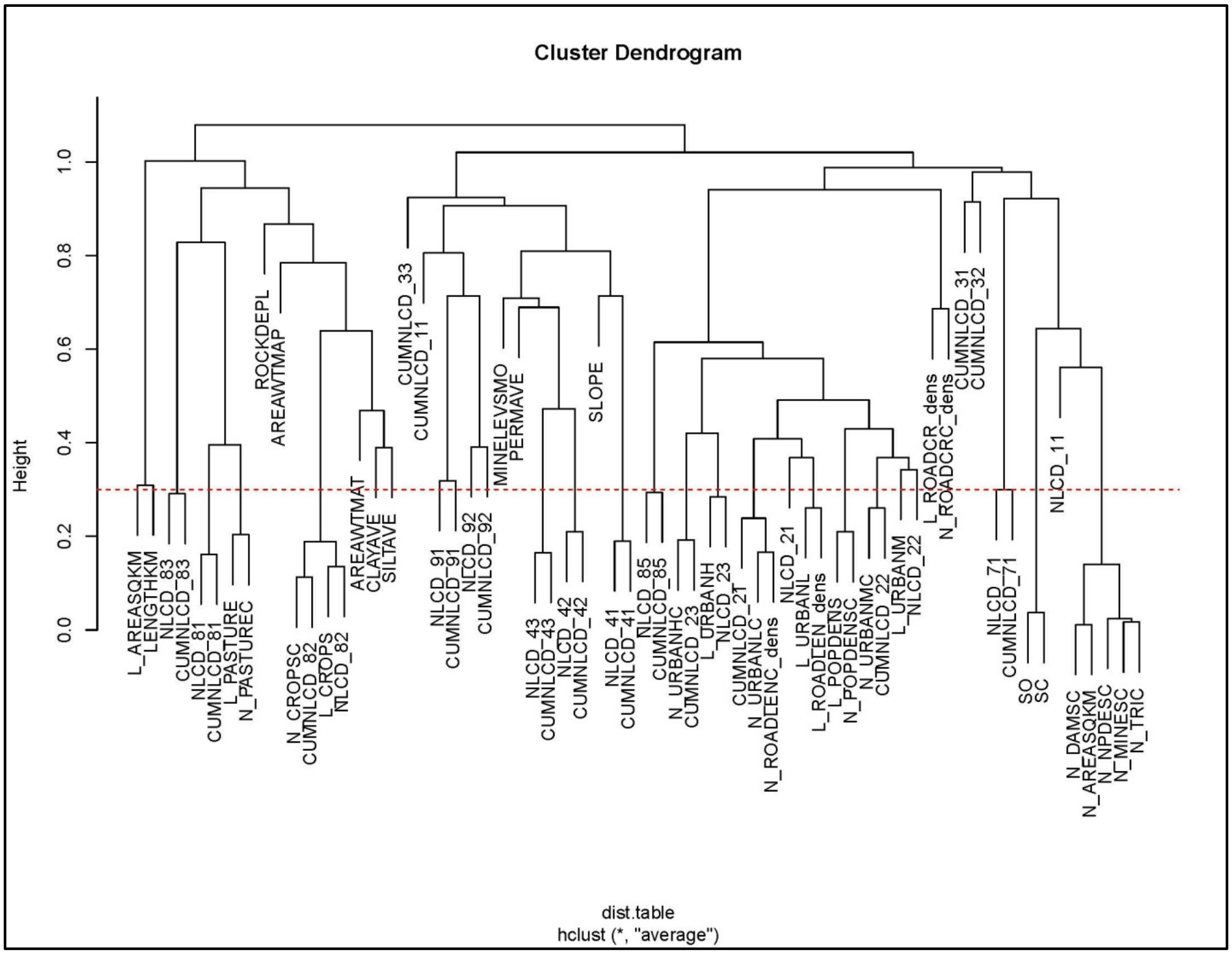

Figure 1. Hierarchical agglomerative cluster dendrogram for 64 environmental variables that were candidate predictors for aquatic species distribution models. Horizontal dashed line indicates a cutoff of distance = (1 - Pearson's r) = 0.3; branch points below this line indicate divisions with Pearson's r > 0.7.

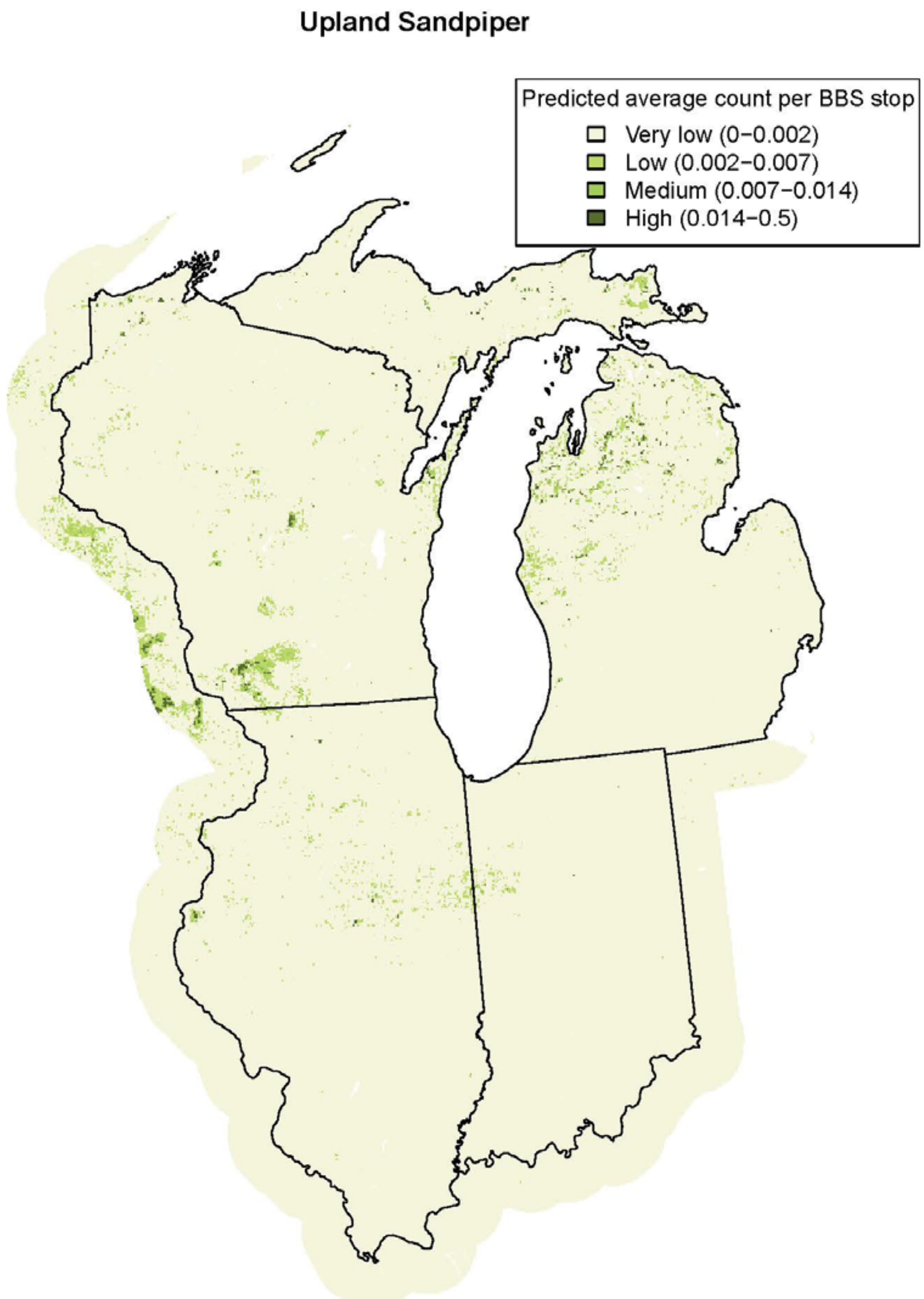

Figure 2a. Upland Sandpiper distribution. Shading indicates each species' predicted relative abundance, expressed as the average count per BBS point count. The model's spatial resolution is 1 km x 1 km.

Bobolink

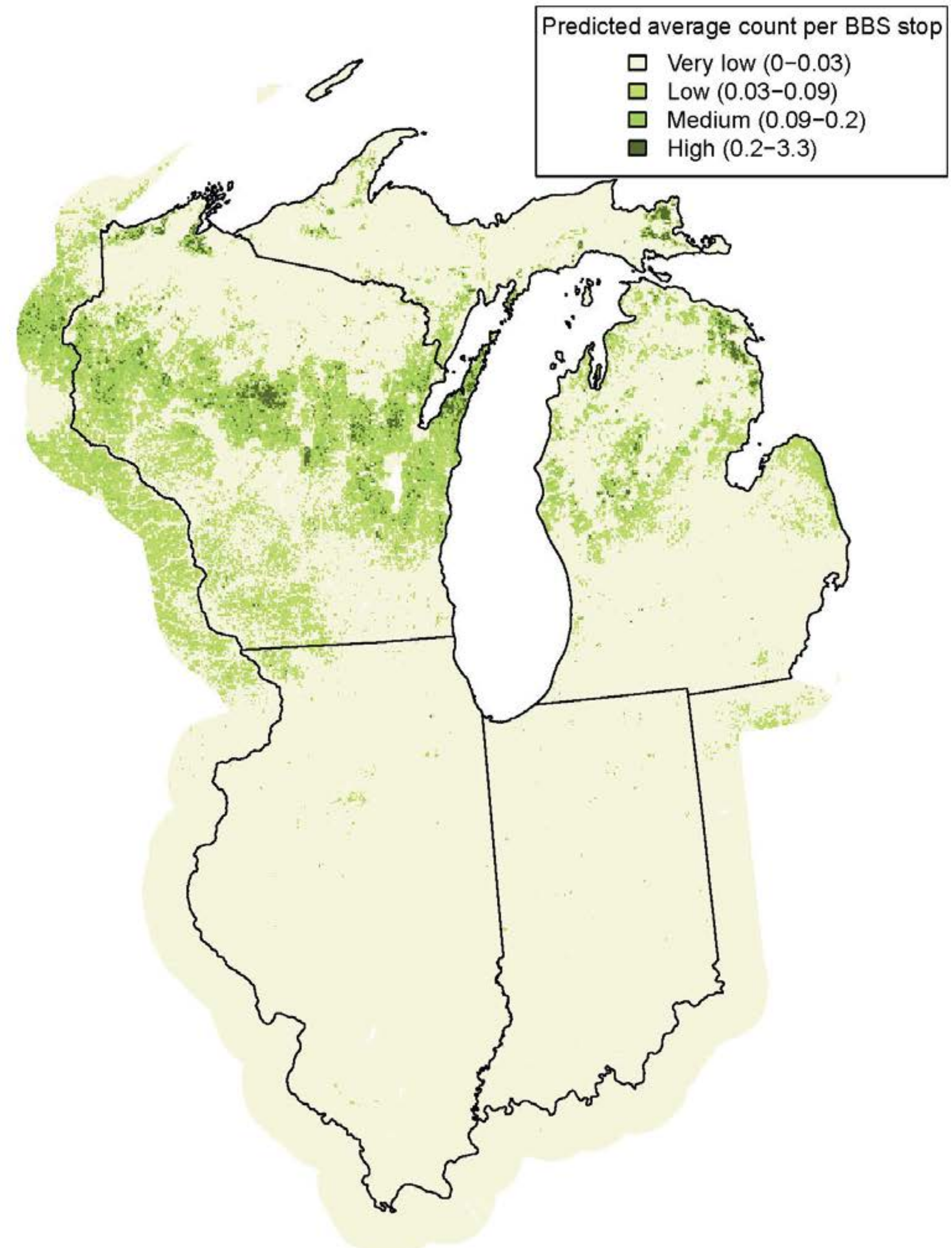

Figure 2b. Bobolink Distribution. Shading indicates each species' predicted relative abundance, expressed as the average count per BBS point count. The model's spatial resolution is 1 km x 1 km.

Eastern Meadowlark

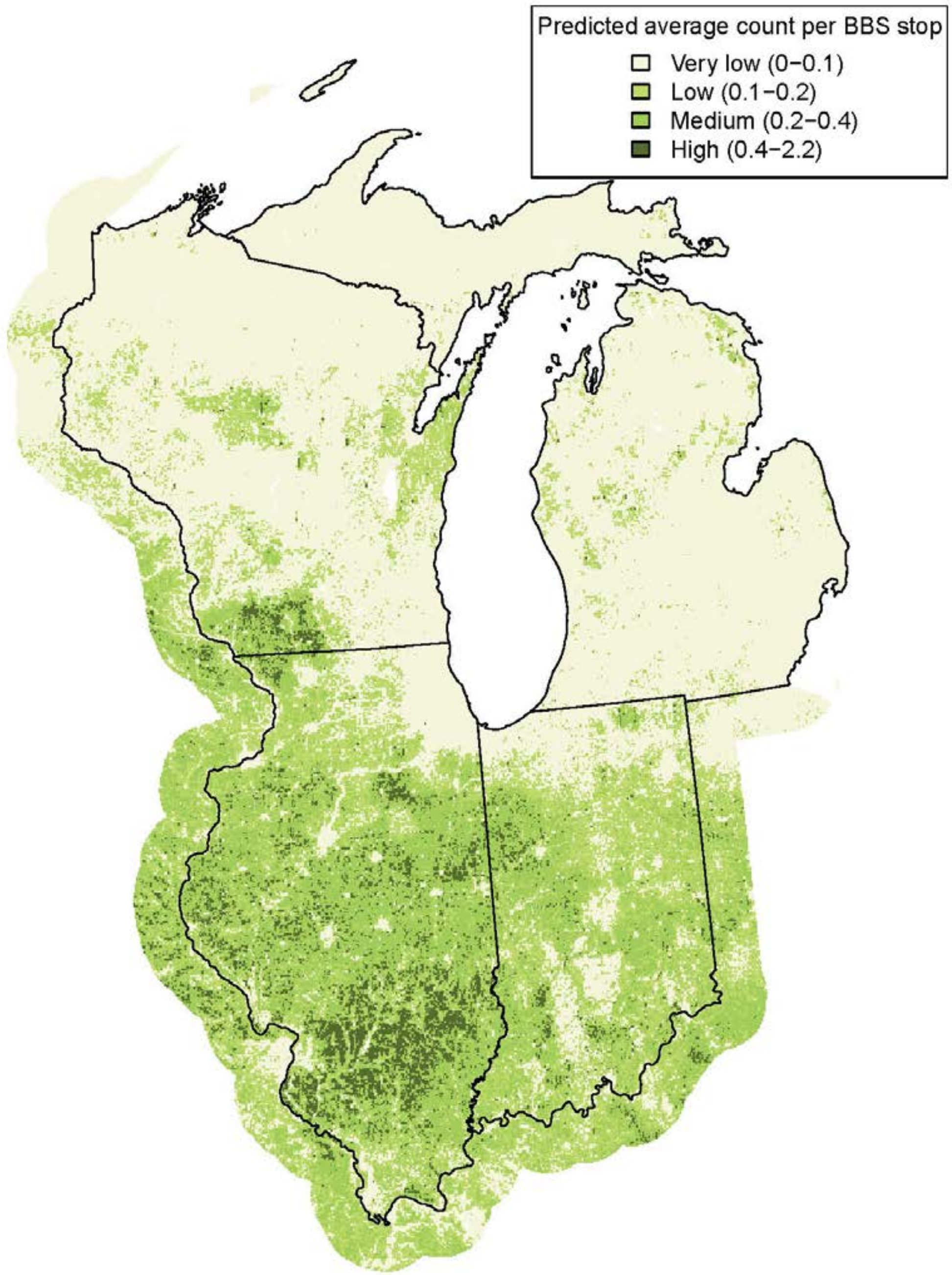

Figure 2c. Eastern Meadowlark distribution. Shading indicates each species' predicted relative abundance, expressed as the average count per BBS point count. The model's spatial resolution is 1 km x 1 km.

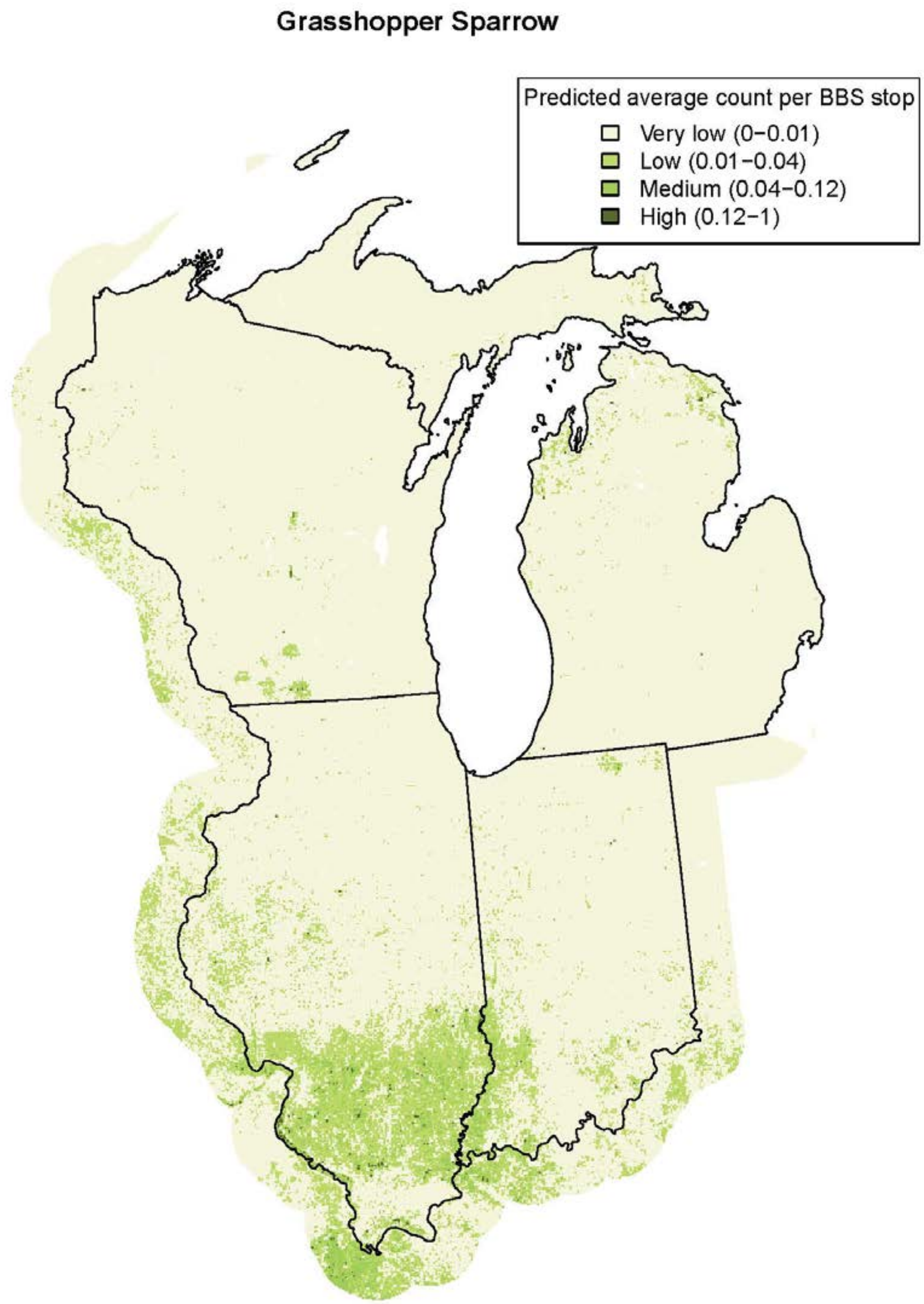

Figure 2d. Grasshopper Sparrow distribution. Shading indicates each species' predicted relative abundance, expressed as the average count per BBS point count. The model's spatial resolution is 1 km x 1 km.

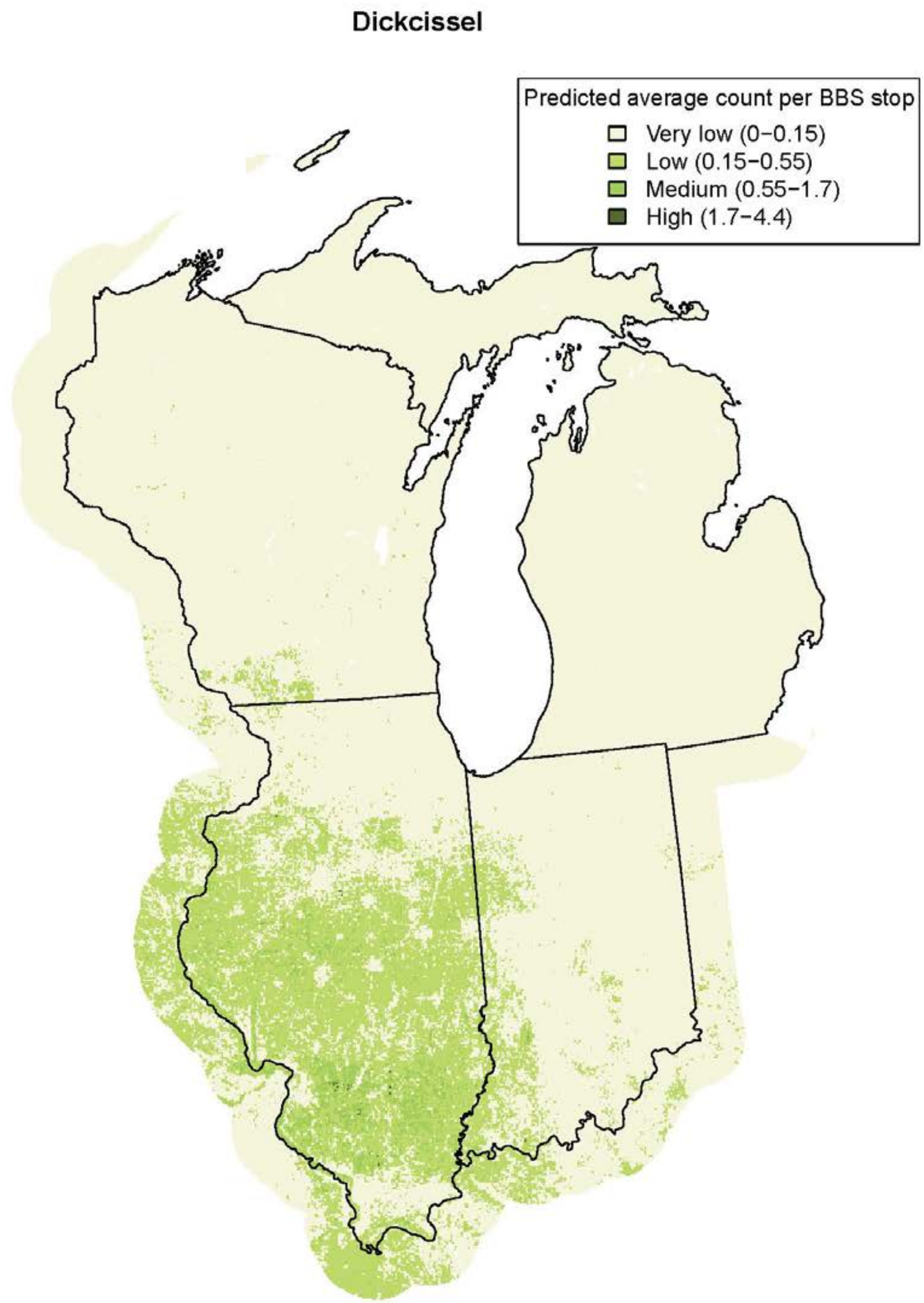

Figure 2e. Diskcissel distribution. Shading indicates each species' predicted relative abundance, expressed as the average count per BBS point count. The model's spatial resolution is 1 km x 1 km.

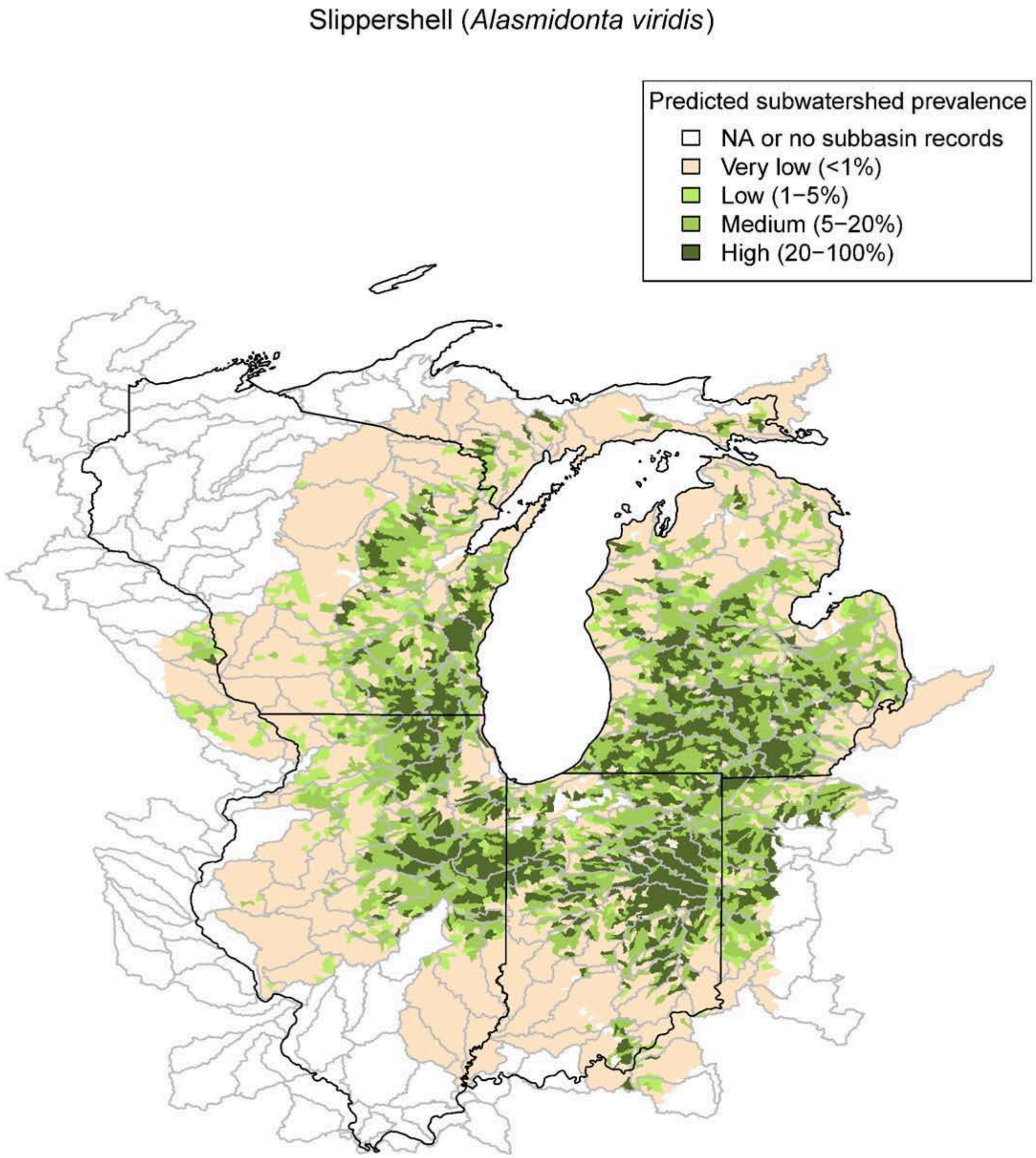

Figure 3a. Slippershell distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

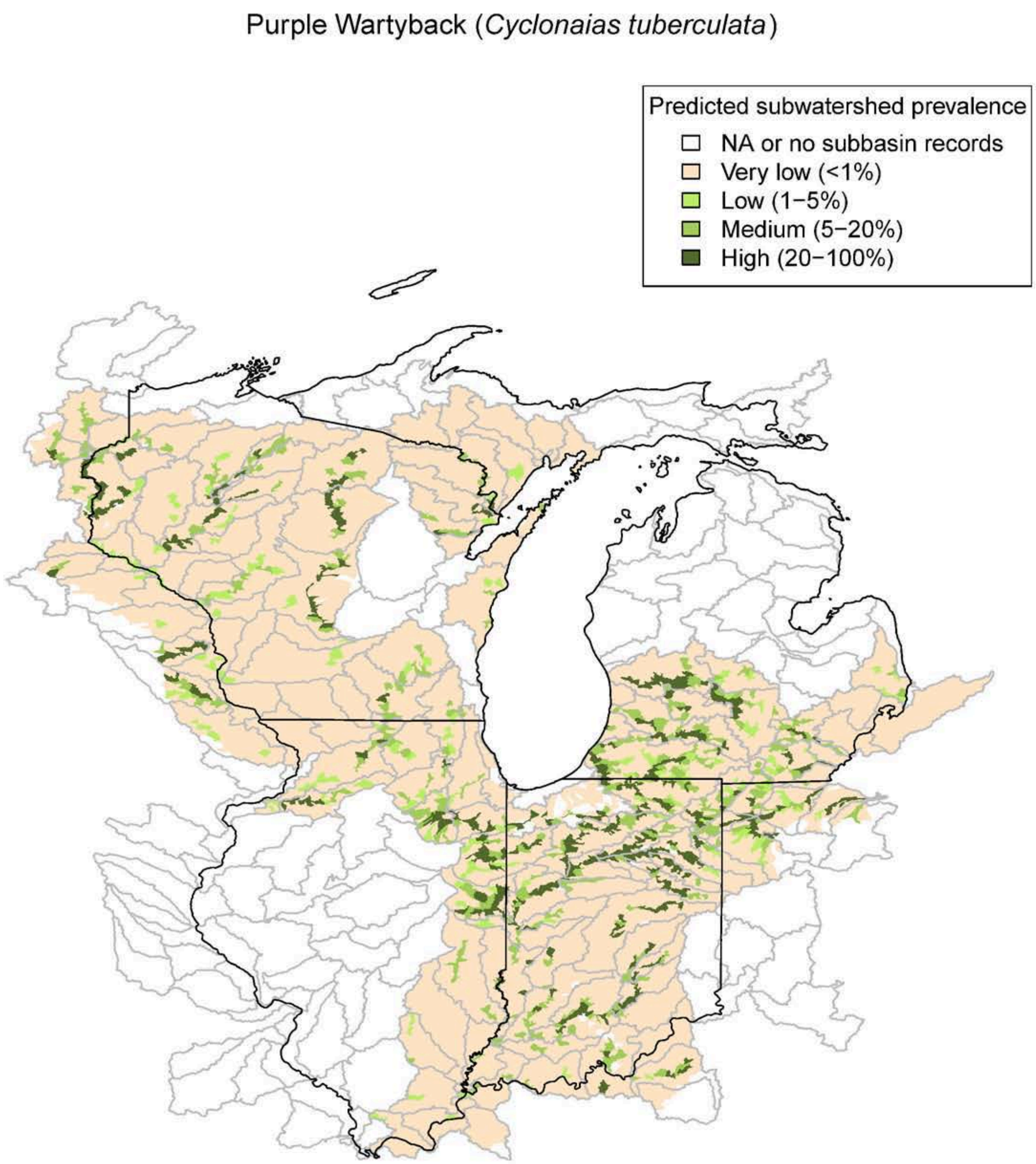

Figure 3c. Purple Wartyback distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record. .

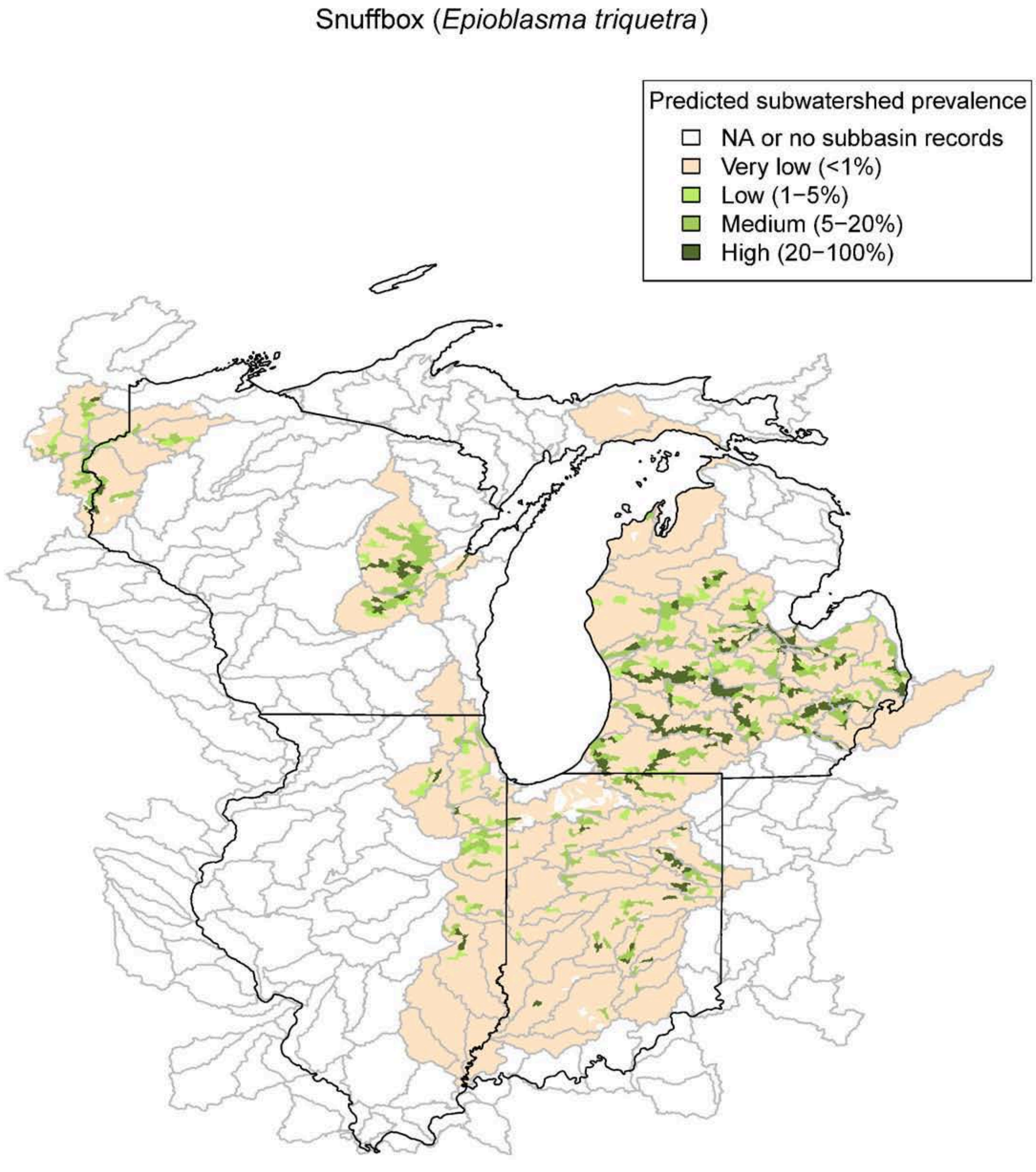

Figure 3c. Snuffbox distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

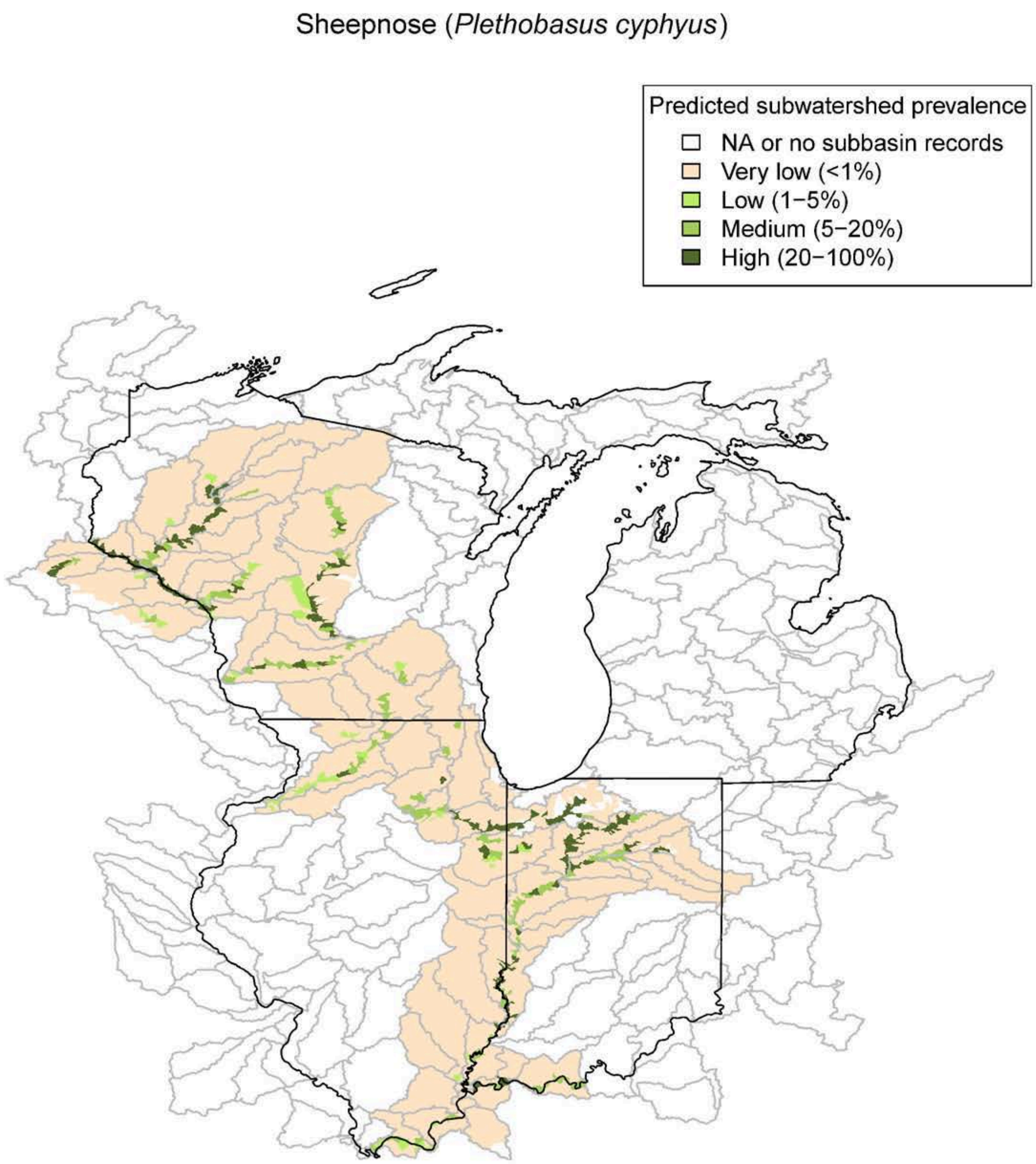

Figure 3d. Sheepnose distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Fat Pocketbook (*Potamilus capax*)

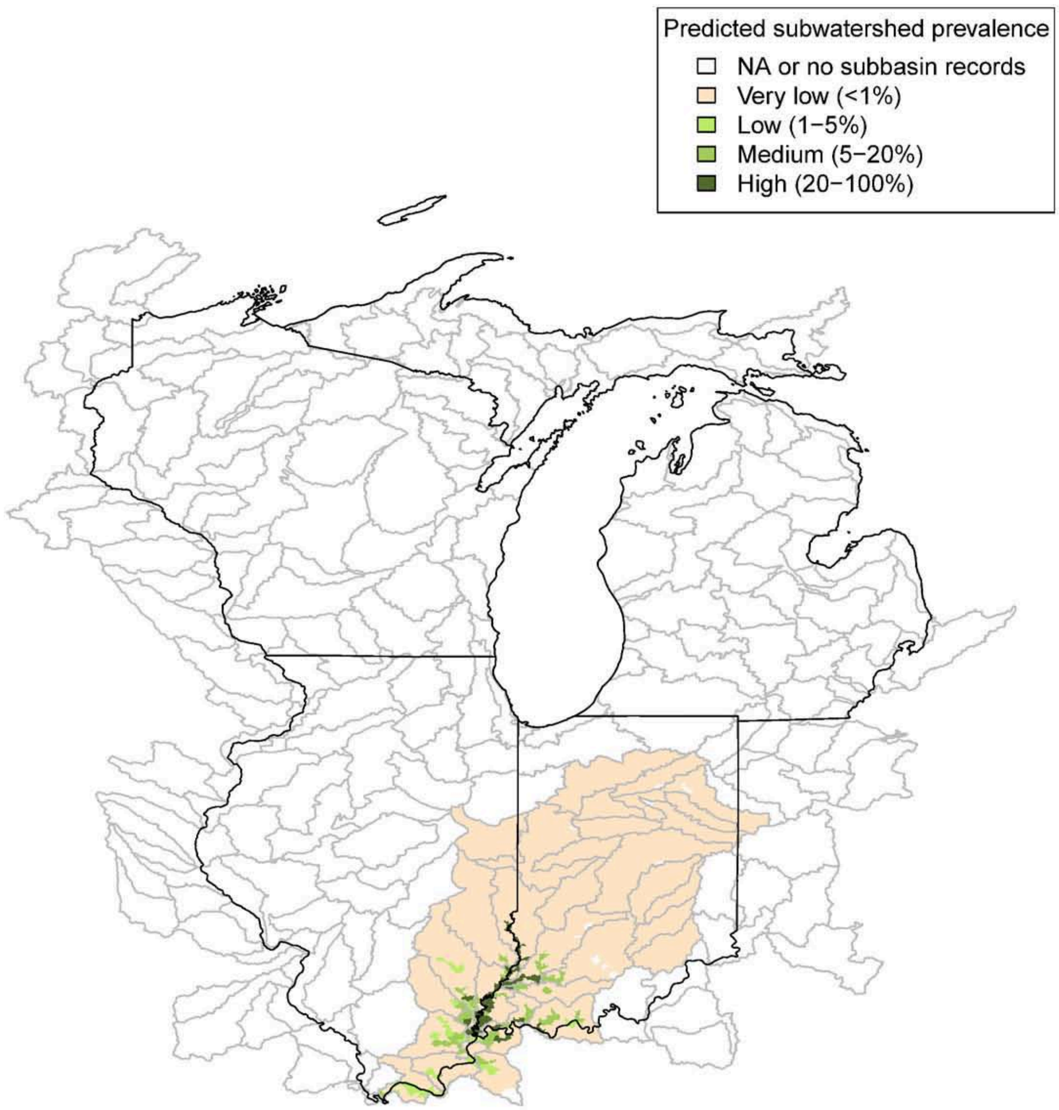

Figure 3e. Fat Pocketbook distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Kidneyshell (*Ptychobranchus fasciolaris*)

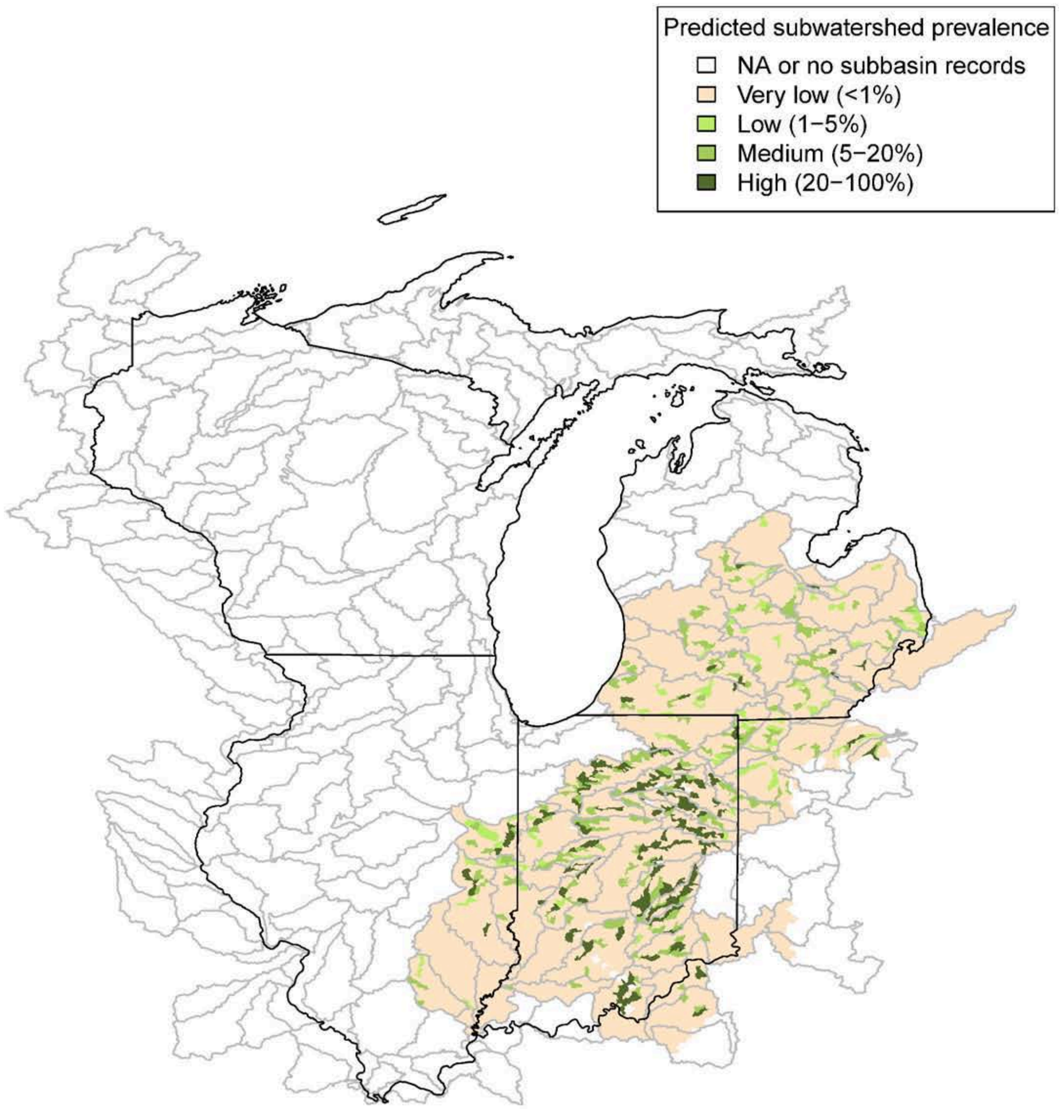

Figure 3f. Kidneyshell distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Salamander Mussel (*Simpsonaias ambigua*)

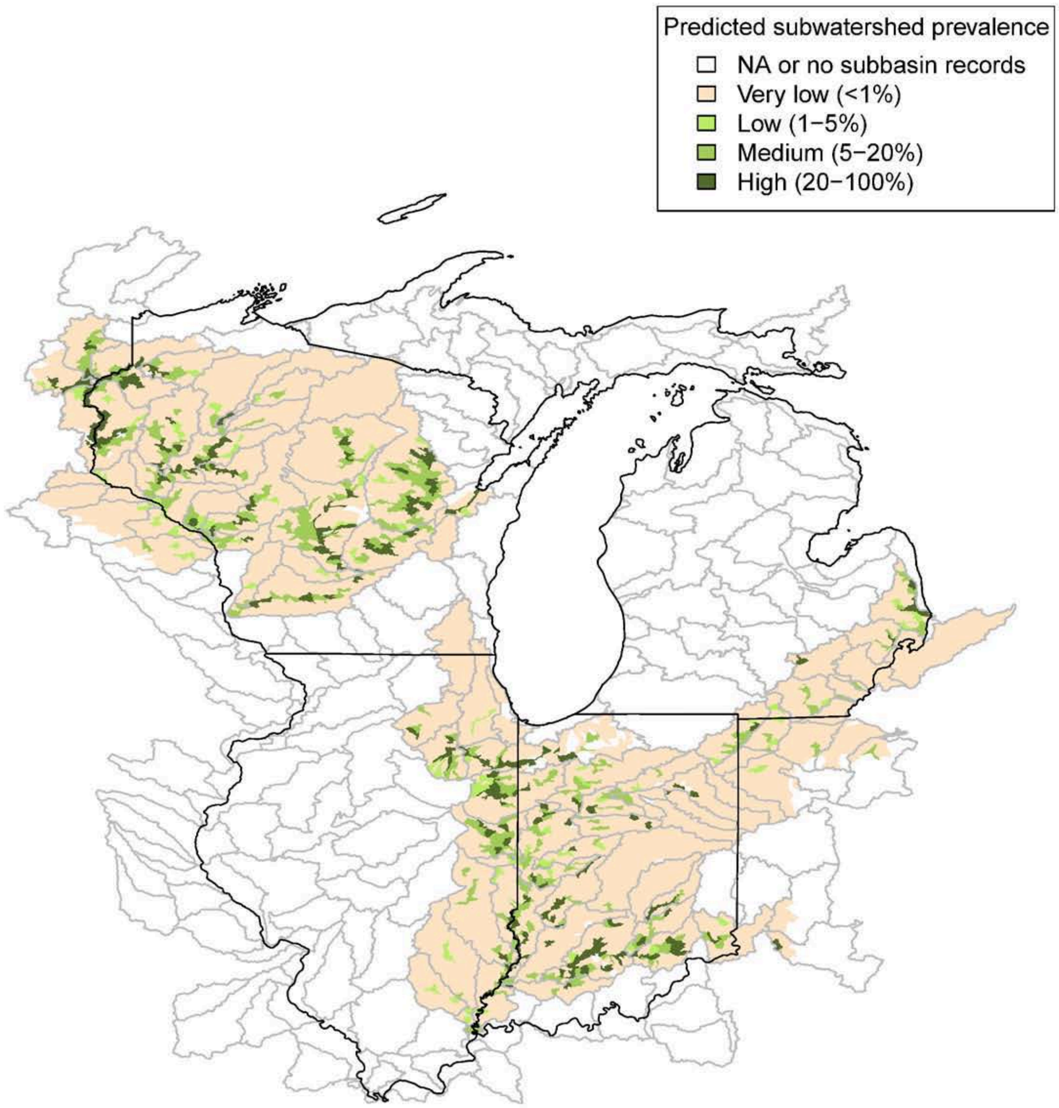

Figure 3g. Salamander Mussel distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Purple Lilliput (*Toxolasma lividus*)

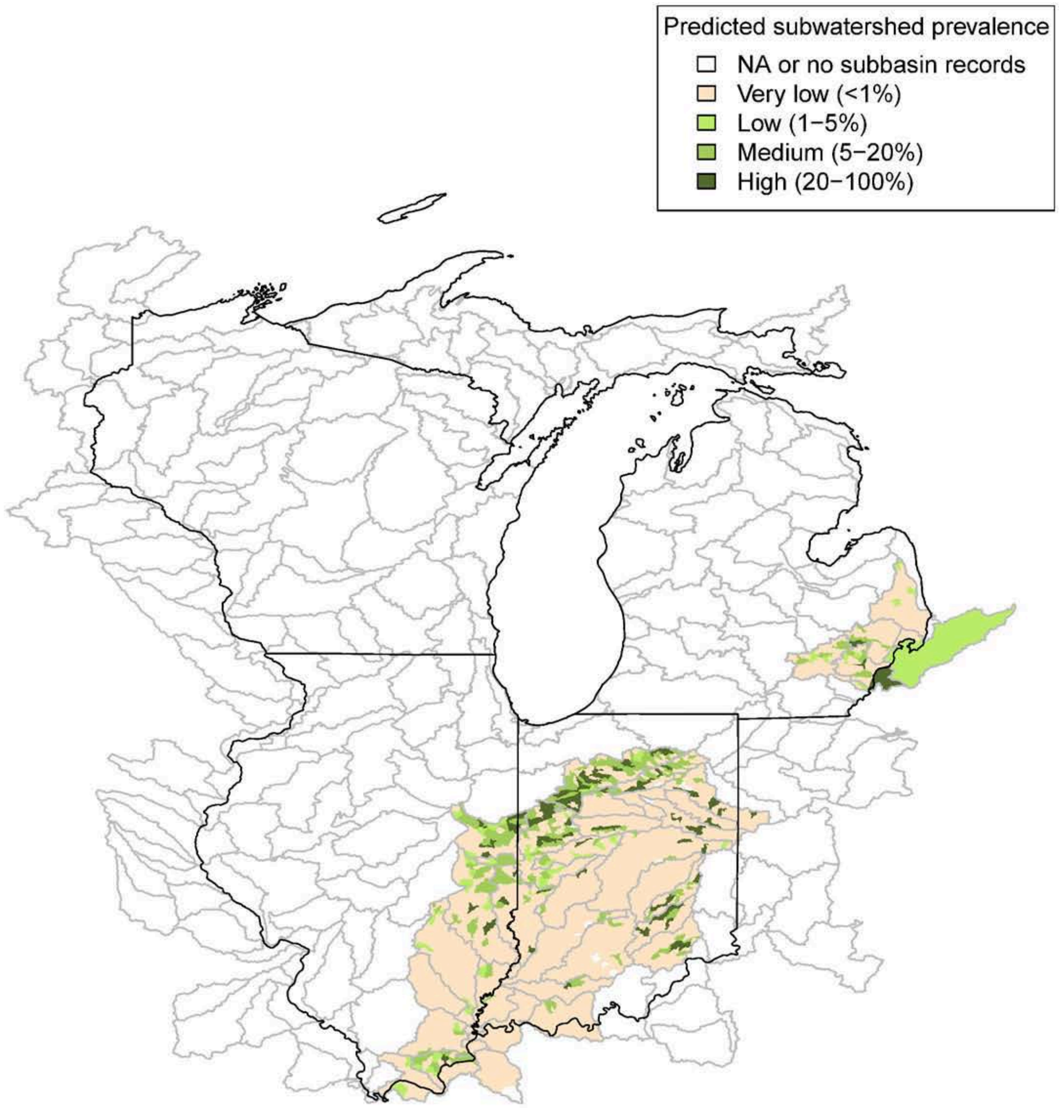

Figure 3h. Purple Lilliput distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Ellipse (*Venustaconcha ellipsiformis*)

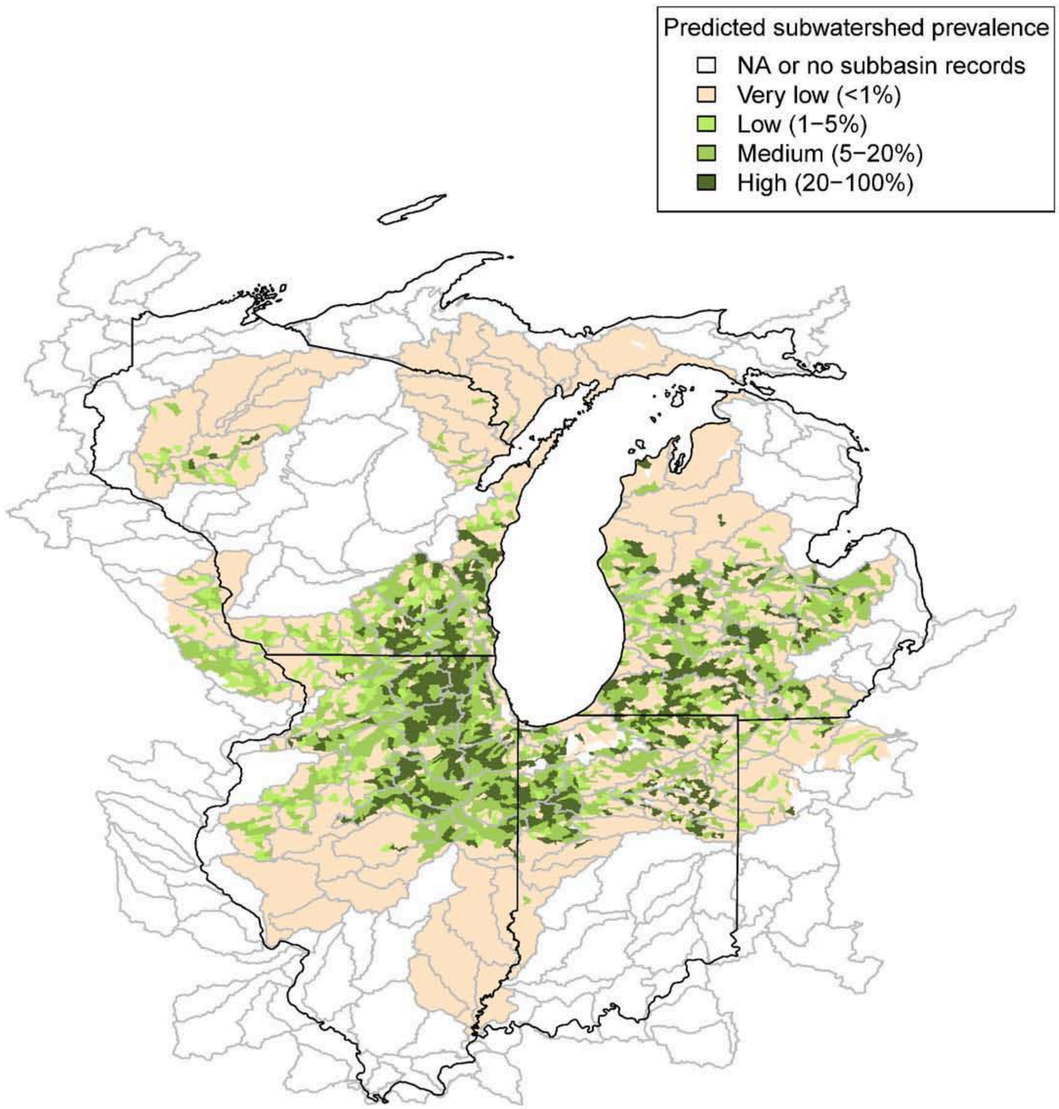

Figure 3i. Ellipse distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Rainbow (*Villosa iris*)

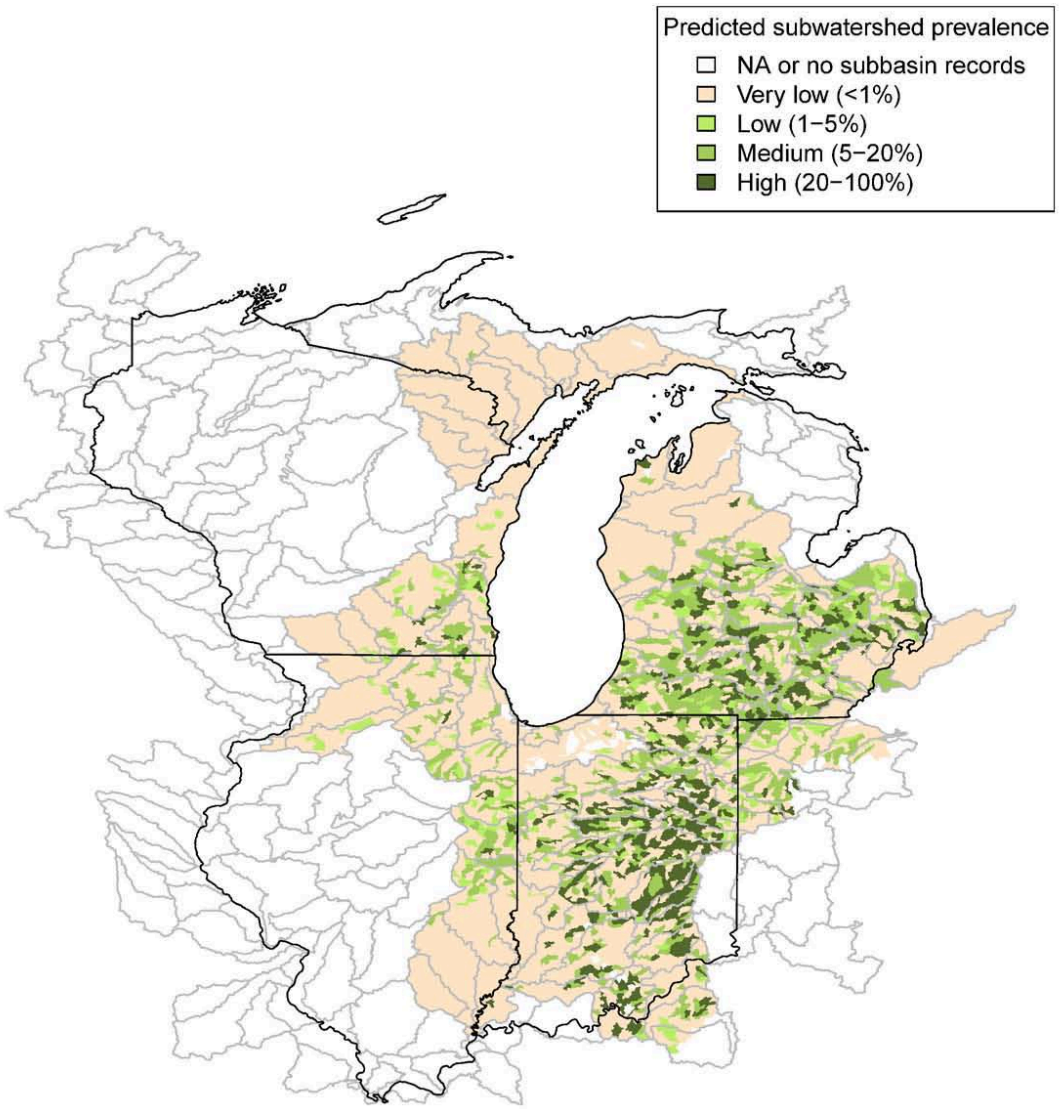

Figure 3j. Rainbow distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

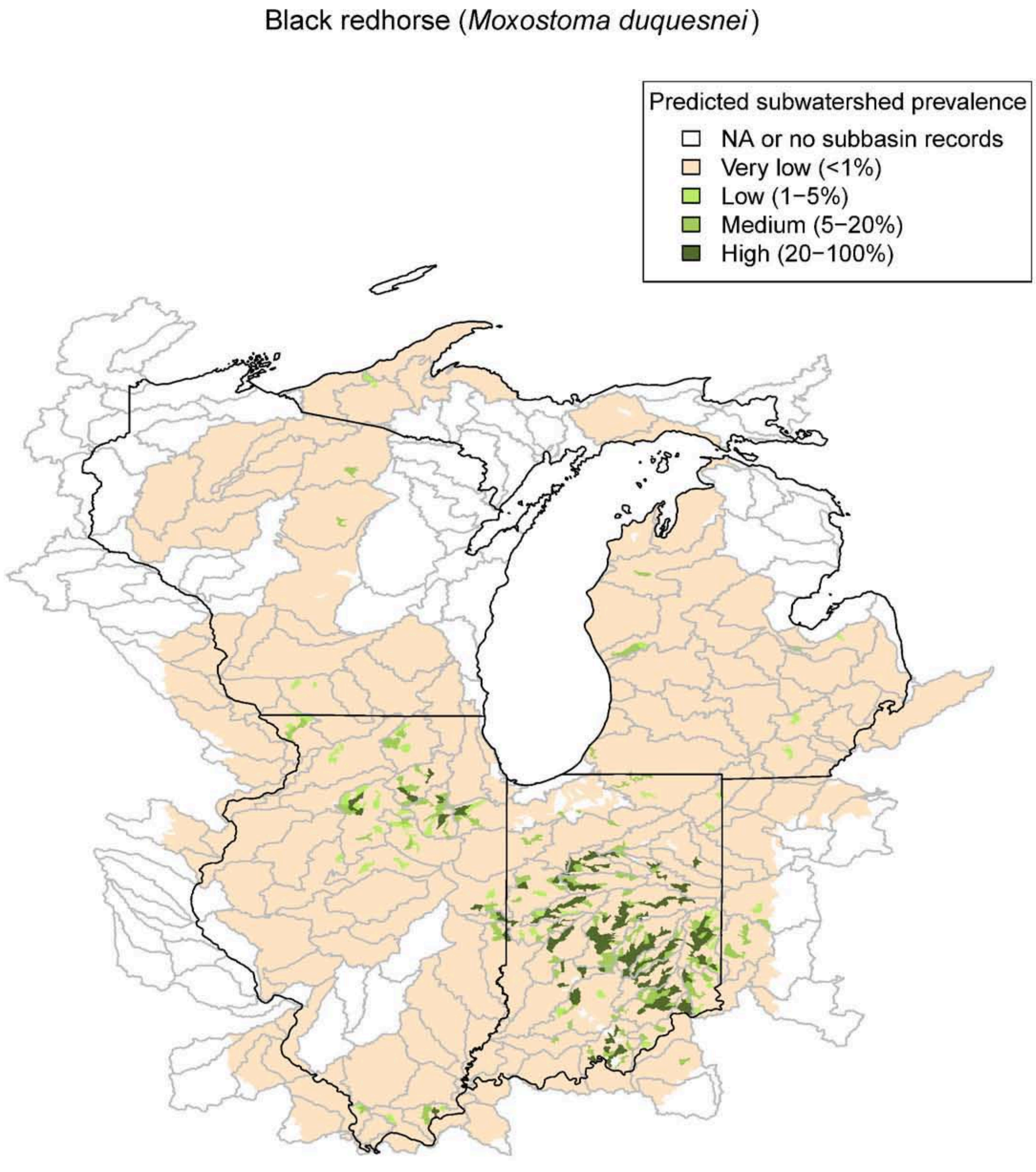

Figure 3k. Black Redhorse distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Blackside darter (*Percina maculata*)

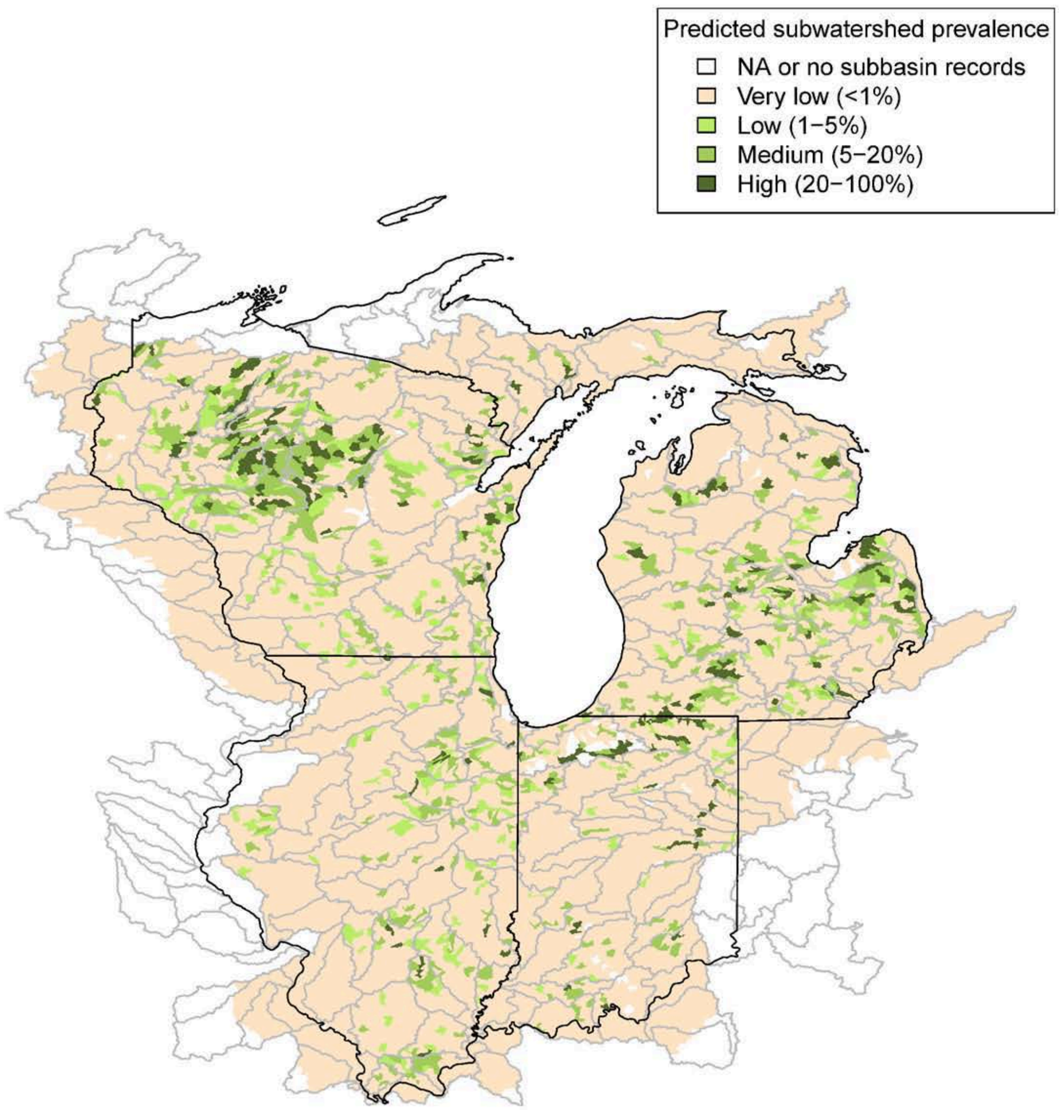

Figure 3l. Blackside Darter distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

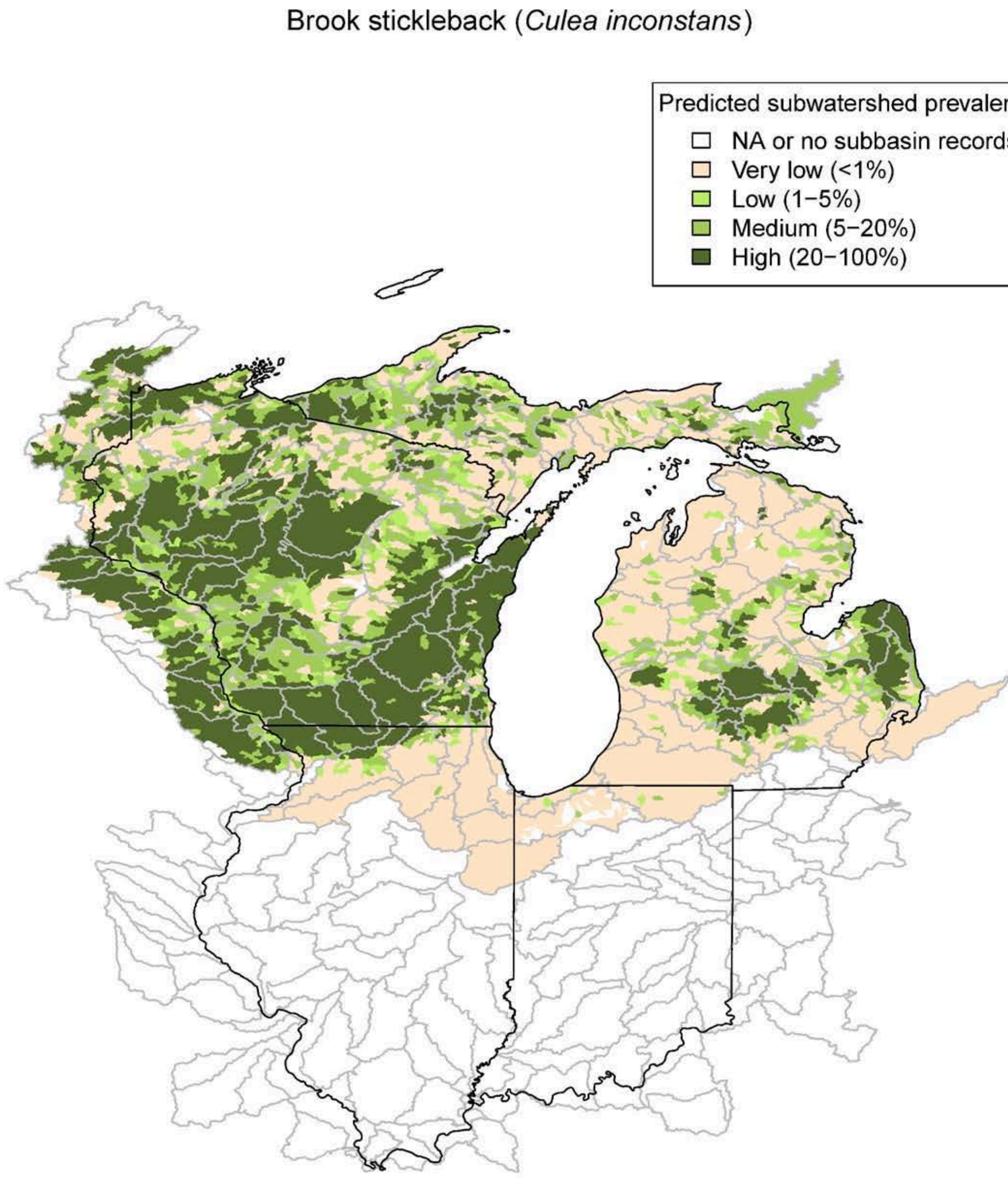

Figure 3m. Brook Stickleback distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

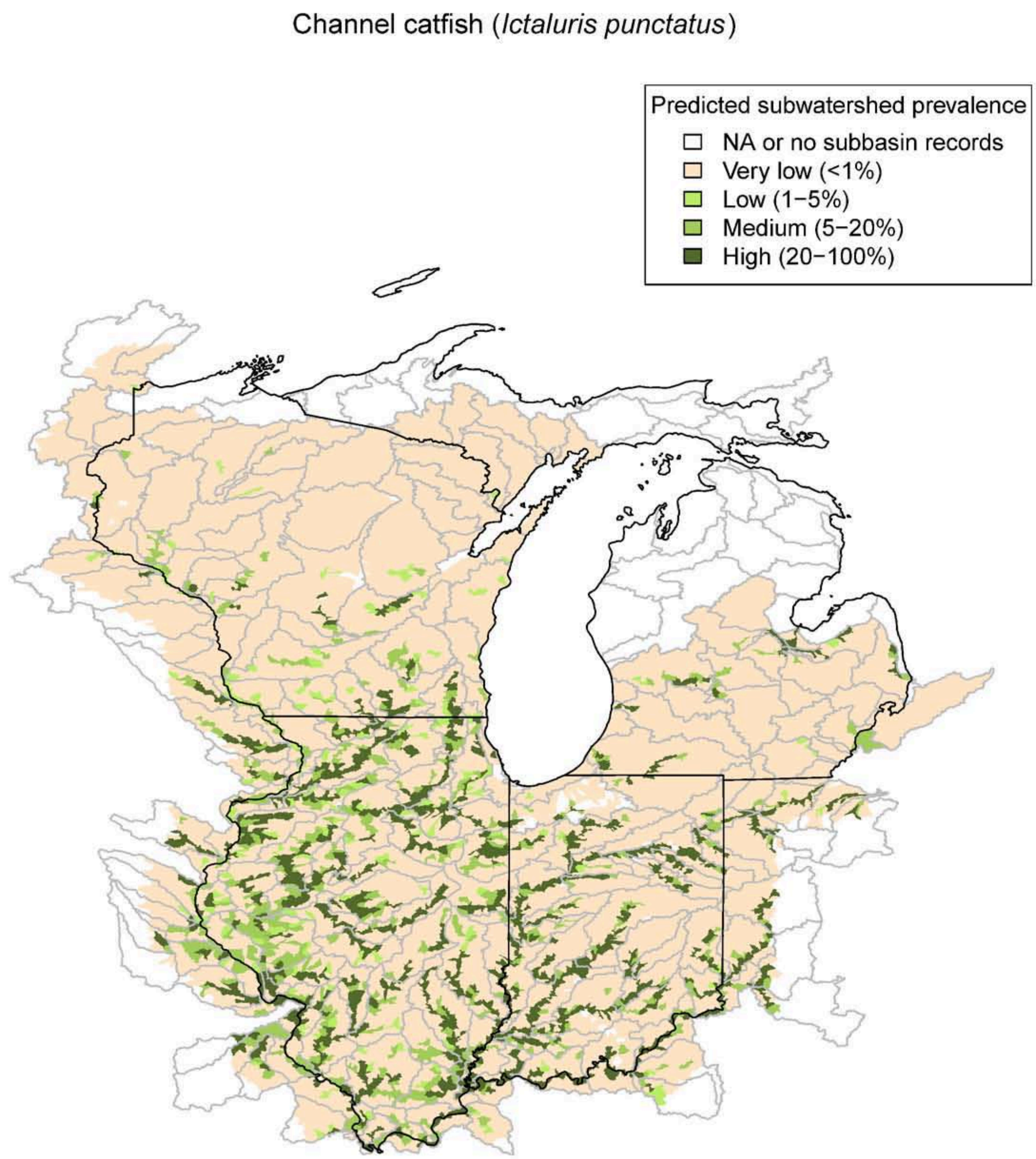

Figure 3n. Channel Catfish distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Freshwater drum (*Aplodinotus grunniens*)

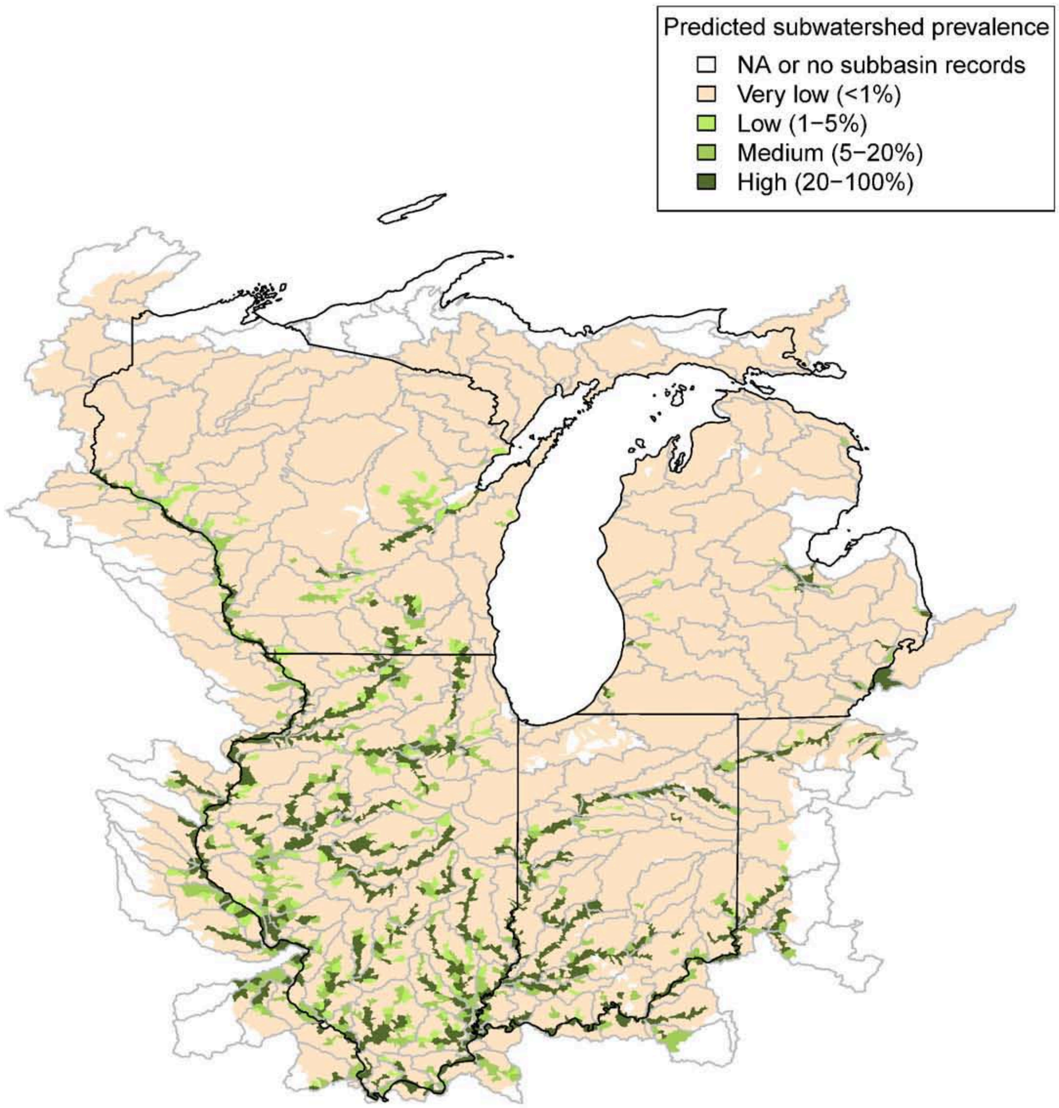

Figure 3o. Freshwater Drum distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

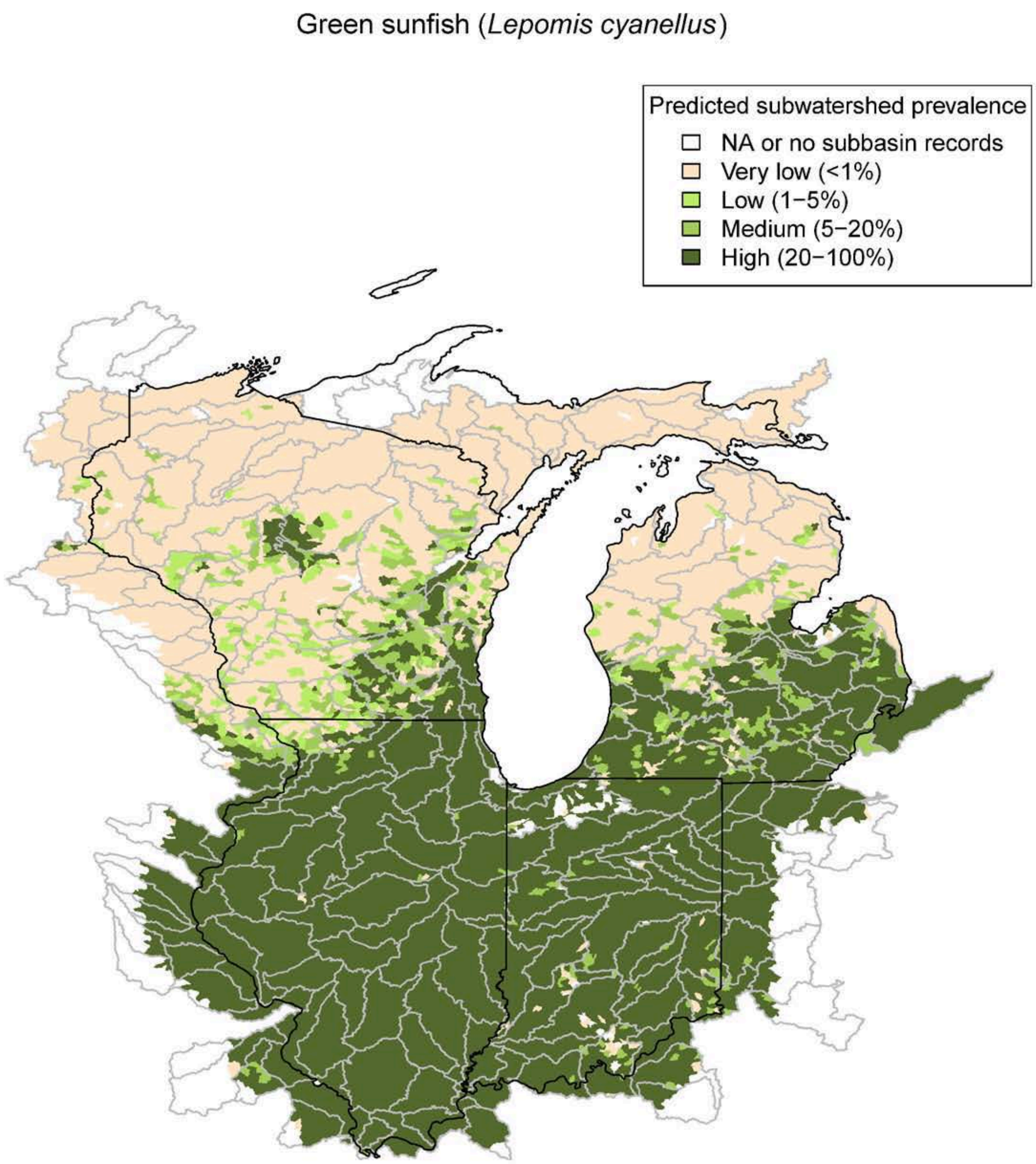

Figure 3p. Green Sunfish distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

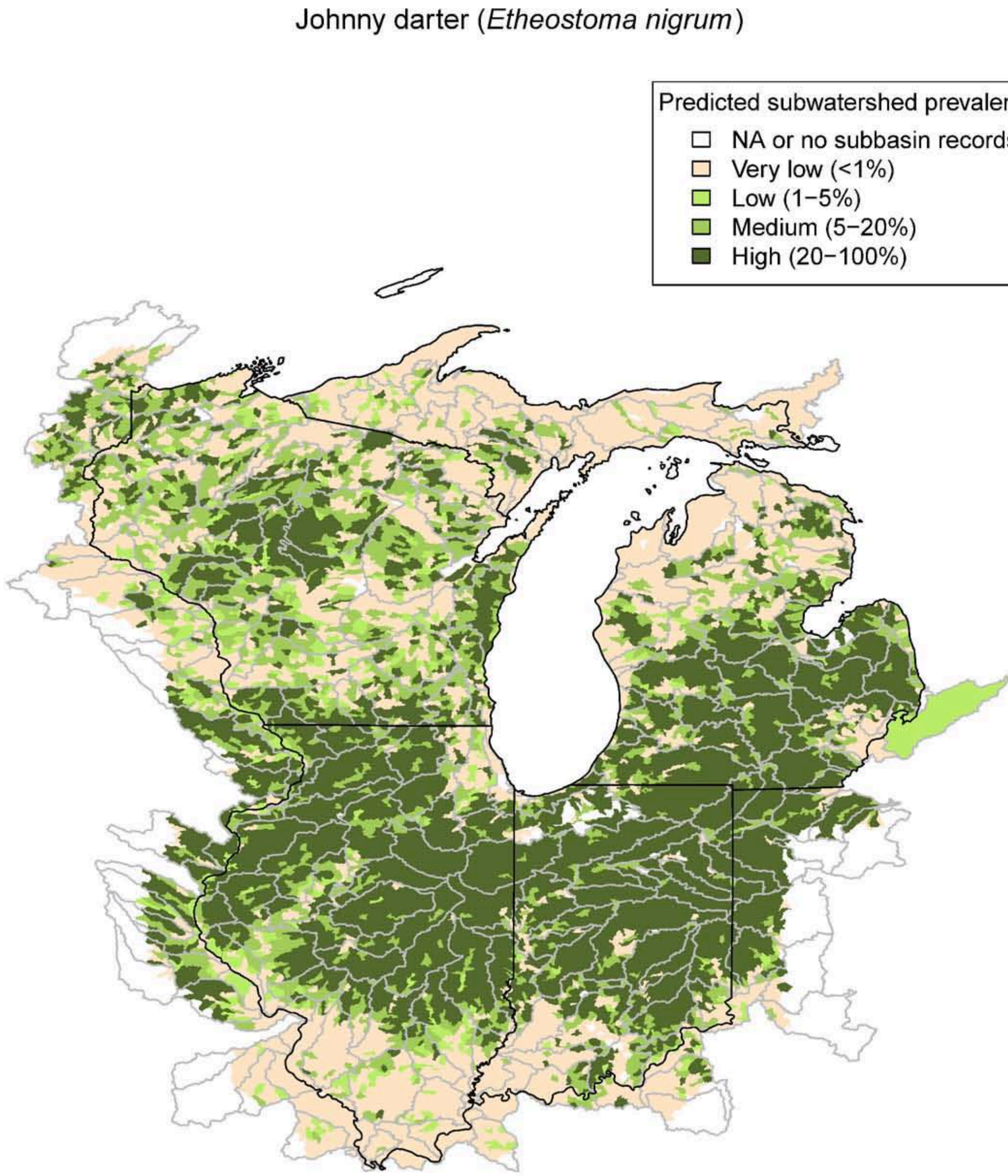

Figure 3q. Johnny Darter distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

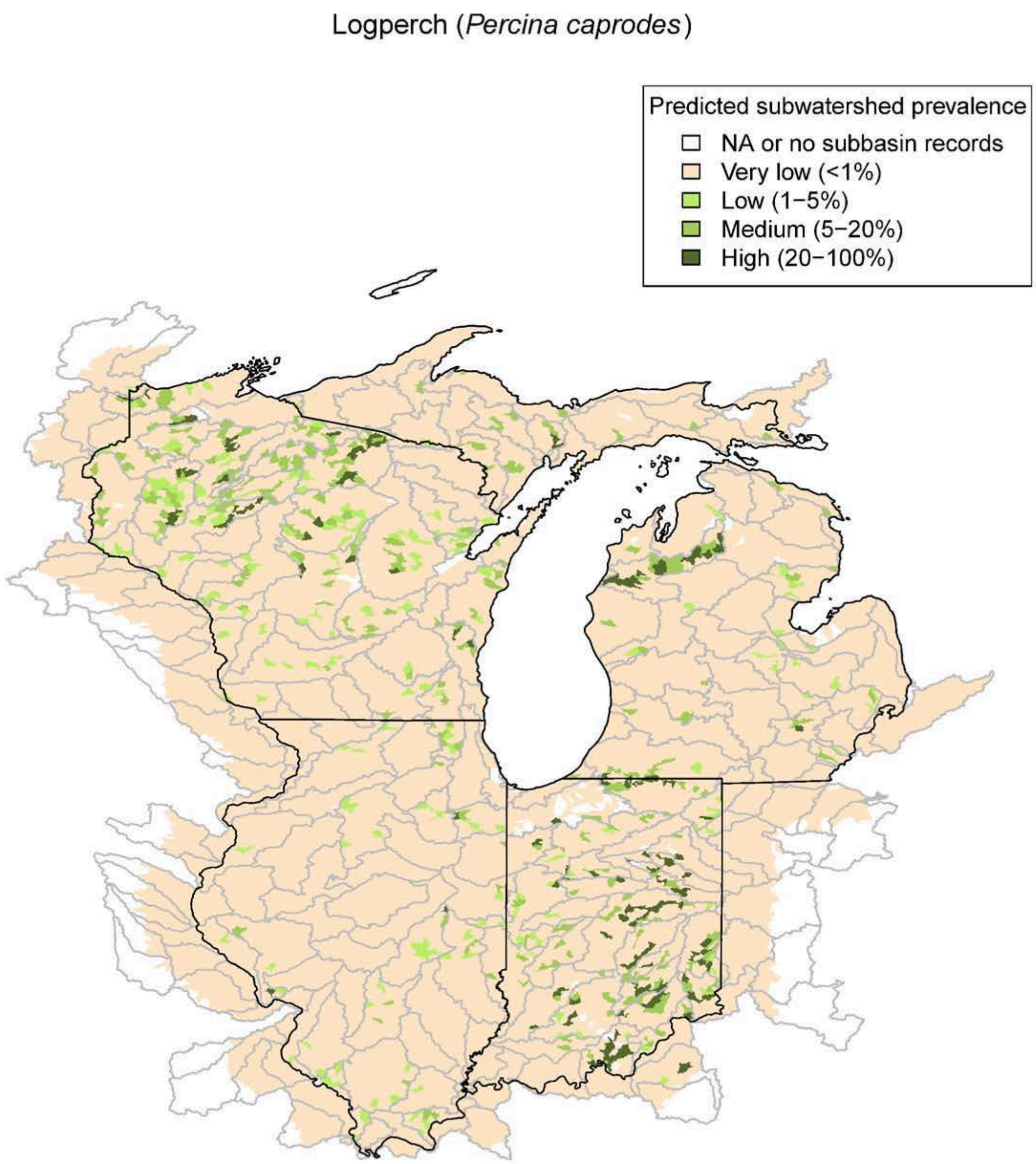

Figure 3r. Logperch distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Longear sunfish (*Lepomis megalotus*)

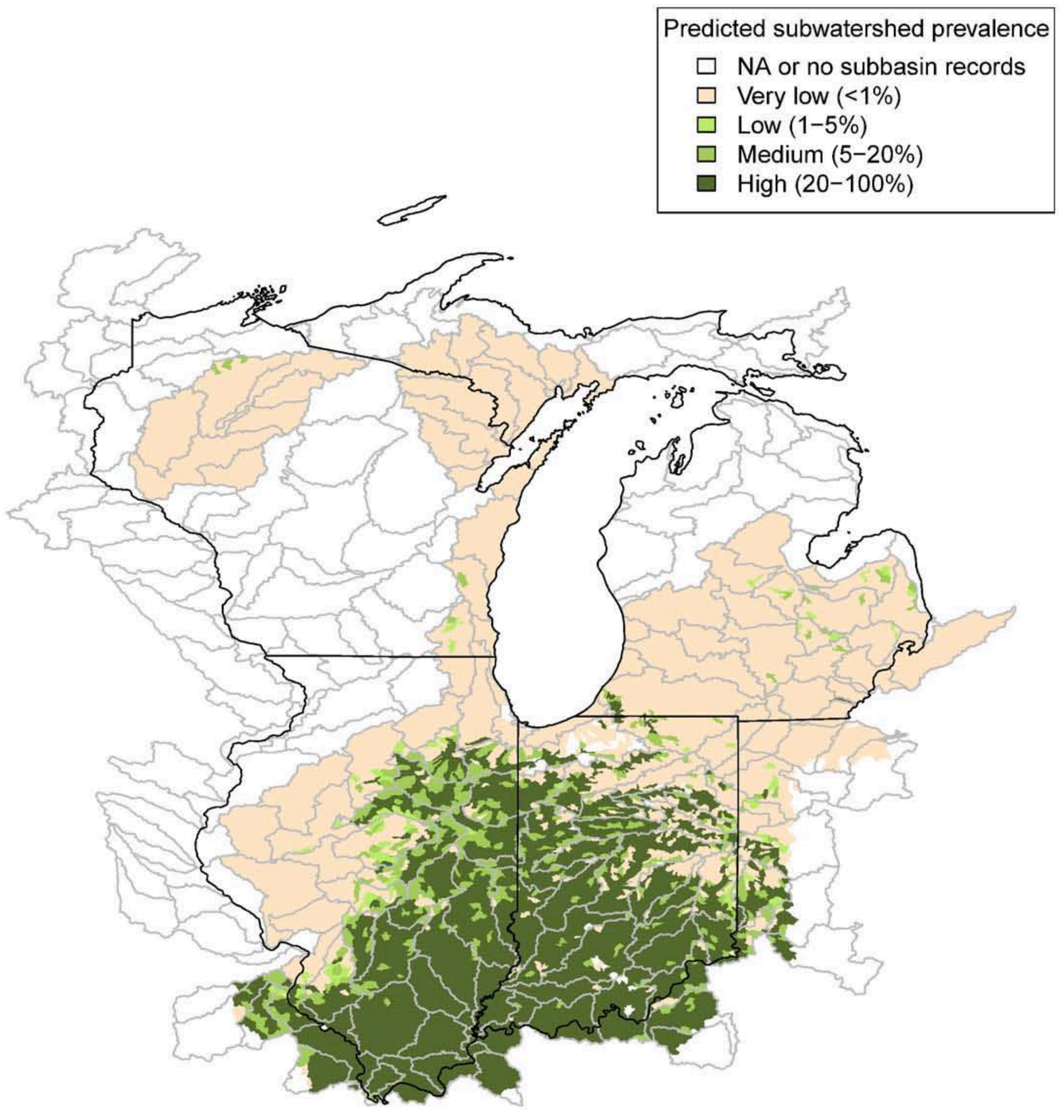

Figure 3s. Longear Sunfish distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

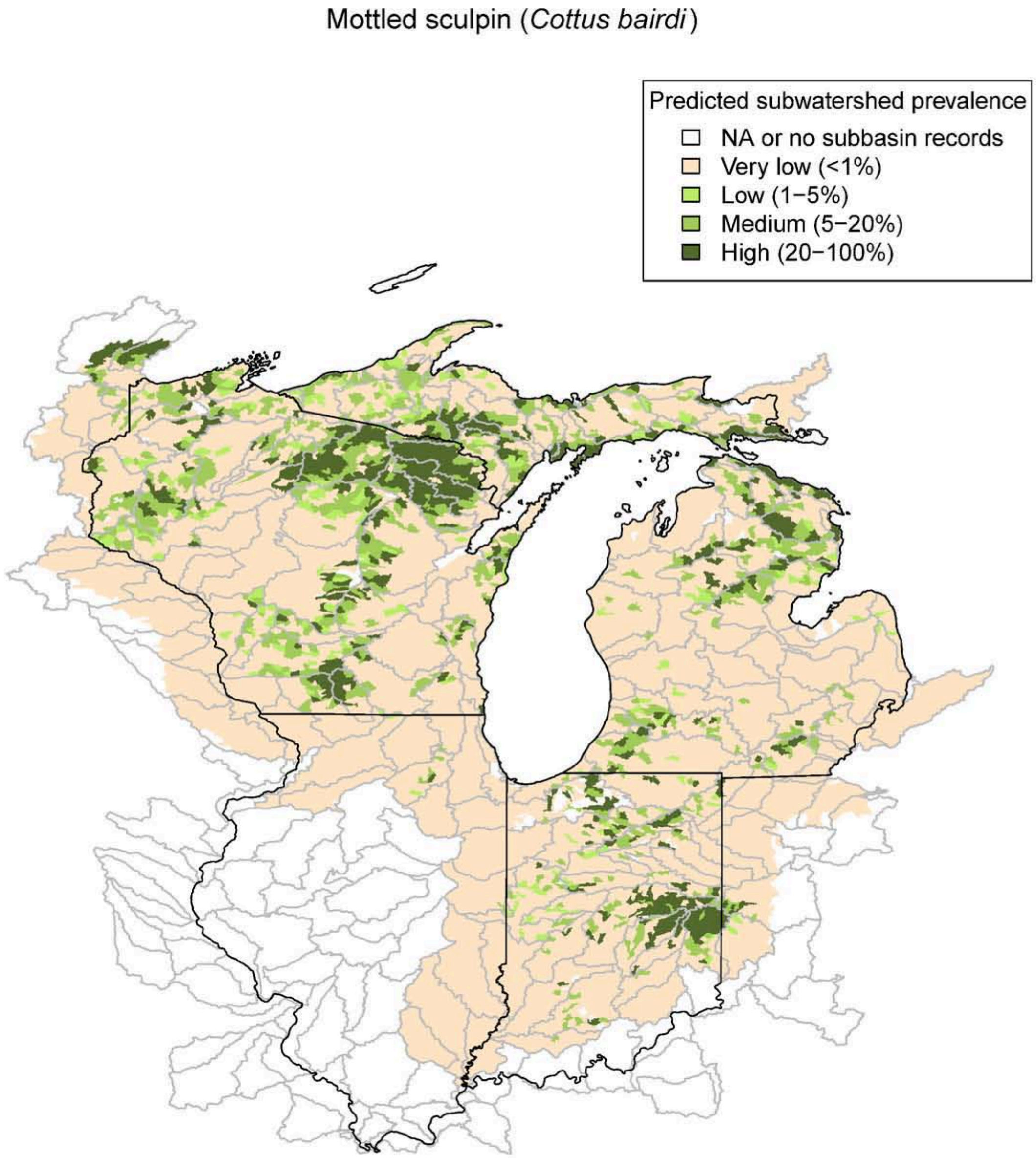

Figure 3t. Mottled Sculpin distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

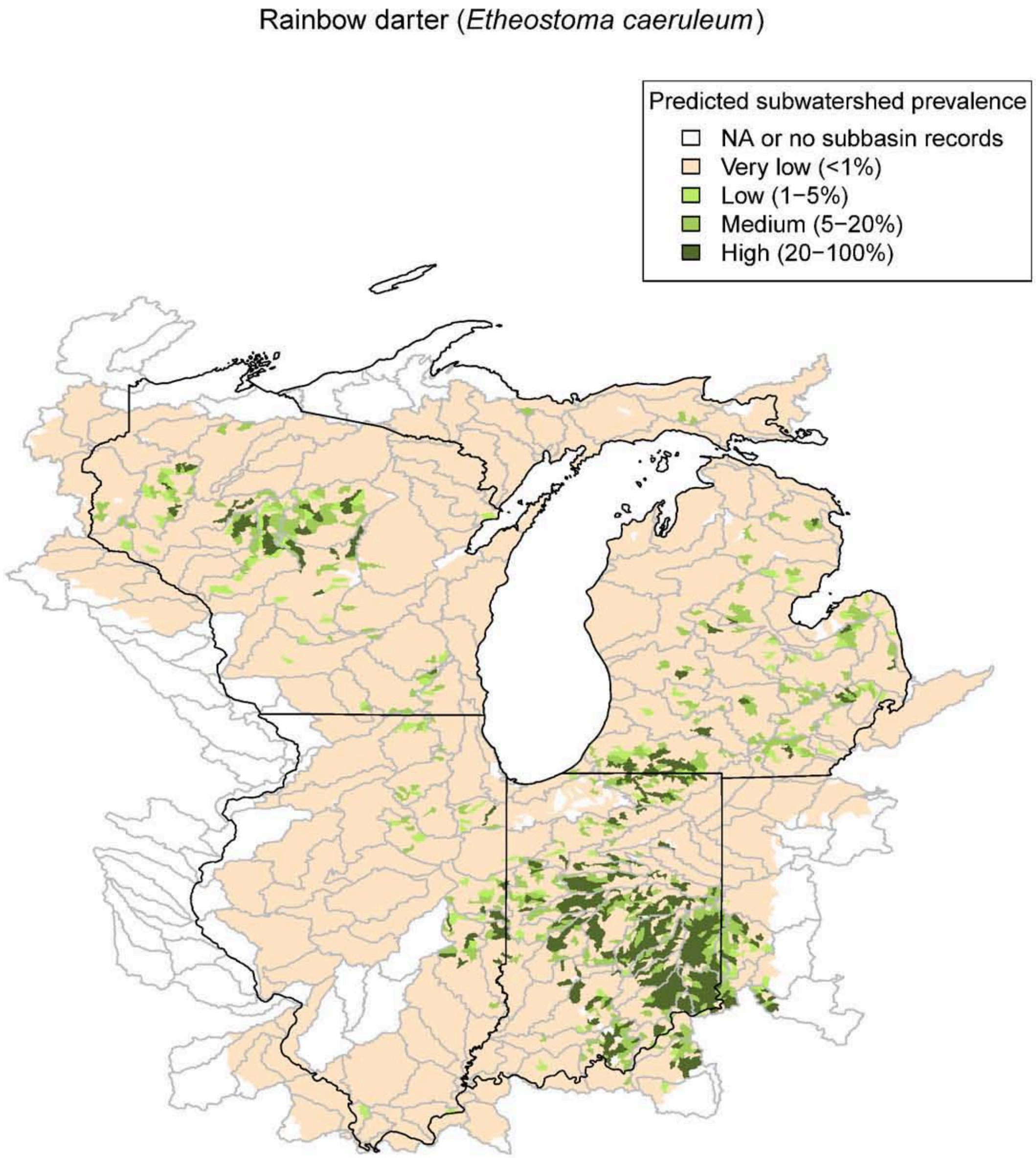

Figure 3u. Rainbow Darter distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Striped shiner (*Luxilus chrysocephalus*)

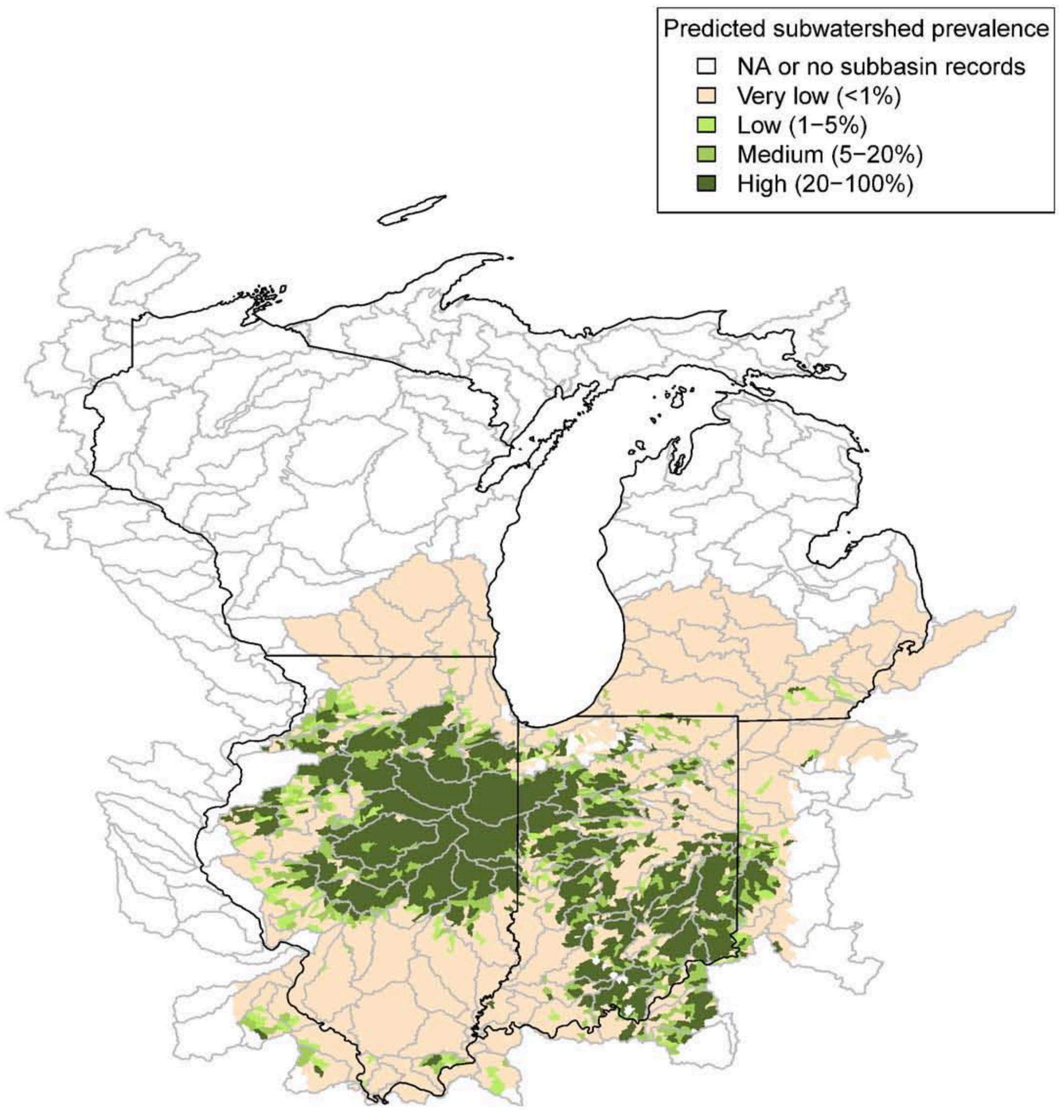

Figure 3v. Striped Shiner distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

Mudpuppy (*Necturus maculosus*)

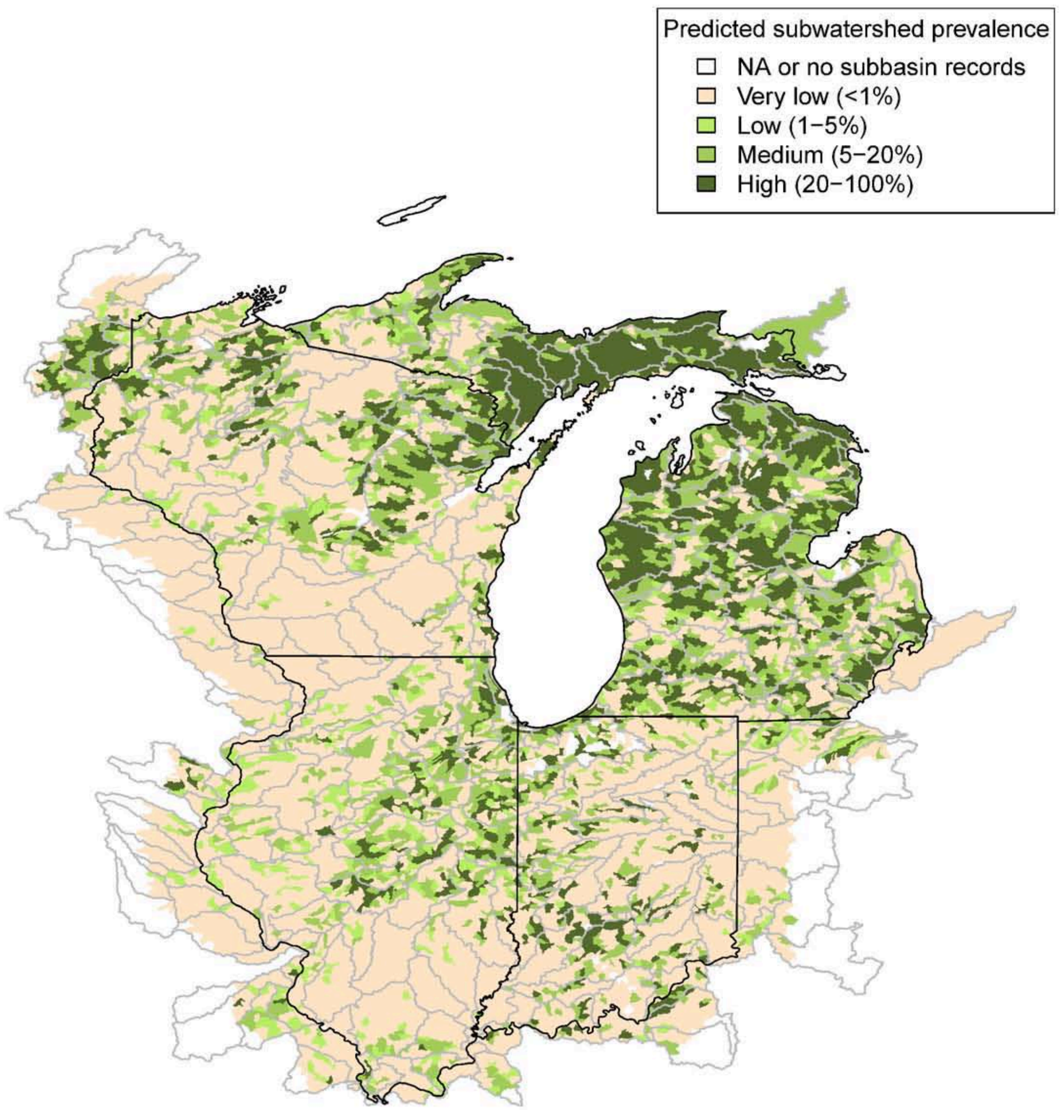

Figure 3w. Mudpuppy distribution. Predicted subwatershed (12-digit HUC) prevalence calculated as the proportion of reaches in which the species was predicted to be present. Note that model domains are restricted to subbasins (8-digit HUC) with at least one species record.

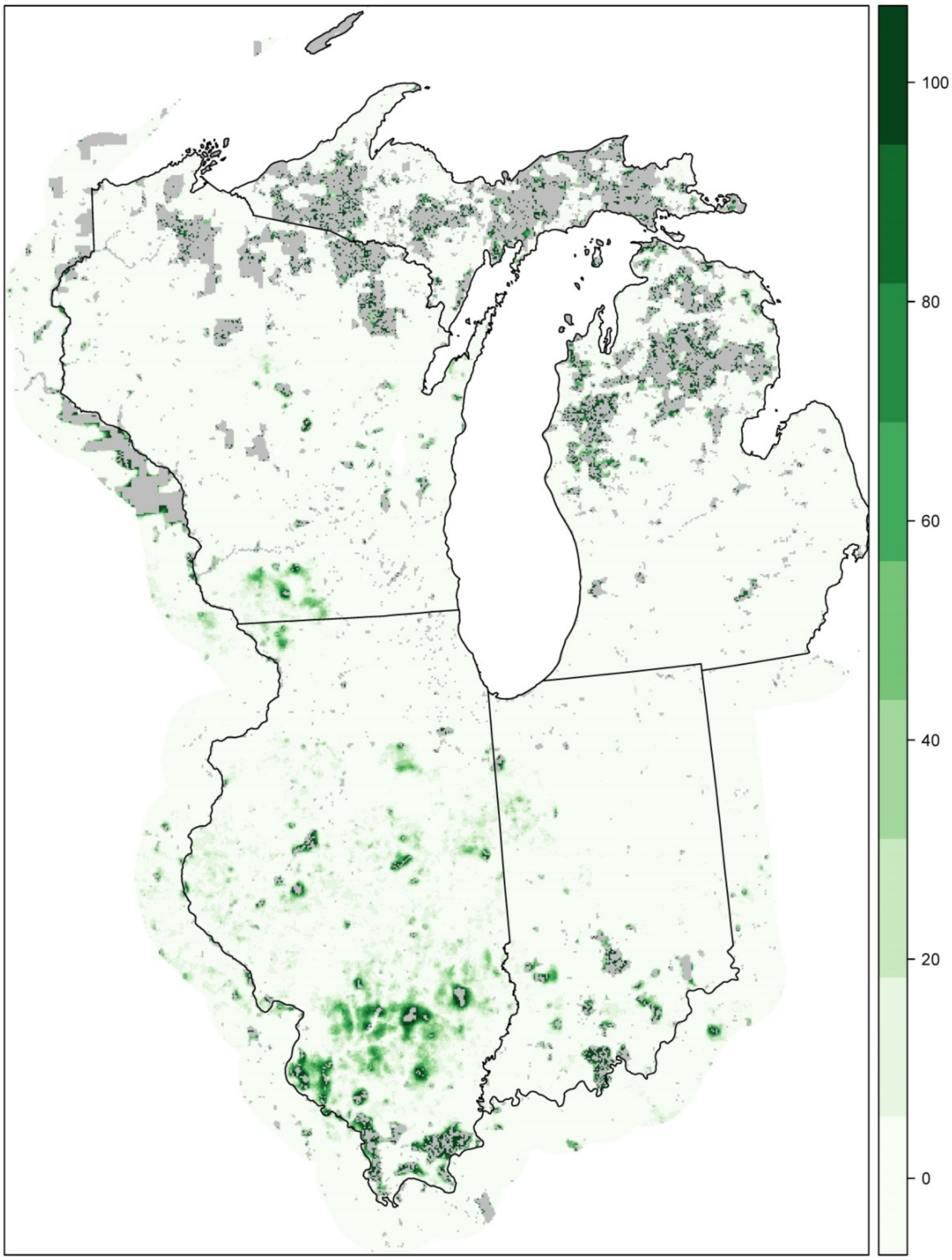

Figure 4a. Grassland bird conservation priorities generated using Marxan conservation planning software. Existing protected areas (PAD-US categories 1, 2, or 3) were locked into the reserve solution and are indicated in grey. The irreplaceability of planning units, defined as the number of Marxan reserve design solutions out of 100 iterations that included that planning unit, are indicated by shades of green.

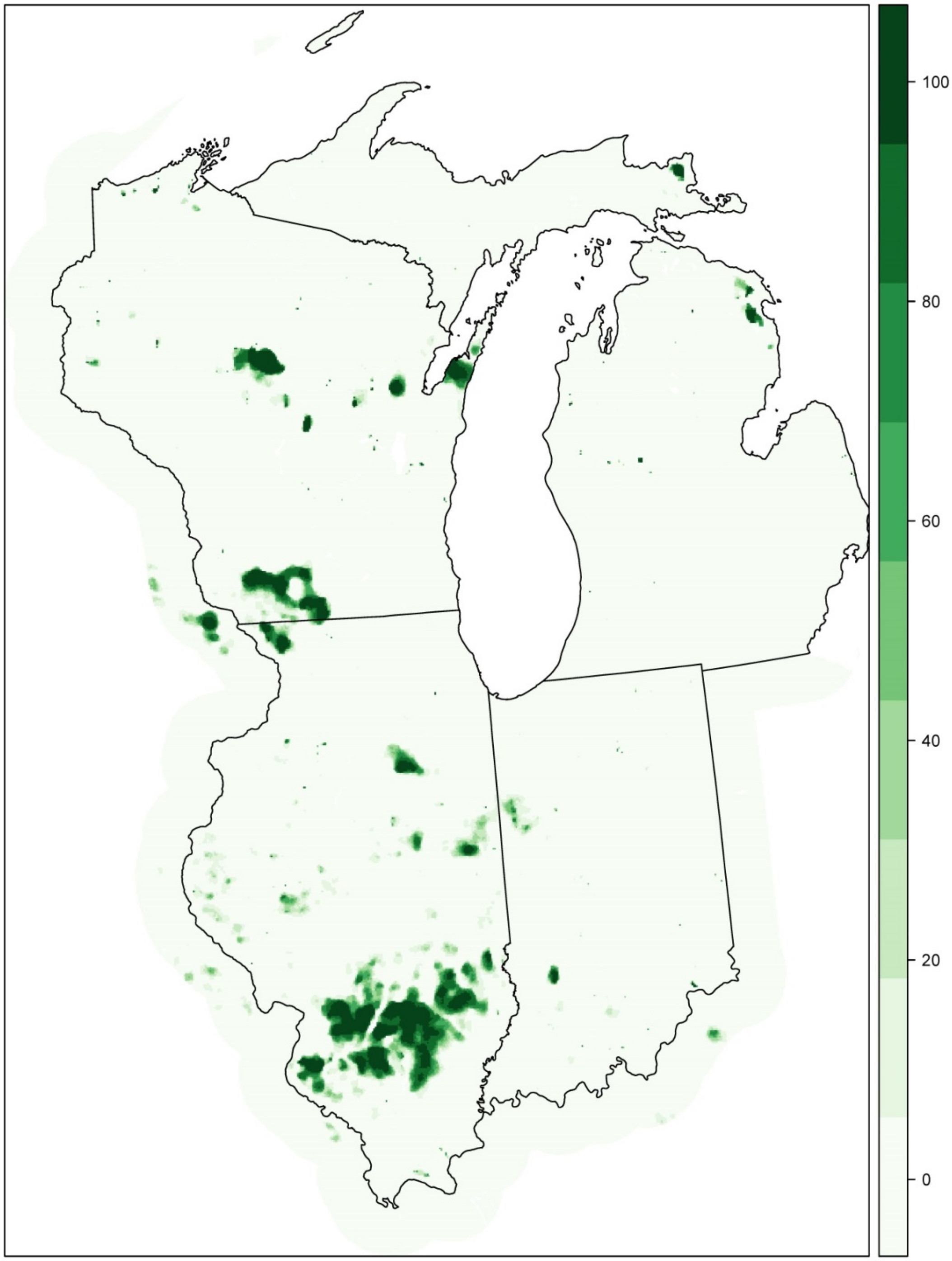

Figure 4b. Grassland bird conservation priorities generated using Marxan conservation planning software. In this Marxan analysis, no lands were locked in to the reserve solution. The irreplaceability of planning units, defined as the number of Marxan reserve design solutions out of 100 iterations that included that planning unit, are indicated by shades of green.

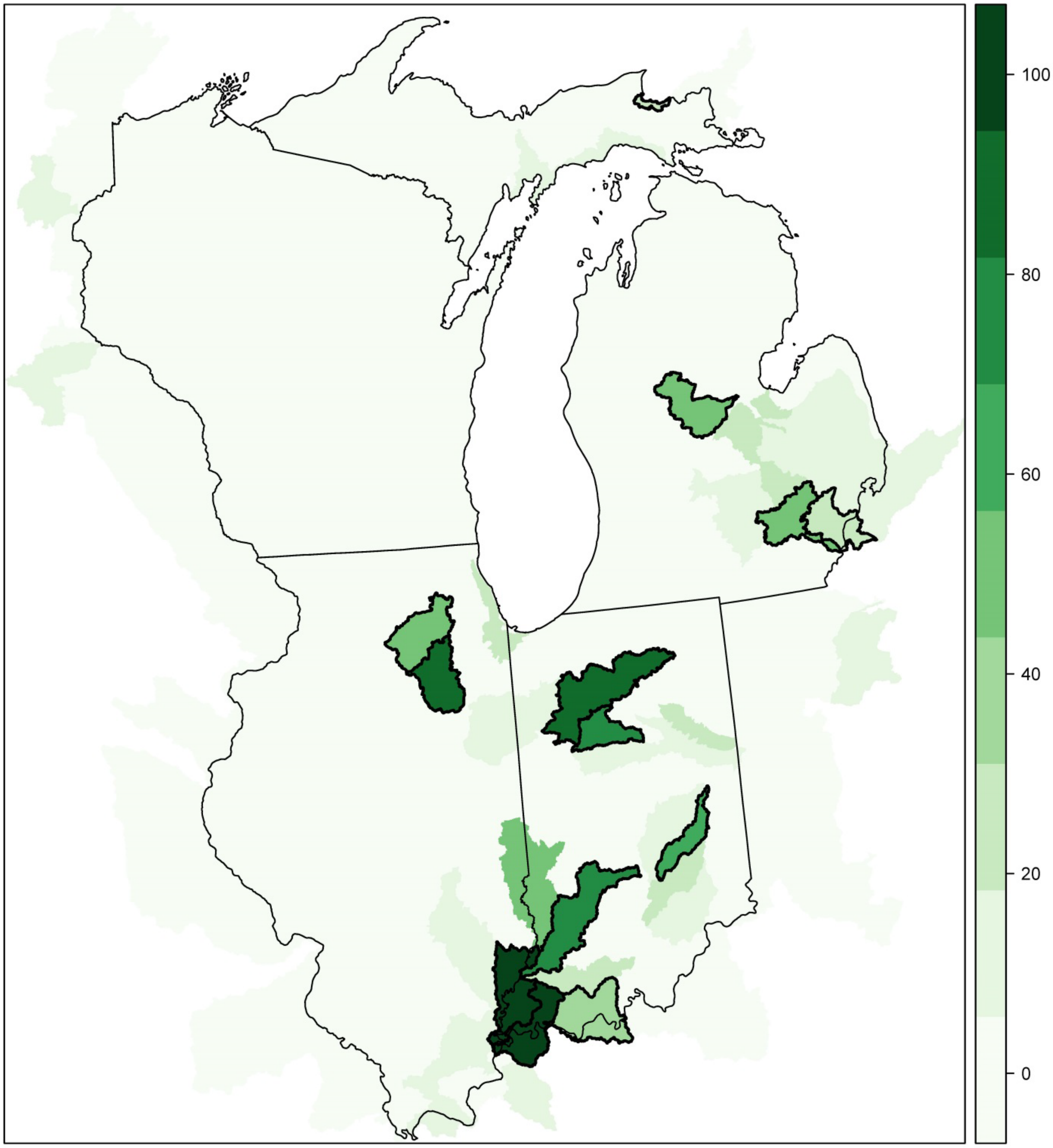

Figure 5. HUC8-scale stream conservation priorities generated by Marxan analysis. The irreplaceability of each planning unit is indicated with green shading. HUC8 watersheds that were selected by the best of 100 Marxan runs (i.e., the reserve solution with the lowest objective function value) are outlined in bold.