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

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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 (m²) 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 (172\textsuperscript{nd} 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 \((90k)^\circ\) and \((90k + 45)^\circ\) 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 \(\frac{7}{-2 + 3\sqrt{2}} \approx 3.12\) 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 $\geq$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.

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REFERENCES


**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.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>IL</th>
<th>IN</th>
<th>MI</th>
<th>WI</th>
</tr>
</thead>
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<tr>
<td><strong>Birds</strong></td>
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<tr>
<td>Bobolink</td>
<td><em>Dolichonyx oryzivorus</em></td>
<td>SGCN</td>
<td>SGCN</td>
<td>SGCN</td>
<td></td>
</tr>
<tr>
<td>Dickcissel</td>
<td><em>Spiza americana</em></td>
<td>SGCN</td>
<td>SGCN</td>
<td>SGCN</td>
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<tr>
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<td>SGCN</td>
<td>SGCN</td>
<td></td>
</tr>
<tr>
<td>Grasshopper Sparrow</td>
<td><em>Ammomanus savannarum</em></td>
<td>SGCN</td>
<td>SGCN</td>
<td>SGCN</td>
<td></td>
</tr>
<tr>
<td>Henslow's Sparrow</td>
<td><em>Ammomanus henslowii</em></td>
<td>ST</td>
<td>SE</td>
<td>SE</td>
<td>ST</td>
</tr>
<tr>
<td>Northern Harrier</td>
<td><em>Circus cyaneus</em></td>
<td>SE</td>
<td>SE</td>
<td>SGCN</td>
<td>SGCN</td>
</tr>
<tr>
<td>Short-eared Owl</td>
<td><em>Asio flammeus</em></td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SGCN</td>
</tr>
<tr>
<td>Upland Sandpiper</td>
<td><em>Bartramia longicauda</em></td>
<td>SE</td>
<td>SE</td>
<td>SGCN</td>
<td>ST</td>
</tr>
<tr>
<td><strong>Fish</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Redhorse</td>
<td><em>Moxostoma duquesnei</em></td>
<td>SGCN</td>
<td>SGCN</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td><strong>Freshwater mussels</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ellipse</td>
<td><em>Venustaconcha ellipsiformis</em></td>
<td>SGCN</td>
<td>SGCN</td>
<td>SGCN</td>
<td>ST</td>
</tr>
<tr>
<td>Fat Pocketbook</td>
<td><em>Potamilus capax</em></td>
<td>SE</td>
<td>SE</td>
<td>SGCN</td>
<td>SGCN</td>
</tr>
<tr>
<td>Kidneysshell</td>
<td><em>Ptychobranchus fasciolaris</em></td>
<td>SE</td>
<td>SGCN</td>
<td>SGCN</td>
<td></td>
</tr>
<tr>
<td>Purple Lilliput</td>
<td><em>Toxolasma lividus</em></td>
<td>SE</td>
<td>SGCN</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>Purple Wartyback</td>
<td><em>Cyclonaias tuberculata</em></td>
<td>SE</td>
<td>ST</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>Rainbow</td>
<td><em>Villosa iris</em></td>
<td>SE</td>
<td>SGCN</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>Salamander Mussel</td>
<td><em>Simpsonaias ambigua</em></td>
<td>SE</td>
<td>SGCN</td>
<td>SE</td>
<td>ST</td>
</tr>
<tr>
<td>Sheepnose</td>
<td><em>Plethobasus cyphyus</em></td>
<td>SE</td>
<td>SE</td>
<td>SGCN</td>
<td>SE</td>
</tr>
<tr>
<td>Slippershell</td>
<td><em>Alasmidonta viridis</em></td>
<td>SGCN</td>
<td>ST</td>
<td>ST</td>
<td></td>
</tr>
<tr>
<td>Snuffbox</td>
<td><em>Epioblasma triquetra</em></td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
</tr>
<tr>
<td><strong>Salamanders</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mudpuppy</td>
<td><em>Necturus maculosus</em></td>
<td>SGCN</td>
<td>SGCN</td>
<td>SGCN</td>
<td>SGCN</td>
</tr>
</tbody>
</table>
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).

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th>Mussel Species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alasmidonta viridis</td>
</tr>
<tr>
<td>Fish</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aplodinotus grunniens</td>
<td>Freshwater Drum</td>
<td></td>
</tr>
<tr>
<td>Cottus bairdi</td>
<td>Mottled Sculpin</td>
<td>✓</td>
</tr>
<tr>
<td>Culaea inconstans</td>
<td>Brook Stickleback</td>
<td></td>
</tr>
<tr>
<td>Etheostoma caeruleum</td>
<td>Rainbow Darter</td>
<td></td>
</tr>
<tr>
<td>Etheostoma nigrum</td>
<td>Johnny Darter</td>
<td>✓</td>
</tr>
<tr>
<td>Ictalurus punctatus</td>
<td>Channel Catfish</td>
<td></td>
</tr>
<tr>
<td>Lepomis cyanellus</td>
<td>Green Sunfish</td>
<td></td>
</tr>
<tr>
<td>Lepomis megalotis</td>
<td>Longear Sunfish</td>
<td></td>
</tr>
<tr>
<td>Luxilus chrysocephalus</td>
<td>Striped Shiner</td>
<td></td>
</tr>
<tr>
<td>Percina caprodes</td>
<td>Logperch</td>
<td></td>
</tr>
<tr>
<td>Percina maculata</td>
<td>Blackside Darter</td>
<td></td>
</tr>
<tr>
<td>Salamander</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Necturus maculosis</td>
<td>Mudpuppy</td>
<td></td>
</tr>
<tr>
<td># of modeled hosts</td>
<td>2 1 3 1</td>
<td></td>
</tr>
<tr>
<td>Total # listed hosts</td>
<td>3 4 6 27 1</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Project partners and data contributors.

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

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Illinois</th>
<th>Indiana</th>
<th>Michigan</th>
<th>Wisconsin</th>
<th>All states</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td># stops</td>
<td>%</td>
<td># stops</td>
<td>%</td>
<td># stops</td>
</tr>
<tr>
<td>Bobolink</td>
<td>Dolichonyx oryzivorus</td>
<td>181</td>
<td>3.5%</td>
<td>164</td>
<td>5.9%</td>
<td>546</td>
</tr>
<tr>
<td>Dickcissel</td>
<td>Spiza americana</td>
<td>2000</td>
<td>62.7%</td>
<td>736</td>
<td>26.3%</td>
<td>62</td>
</tr>
<tr>
<td>Eastern Meadowlark</td>
<td>Synallaxis magna</td>
<td>3696</td>
<td>72.5%</td>
<td>1632</td>
<td>58.3%</td>
<td>825</td>
</tr>
<tr>
<td>Grasshopper Sparrow</td>
<td>Ammodramus savannarum</td>
<td>768</td>
<td>15.1%</td>
<td>344</td>
<td>12.3%</td>
<td>147</td>
</tr>
<tr>
<td>Henslow's Sparrow</td>
<td>Ammodramus henslowi</td>
<td>30</td>
<td>0.6%</td>
<td>47</td>
<td>1.7%</td>
<td>22</td>
</tr>
<tr>
<td>Northern Harrier</td>
<td>Circus cyanus</td>
<td>42</td>
<td>0.8%</td>
<td>15</td>
<td>0.5%</td>
<td>79</td>
</tr>
<tr>
<td>Short-eared Owl</td>
<td>Asio flammeus</td>
<td>0</td>
<td>0.0%</td>
<td>0</td>
<td>0.0%</td>
<td>1</td>
</tr>
<tr>
<td>Upland Sandpiper</td>
<td>Bartramia longicauda</td>
<td>90</td>
<td>1.8%</td>
<td>13</td>
<td>0.5%</td>
<td>96</td>
</tr>
</tbody>
</table>

All surveys    |                                   | 5100     | 2800    | 4450     | 4450      | 16800      | 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.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Illinois</th>
<th>Indiana</th>
<th>Michigan</th>
<th>Wisconsin</th>
<th>All states</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td># records</td>
<td>%</td>
<td># records</td>
<td>%</td>
<td># records</td>
</tr>
<tr>
<td>Black Redhorse</td>
<td>Moxostoma duquesnei</td>
<td>269</td>
<td>8%</td>
<td>288</td>
<td>17%</td>
<td>13</td>
</tr>
<tr>
<td>Blackside Darter</td>
<td>Percina maculata</td>
<td>558</td>
<td>16%</td>
<td>184</td>
<td>11%</td>
<td>234</td>
</tr>
<tr>
<td>Brook Stickleback</td>
<td>Culea inconstans</td>
<td>19</td>
<td>1%</td>
<td>5</td>
<td>0%</td>
<td>146</td>
</tr>
<tr>
<td>Channel Catfish</td>
<td>Ictalurus punctatus</td>
<td>1347</td>
<td>39%</td>
<td>240</td>
<td>14%</td>
<td>35</td>
</tr>
<tr>
<td>Freshwater Drum</td>
<td>Aplodinotus grunniens</td>
<td>986</td>
<td>29%</td>
<td>154</td>
<td>9%</td>
<td>21</td>
</tr>
<tr>
<td>Green Sunfish</td>
<td>Lepomis cyanellus</td>
<td>2164</td>
<td>63%</td>
<td>1205</td>
<td>69%</td>
<td>334</td>
</tr>
<tr>
<td>Johnny Darter</td>
<td>Ethostoma nigrum</td>
<td>1278</td>
<td>37%</td>
<td>951</td>
<td>55%</td>
<td>446</td>
</tr>
<tr>
<td>Logperch</td>
<td>Percina caprodes</td>
<td>299</td>
<td>9%</td>
<td>264</td>
<td>15%</td>
<td>101</td>
</tr>
<tr>
<td>Longear Sunfish</td>
<td>Lepomis megalotus</td>
<td>1325</td>
<td>39%</td>
<td>834</td>
<td>48%</td>
<td>33</td>
</tr>
<tr>
<td>Mottled Sculpin</td>
<td>Cottus baiki</td>
<td>35</td>
<td>1%</td>
<td>345</td>
<td>20%</td>
<td>330</td>
</tr>
<tr>
<td>Rainbow Darter</td>
<td>Ethostoma caeruleum</td>
<td>222</td>
<td>6%</td>
<td>478</td>
<td>27%</td>
<td>180</td>
</tr>
<tr>
<td>Striped Shiner</td>
<td>Luxilus chrysomelas</td>
<td>967</td>
<td>28%</td>
<td>639</td>
<td>37%</td>
<td>17</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Scientific name</th>
<th>Common name</th>
<th># records</th>
<th>Maxent AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IL</td>
<td>IN</td>
</tr>
<tr>
<td>Alasmidonta viridis</td>
<td>Slippershell</td>
<td>104</td>
<td>49</td>
</tr>
<tr>
<td>Cyclonaias tuberculata</td>
<td>Purple Wartyback</td>
<td>59</td>
<td>108</td>
</tr>
<tr>
<td>Epioblasma triquetra</td>
<td>Snuffbox</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Plethobasus cyphus</td>
<td>Sheepnose</td>
<td>8</td>
<td>28</td>
</tr>
<tr>
<td>Potamilus capax</td>
<td>Fat Pocketbook</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Ptychobranchus fasciolaris</td>
<td>Kidneyshell</td>
<td>12</td>
<td>102</td>
</tr>
<tr>
<td>Simpsonaias ambigua</td>
<td>Salamander Mussel</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Toxolasma lividus</td>
<td>Purple Lilliput</td>
<td>20</td>
<td>34</td>
</tr>
<tr>
<td>Venustaconcha ellipsiformis</td>
<td>Ellipse</td>
<td>164</td>
<td>36</td>
</tr>
<tr>
<td>Villosa iris</td>
<td>Rainbow</td>
<td>16</td>
<td>105</td>
</tr>
<tr>
<td>Necturus maculosus</td>
<td>Mudpuppy</td>
<td>24</td>
<td>15</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Variable type</th>
<th>Selected</th>
<th>Variable name</th>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disturbance</td>
<td>✓</td>
<td>L_URBANL</td>
<td>NFHD</td>
<td>% of local catchment defined as developed, open space and low intensity</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_URBANM</td>
<td>NFHD</td>
<td>% of local catchment defined as developed, medium intensity</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_URBANH</td>
<td>NFHD</td>
<td>% of local catchment defined as developed, high intensity</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_PASTURE</td>
<td>NFHD</td>
<td>% of local catchment defined as pasture/hay</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_CROPS</td>
<td>NFHD</td>
<td>% of local catchment defined as cultivated crops</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_POPDENS</td>
<td>NFHD</td>
<td>% of local catchment defined as developed, open space and low intensity</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_ROADCR_dens</td>
<td>NFHD</td>
<td>Density of road crossings within local catchment (number/area)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_ROADLEN_dens</td>
<td>NFHD</td>
<td>Density of roads within local catchment in meters (length/area)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_DAMS</td>
<td>NFHD</td>
<td>Number of dams within local catchment</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_MINES</td>
<td>NFHD</td>
<td>Number of mines or mineral processing plants within local catchment</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_TRI</td>
<td>NFHD</td>
<td>Number of TRI sites within local catchment; Toxics Release Inventory (TRI) Program</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_NPDES</td>
<td>NFHD</td>
<td>Number of NPDES sites within local catchment; National Pollutant Discharge Elimination System (NPDES)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>L_CERC</td>
<td>NFHD</td>
<td>Number of SNPL sites within local catchment; Superfund National Priorities List (SNPL) from the Compensation and Liability Information System (CERCLIS)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_URBANLC</td>
<td>NFHD</td>
<td>% of network catchment defined as developed, open space and low intensity</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_URBANMC</td>
<td>NFHD</td>
<td>% of network catchment defined as developed, medium intensity</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_URBANHC</td>
<td>NFHD</td>
<td>% of network catchment defined as developed, high intensity</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_PASTUREC</td>
<td>NFHD</td>
<td>% of network catchment defined as pasture/hay</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_CROPSC</td>
<td>NFHD</td>
<td>% of network catchment defined as cultivated crops</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_POPDENS</td>
<td>NFHD</td>
<td>Mean population density within network catchment (units = Individuals/km2)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_ROADCR_dens</td>
<td>NFHD</td>
<td>Density of road crossings within network catchment (number/area)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_ROADLEN_dens</td>
<td>NFHD</td>
<td>Density of roads within network catchment in meters (length/area)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_DAMSC</td>
<td>NFHD</td>
<td>Number of dams within network catchment</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_MINESC</td>
<td>NFHD</td>
<td>Number of mines or mineral processing plants within network catchment</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_TRIC</td>
<td>NFHD</td>
<td>Number of TRI sites within network catchment; Toxics Release Inventory (TRI) Program</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_NPDESC</td>
<td>NFHD</td>
<td>Number of NPDES sites within local catchment; National Pollutant Discharge Elimination System (NPDES)</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>N_CERC</td>
<td>NFHD</td>
<td>Number of SNPL sites within local catchment; Superfund National Priorities List (SNPL) from the Compensation and Liability Information System (CERCLIS)</td>
</tr>
<tr>
<td>Land cover</td>
<td>✓</td>
<td>NLCD_11</td>
<td>NLCD</td>
<td>% of catchment area classified as Open Water in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_12</td>
<td>NLCD</td>
<td>% of catchment area classified as Perennial Ice/Snow in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_21</td>
<td>NLCD</td>
<td>% of catchment area classified as Low Intensity Residential in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_22</td>
<td>NLCD</td>
<td>% of catchment area classified as High Intensity Residential in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_23</td>
<td>NLCD</td>
<td>% of catchment area classified as Commercial/Industrial/Transportation in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_32</td>
<td>NLCD</td>
<td>% of catchment area classified as Aquararies/Strip Mines/Gravel Pits in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_33</td>
<td>NLCD</td>
<td>% of catchment area classified as Transitional in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_41</td>
<td>NLCD</td>
<td>% of catchment area classified as Deciduous Forest in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_42</td>
<td>NLCD</td>
<td>% of catchment area classified as Evergreen Forest in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_43</td>
<td>NLCD</td>
<td>% of catchment area classified as Mixed Forest in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_51</td>
<td>NLCD</td>
<td>% of catchment area classified as Shrubland in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_61</td>
<td>NLCD</td>
<td>% of catchment area classified as Orchards/Vineyards/Other in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_71</td>
<td>NLCD</td>
<td>% of catchment area classified as Grasslands/Herbaceous in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_81</td>
<td>NLCD</td>
<td>% of catchment area classified as Pasture/Hay in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_82</td>
<td>NLCD</td>
<td>% of catchment area classified as Row Crops in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_83</td>
<td>NLCD</td>
<td>% of catchment area classified as Small Grains in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_84</td>
<td>NLCD</td>
<td>% of catchment area classified as Fallow in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_85</td>
<td>NLCD</td>
<td>% of catchment area classified as Urban/Recreational Grasses in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_91</td>
<td>NLCD</td>
<td>% of catchment area classified as Woody Wetlands in NLCD</td>
</tr>
<tr>
<td></td>
<td>✓</td>
<td>NLCD_92</td>
<td>NLCD</td>
<td>% of catchment area classified as Emergent Herbaceous Wetland in NLCD</td>
</tr>
</tbody>
</table>
Table 8. Predictors used for aquatic species modeling. Continued...

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

Climate
Table 9. Grassland bird modeling effectiveness expressed as mtry and pseudo-R².

<table>
<thead>
<tr>
<th>Species</th>
<th>Scientific name</th>
<th>mtry</th>
<th>pseudo-R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upland Sandpiper</td>
<td><em>Bartramia longicauda</em></td>
<td>2</td>
<td>0.17</td>
</tr>
<tr>
<td>Bobolink</td>
<td><em>Dolichonyx oryzivorus</em></td>
<td>2</td>
<td>0.28</td>
</tr>
<tr>
<td>Eastern Meadowlark</td>
<td><em>Sturnella magna</em></td>
<td>2</td>
<td>0.41</td>
</tr>
<tr>
<td>Grasshopper Sparrow</td>
<td><em>Ammodramus savannarum</em></td>
<td>2</td>
<td>0.16</td>
</tr>
<tr>
<td>Dickcissel</td>
<td><em>Spiza americana</em></td>
<td>3</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Table 10. Fish modeling effectiveness for presence and abundance models expressed as mtry and pseudo-R² and misclassifications.

<table>
<thead>
<tr>
<th>Fish Species</th>
<th>Modeled prevalence</th>
<th>Presence</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mtry</td>
<td>OOB error</td>
<td>Misclassification of absences</td>
</tr>
<tr>
<td>Black Redhorse</td>
<td>0.04</td>
<td>9</td>
<td>0.02</td>
</tr>
<tr>
<td>Blackside Darter</td>
<td>0.11</td>
<td>4</td>
<td>0.09</td>
</tr>
<tr>
<td>Brook Stickleback</td>
<td>0.24</td>
<td>10</td>
<td>0.19</td>
</tr>
<tr>
<td>Channel Catfish</td>
<td>0.09</td>
<td>8</td>
<td>0.06</td>
</tr>
<tr>
<td>Freshwater Drum</td>
<td>0.07</td>
<td>7</td>
<td>0.04</td>
</tr>
<tr>
<td>Green Sunfish</td>
<td>0.25</td>
<td>9</td>
<td>0.14</td>
</tr>
<tr>
<td>Johnny Darter</td>
<td>0.34</td>
<td>9</td>
<td>0.20</td>
</tr>
<tr>
<td>Logperch</td>
<td>0.07</td>
<td>5</td>
<td>0.07</td>
</tr>
<tr>
<td>Longear Sunfish</td>
<td>0.19</td>
<td>4</td>
<td>0.06</td>
</tr>
<tr>
<td>Mottled Sculpin</td>
<td>0.20</td>
<td>8</td>
<td>0.14</td>
</tr>
<tr>
<td>Rainbow Darter</td>
<td>0.06</td>
<td>7</td>
<td>0.04</td>
</tr>
<tr>
<td>Striped Shiner</td>
<td>0.20</td>
<td>9</td>
<td>0.09</td>
</tr>
<tr>
<td>Average</td>
<td>0.16</td>
<td>7</td>
<td>0.10</td>
</tr>
</tbody>
</table>
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).

<table>
<thead>
<tr>
<th>Bird Species</th>
<th>Predicted relative population size</th>
<th>Target protected relative population size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dickcissel</td>
<td>21385</td>
<td>2139</td>
</tr>
<tr>
<td>Grasshopper Sparrow</td>
<td>1241</td>
<td>124</td>
</tr>
<tr>
<td>Eastern Meadowlark</td>
<td>32681</td>
<td>3268</td>
</tr>
<tr>
<td>Bobolink</td>
<td>4453</td>
<td>445</td>
</tr>
<tr>
<td>Upland Sandpiper</td>
<td>79</td>
<td>8</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Predicted length of stream occupied (km)</th>
<th>Target length of stream protected (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fish</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black redhorse</td>
<td>3203</td>
<td>500</td>
</tr>
<tr>
<td><strong>Freshwater mussels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainbow</td>
<td>12383</td>
<td>1238</td>
</tr>
<tr>
<td>Ellipse</td>
<td>15939</td>
<td>1594</td>
</tr>
<tr>
<td>Purple Lilliput</td>
<td>2600</td>
<td>500</td>
</tr>
<tr>
<td>Salamander Mussel</td>
<td>5983</td>
<td>598</td>
</tr>
<tr>
<td>Kidneyshell</td>
<td>4012</td>
<td>500</td>
</tr>
<tr>
<td>Fat Pocketbook</td>
<td>868</td>
<td>500</td>
</tr>
<tr>
<td>Sheepnose</td>
<td>2258</td>
<td>500</td>
</tr>
<tr>
<td>Snuffbox</td>
<td>3925</td>
<td>500</td>
</tr>
<tr>
<td>Purple Wartyback</td>
<td>7638</td>
<td>764</td>
</tr>
<tr>
<td>Slippershell</td>
<td>30725</td>
<td>2000</td>
</tr>
<tr>
<td><strong>Salamander</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mudpuppy</td>
<td>34740</td>
<td>2000</td>
</tr>
</tbody>
</table>
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.
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.
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. Dickcissel 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.
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.
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.
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.
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.
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.
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.
Fig. 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.
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.
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.
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.
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.
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.