Cave/Karst Resources Across the Appalachian LCC
A Visual Guide to Results

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Background

For the past 18 months, we have been gathering and analyzing data on caves and karst in the Appalachian LCC. The project is divided into a series of tasks and deliverables, including narratives, data in Excel™ tables, geospatial information layers (shapefiles and raster data), and a variety of maps. The maps and files provide a comprehensive overview of data availability for examining relationships between environmental factors and biological diversity and distribution within karst areas of the Appalachian LCC. This visual survey is intended to be a guide to what we have accomplished, and a guide to what new questions and results would be interesting to end-users. We have focused on region-wide results, but of course smaller areas (*e.g.,* states, counties, or ecoregions) also could be analyzed. We also focused on the obligate cave-dwelling fauna, but we present some preliminary results for cave-inhabiting bats. For convenience, the guide is divided into seven parts:

- The distribution of known caves and karst within the region
- Taxonomic distribution of the obligate cave-dwelling fauna
- Geographic patterns of species richness and ranges of major faunal groups
- Landscape and physical features that are potential predictors of species richness and presence/absence of major groups
- Predictions of the presence of nine major ecological groups
- Geography of risk to the subterranean fauna
- Geographic patterns of bat utilization of caves

The distribution of caves and karst within the region

Figure 1 shows the distribution of caves for the states where data were provided for this project. Most states within the Appalachian LCC have volunteer organizations, usually affiliated with the National Speleological Society, that keep records of locations of caves. These records are of mixed quality because of varying degrees of effort, with some states, such as New York and North Carolina, having no publicly identifiable cave survey, and other such as Virginia having a well-organized survey that provides information to a wide variety of end-users. Additionally, the definition of cave varies from state to state, with minimum lengths for designation as a cave ranging from 5 to 30 m. Because most caves are short, the number of caves in an area is very sensitive to this minimum length threshold making comparisons among states difficult.

The spatial distribution of reported cave locations (displayed as yellow dots) is shown in Figure 1. States for which there are no locations except for those where stygobionts and troglobionts have not been found because their inclusion would be misleading, giving the sense that there were many fewer caves in that state than there actually are. Such biased data would be misleading.

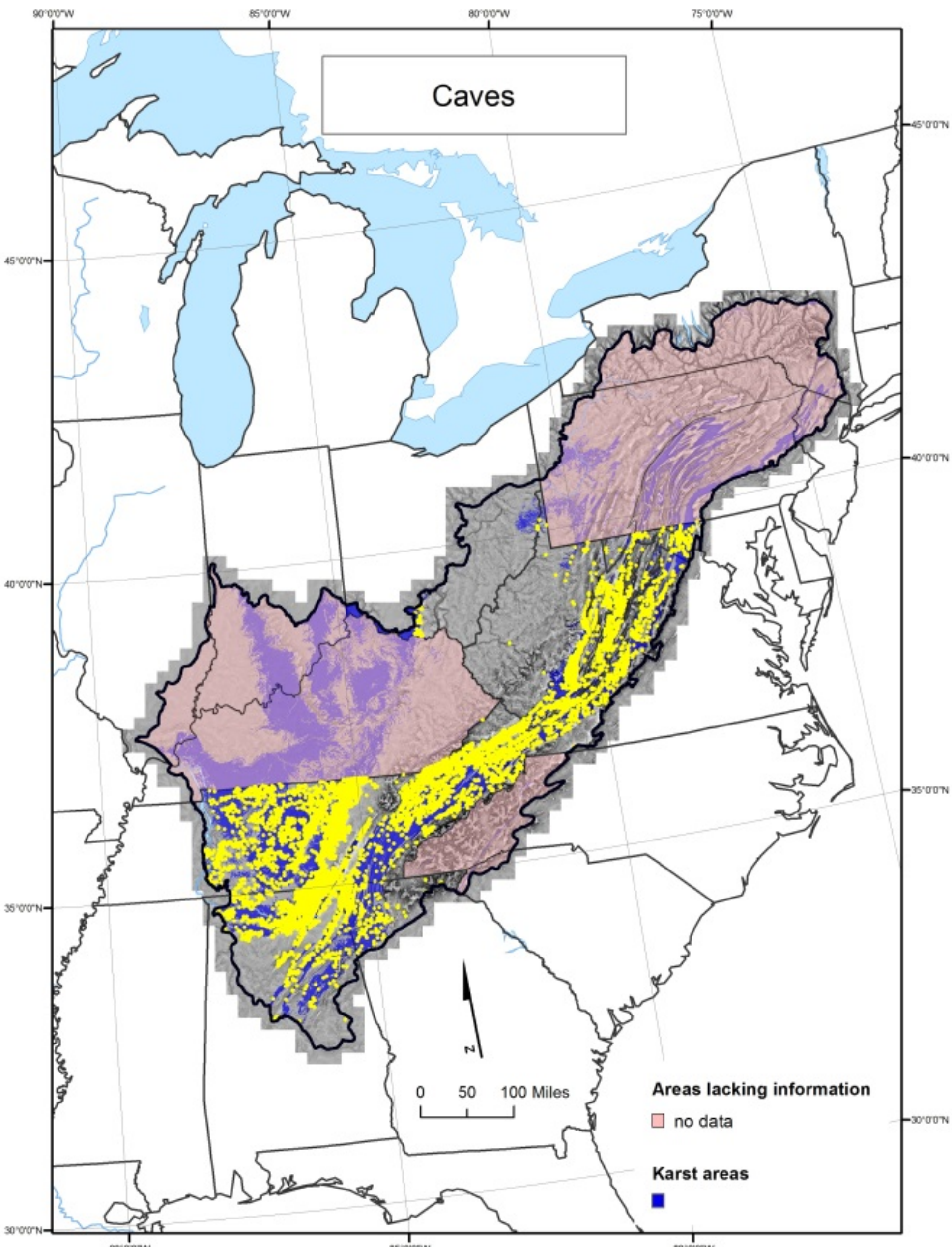


Figure 1.

Figure 2 depicts the same data but displayed in 20 by 20 km grid cells. We used this size grid because when smaller grids are used, many gaps of missing data occur due to varying levels of sampling effort.

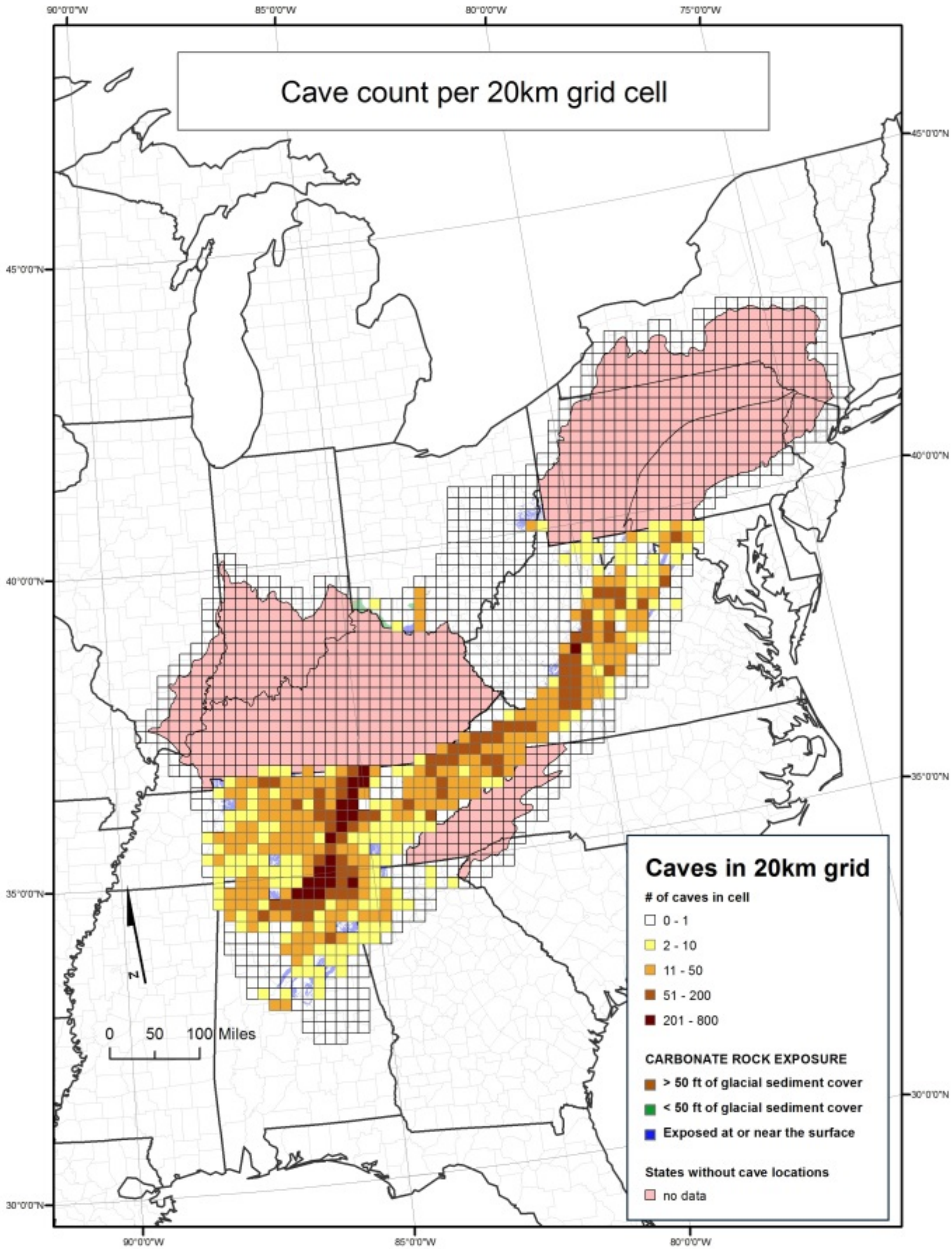


Figure 2.

More useful, and more comparable across the whole region is the USGS karst map, shown in Figure 3 for the Appalachian LCC.

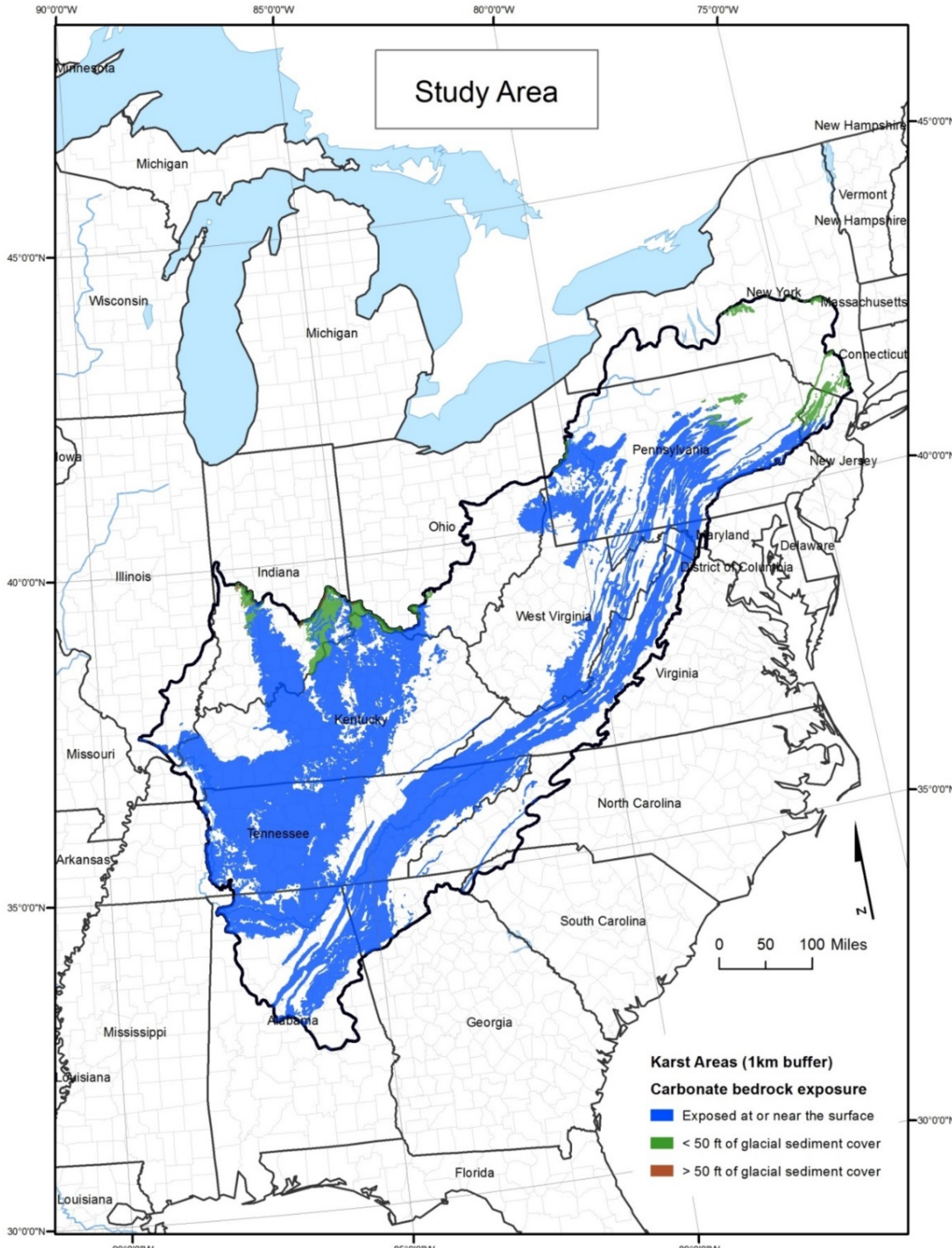


Figure 3.

The karst map provides the basic template for analyzing the distribution of cave species. Almost without exception, all caves occur within the karst areas. There were a few records of cave-dwelling species from outside karst areas (mostly springs) but we trimmed all data to fit within the karst areas, with a 1 km buffer to allow for errors in georeferencing). The aquatic and terrestrial records are shown below in Figure 4 and Figure 5.

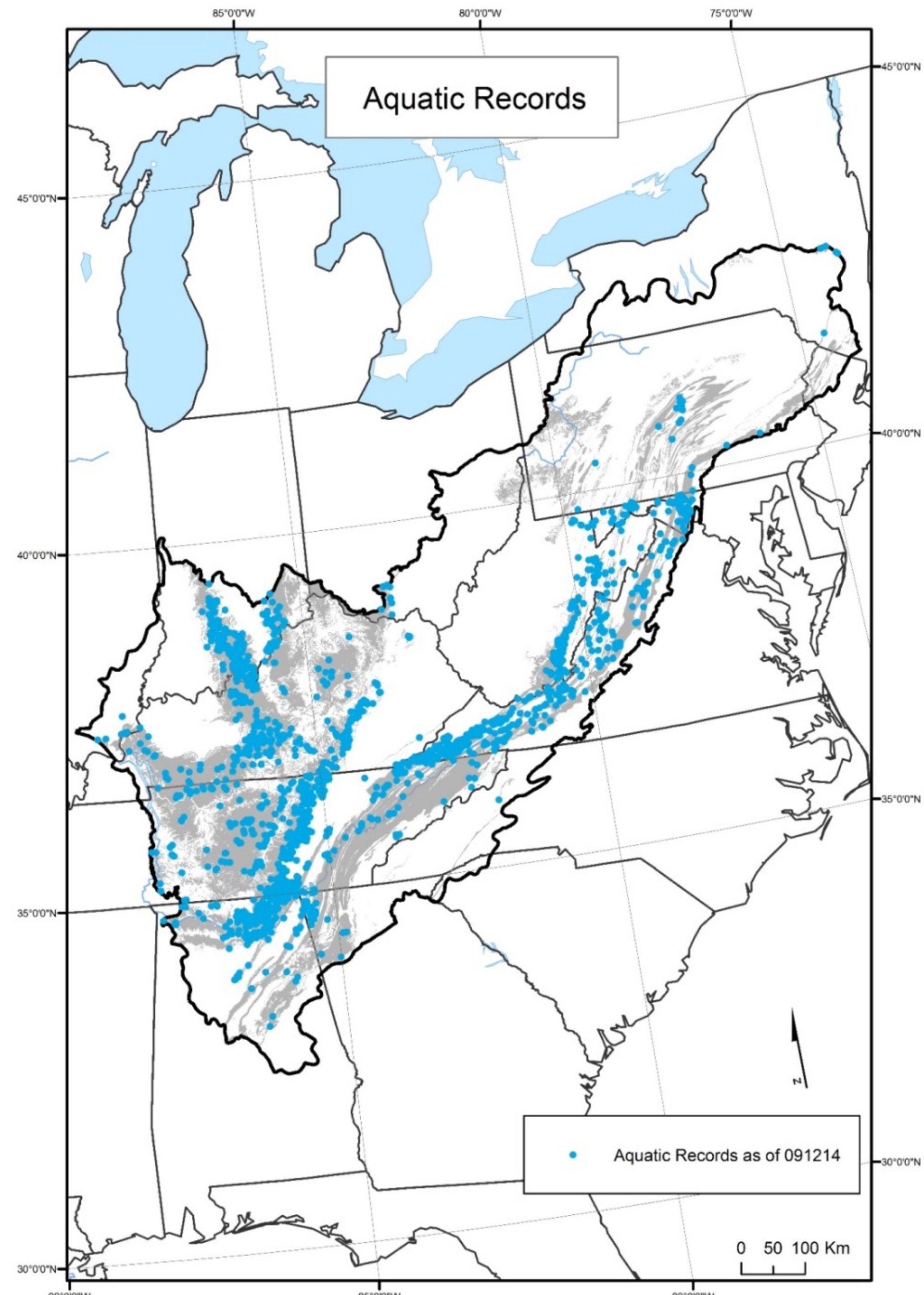


Figure 4.

One striking aspect of the distribution of records is the large number of records for Maryland and the relatively small number of records for Pennsylvania. This line is the result of very strong collecting efforts by Dan Feller of the Maryland Department of Natural Resources and lack of data from Pennsylvania, and highlights the need for additional collecting in Pennsylvania.

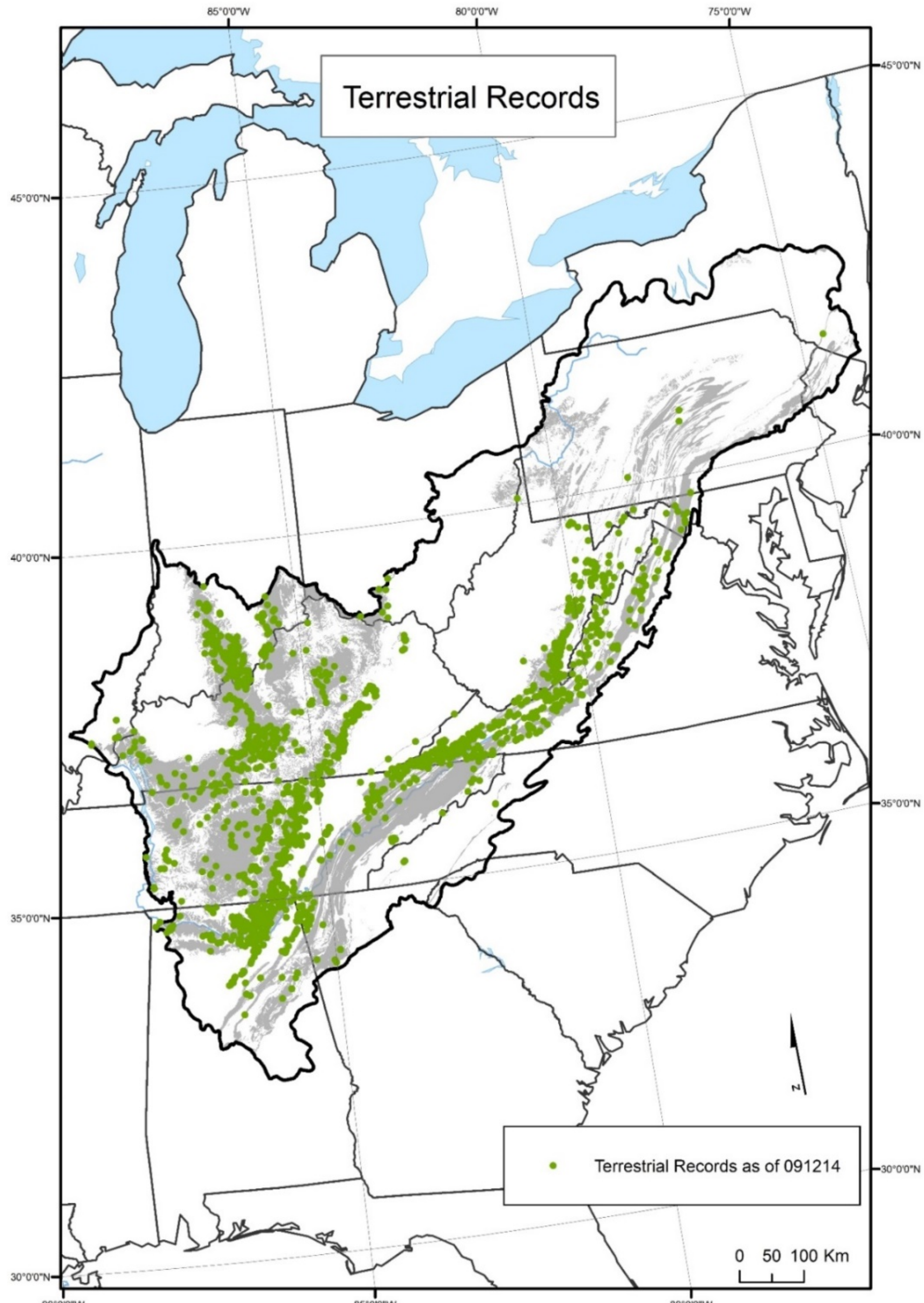


Figure 5.

In addition to supplying the template for available habitat, two specific attributes of the distribution of karst can be used to predict presence/absence of particular ecological groups in caves. These are:

- Percent of karst within a 20 X 20 km grid cell, a measure of habitat quantity (Figure 6)
- Cumulative lengths of contacts between karst and non-karst, measuring both patchiness of available habitat and perhaps dispersal corridors if cave passages are differentially developed along these contacts (Figure 7)

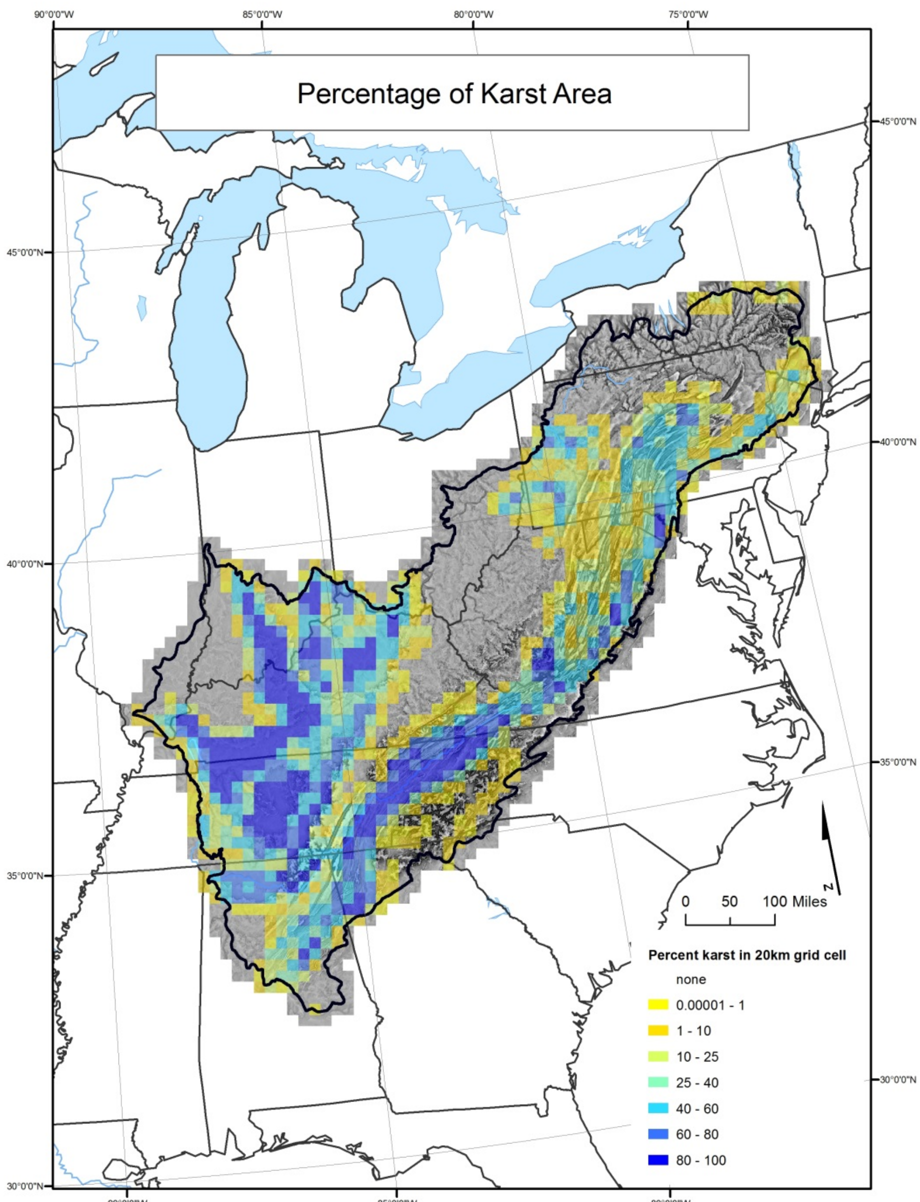


Figure 6.

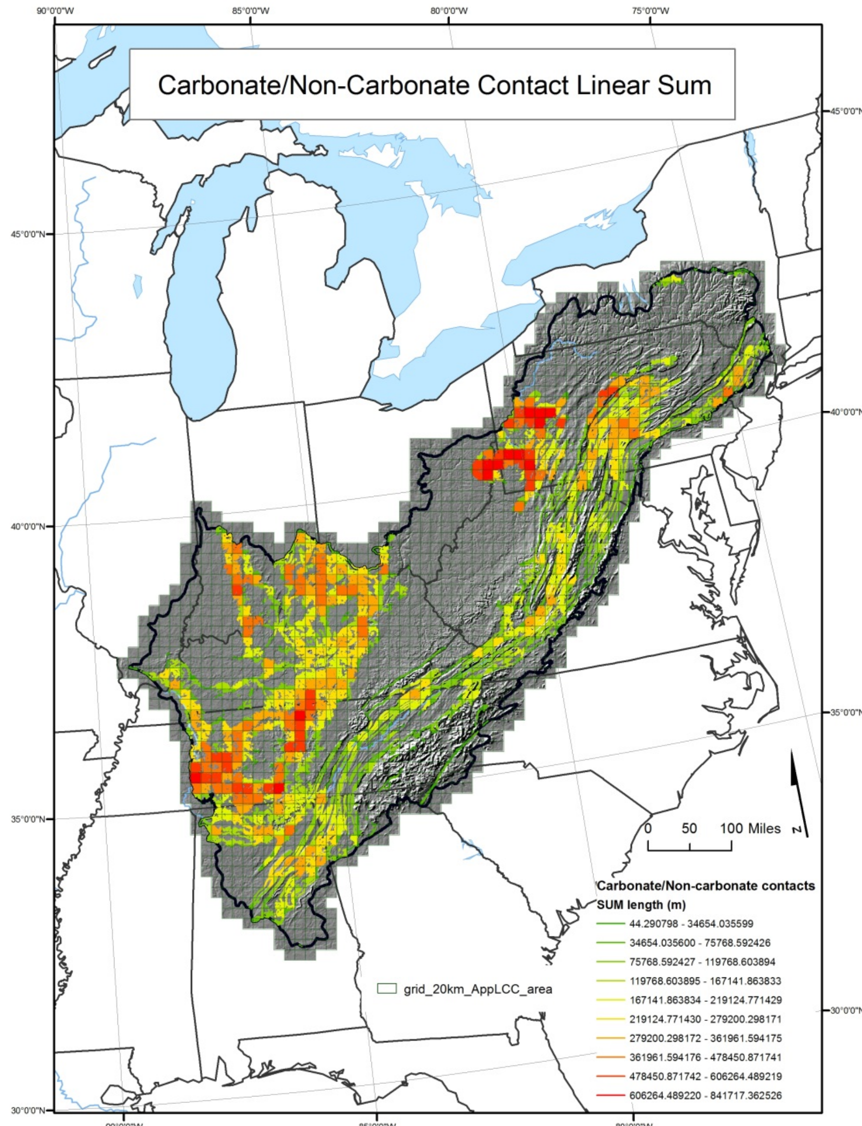


Figure 7.

We also used the three basic regions identified by NatureServe—Interior Low Plateaus, Central Appalachians, and Cumberland Southern Blue Ridge. We note parenthetically that this is not the major subdivision historically used by cave biogeographers such as Thomas Barr, who set the standard for subterranean regions in the eastern U.S. in his classic paper in *American Naturalist,* published in 1967.. He and others divided this area into the Interior Low Plateau and Valley and Ridge, combining the Central Appalachians with the Cumberland Southern Blue Ridge. He argued that limestone was flat-bedded with highly connected caves in the Interior Low Plateau and highly folded with isolated caves in the Valley and Ridge. For this, we have followed the usual practice of dividing the Appalachian LCC into three regions (Figure 8), in order that it can be compared to other biological data for the Appalachian LCC. .

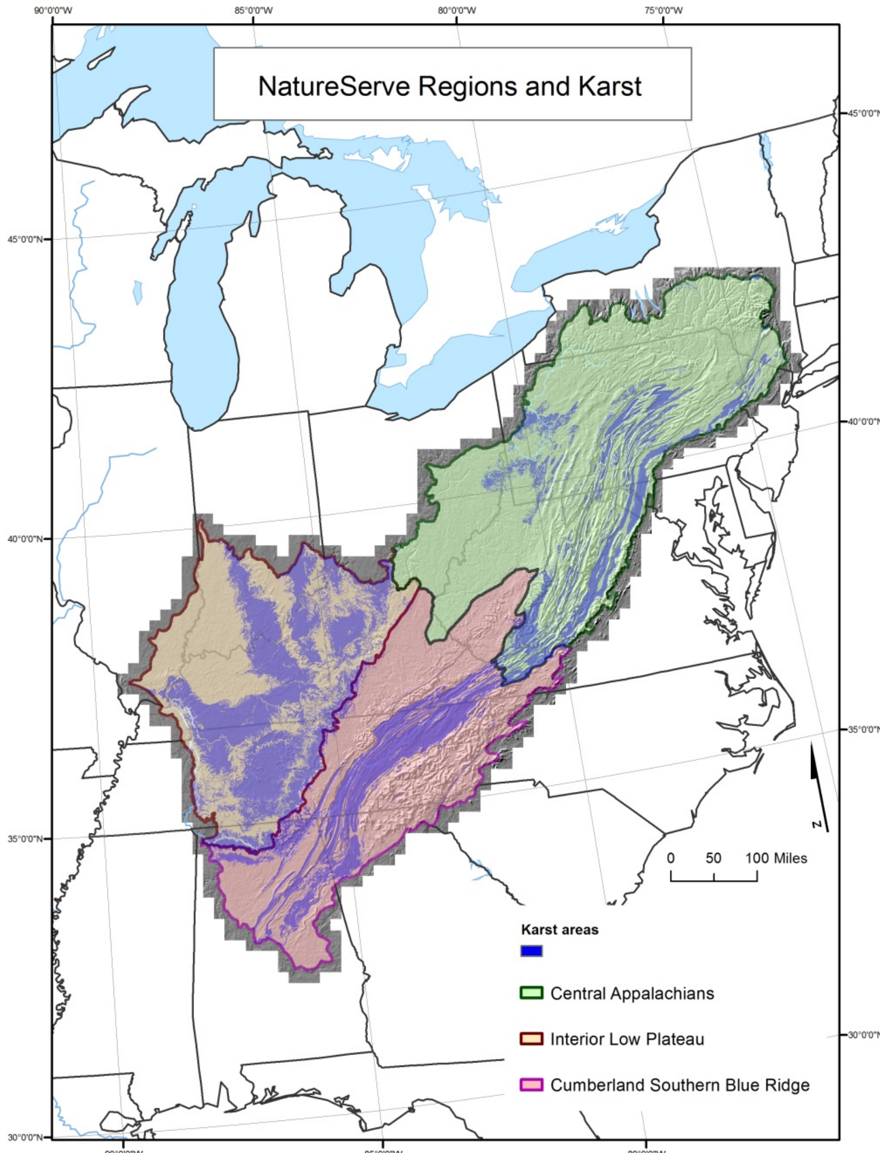


Figure 8.

Taxonomic distribution of the obligate cave-dwelling fauna

In this study, we focused on described species. Undescribed species are just that—they may turn out to be new species or upon close examination, they may turn out to be a variant of a known described species. As is typical of cave fauna, the Appalachian LCC cave fauna is highly diverse taxonomically, with five phyla, 14 classes, 34 orders, 67 families, 131 genera, and 710 species. Even allowing for the possibility of speciation as a result of subterranean dispersal, this fauna is the result of a large number of invasions of the subterranean domain. A brief pictorial review of the cave fauna follows. Please note that the photographs are copyrighted.

Phylum Platyhelminthes

- Class Trepaxonema (18 species)
  - Order Cestoda: 1 species
  - Order Neoophora: 17 species

(L) *Sphalloplana percoeca* and (R) *Sphalloplana hubrichti* (Planariidae)

Phylum Annelida

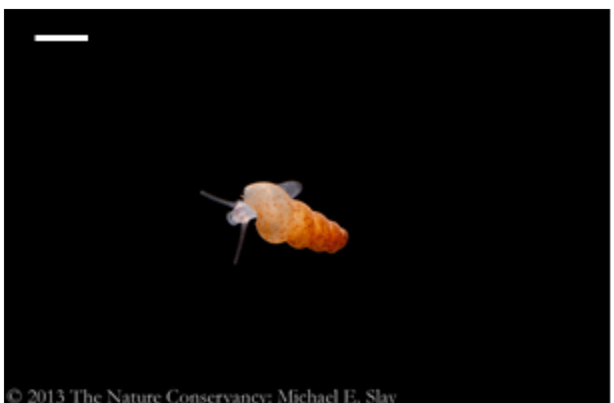
- Class Oligochaeta (9 species)
  - Order Branchiobdellida: 5 species
  - Order Lumbriculida: 4 species

Cambarincola sp. (Cambarincolidae)

Phylum Mollusca

- Class Gastropoda (15 species)
  - Order Basommatophora: 1 species
  - Order Neotaenioglossa: 9 species
  - Order Stylommatophora: 5 species

(L) *Helicodiscus* sp. (Helicodiscidae) and (R) *Carychium stygium* (Carychiidae)



(L) *Fontigens* sp. nov. (Hydrobiidae) and (R) *Antrorbis* sp. nov. (Hydrobiidae)

Phylum Arthropoda

- Class Arachnida (143 species)
  - Order Actinedida: 3 species
  - Order Araneae: 33 species
  - Order Mesostigmata: 4 species
  - Order Opiliones: 7 species
  - Order Oribatida: 2 species
  - Order Pseudoscorpiones: 88 species
  - Order Sarcoptiformes*: 0 species
  - Order Trombidiformes: 6 species

* Undescribed species

(UL) *Phanetta subterranea* (Linyphiidae), (UR) *Nesticus barri* (Nesticidae), (LL) *Kleptochthonius* sp. (Chthoniidae), and (LR) *Tolus appalachius* (Phalangodidae)

Phylum Arthropoda

- Class Chilopoda (1 species)
  - Order Lithobiomorpha: 1 species
- Class Diplopoda (95 species)
  - Order Callipodida: 2 species
  - Order Chordeumatida: 87 species
  - Order Julida: 2 species
  - Order Polydesmida: 4 species

Scoterpes nov. sp. (Trichopetalidae)

(UL) *Scoterpes copei* (Trichopetalidae), (UR) *Tetracion jonesi* (Abacionidae), and (LL) *Pseudotremia barri* (Cleidogonidae)

Phylum Arthropoda

- Class Malacostraca (134 species)
  - Order Amphipoda: 67 species
  - Order Decapoda: 18 species
  - Order Isopoda: 49 species

(L) *Amerigoniscus henroti* (Trichoniscidae) and (R) *Stygobromus pseudospinosus* (Crangonyctidae)

(UL) *Palaemonias alabamae* (Atyidae), (UR) *Orconectes incomptus* (Cambaridae), (LL) *Bactrurus brachycaudus* (Crangonyctidae), and (LR) *Caecidotea pricei* (Asellidae)

Phylum Arthropoda

- Class Maxillopoda (12 species)
  - Order Cyclopoida: 10 species
  - Order Harpacticoida: 1 species
  - Order Siphonostomatoida: 1 species
- Class Ostracoda (5 species)
  - Order Podocopida: 5 species

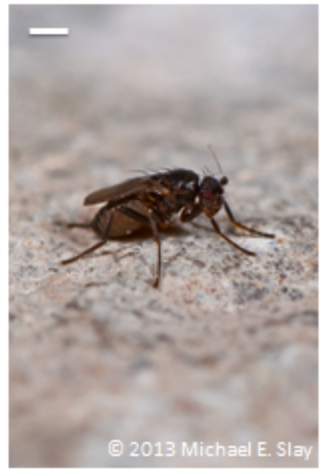
Phylum Arthropoda

- Class Entognatha (71 species)
  - Order Collembola: 64 species
  - Order Diplura: 7 species

(L) *Pseudosinella* sp. (Entomobryidae) and (R) *Litocampa* sp. (Campodeidae)

Phylum Arthropoda

- Class Insecta (217 species)
  - Order Coleoptera: 216 species
  - Order Diptera: 1 species
  - Order Zygentoma*: 0 species



* Undescribed species

Speleobia tenebrarum (Sphaeroceridae)

(UL) *Pseudanopthalmus simplex* (Carabidae) (UR) *Darlingtonea kentuckensis* (Carabidae), (LL) *Batriasymmodes* sp. (Staphylinidae), and (LR) *Ptomphagus barri* (Leiodidae)

Phylum Chordata

- Class Actinopterygii (4 species)
  - Order Percopsiformes: 4 species
- Class Amphibia (4 species)
  - Order Caudata: 4 species

Speoplatyrhinus poulsoni (Amblyopsidae)

(UL) *Amblyopsis spelaea* (Amblyopsidae), (UR) *Typhlichthys subterraneus* (Amblyopsidae), (LL) *Gyrinophilus subterraneus*, and (LR) *Gyrinophilus palleucus*

Geographic patterns of species richness and ranges of major groups

Because aquatic and terrestrial species have quite different geographic patterns, they are displayed separately. Further we summarize the available data at the scale of 20 X 20 km quadrats, our preferred scale of analysis, at the county level, and at the HUC 8 basin level (aquatics) and ecoregion level IV (terrestrial). The 20 X 20 km scale is preferred because at smaller scales the pattern is very patchy (Moran's spatial correlation is reduced and black-white joins are increased).

At this scale of 20 X 20 km (Figure 9), the hotspots of aquatic species richness are in southern Indiana (the Mitchell Plain) and central Kentucky (Mammoth Cave). Note also the paucity of records for southern Pennsylvania.

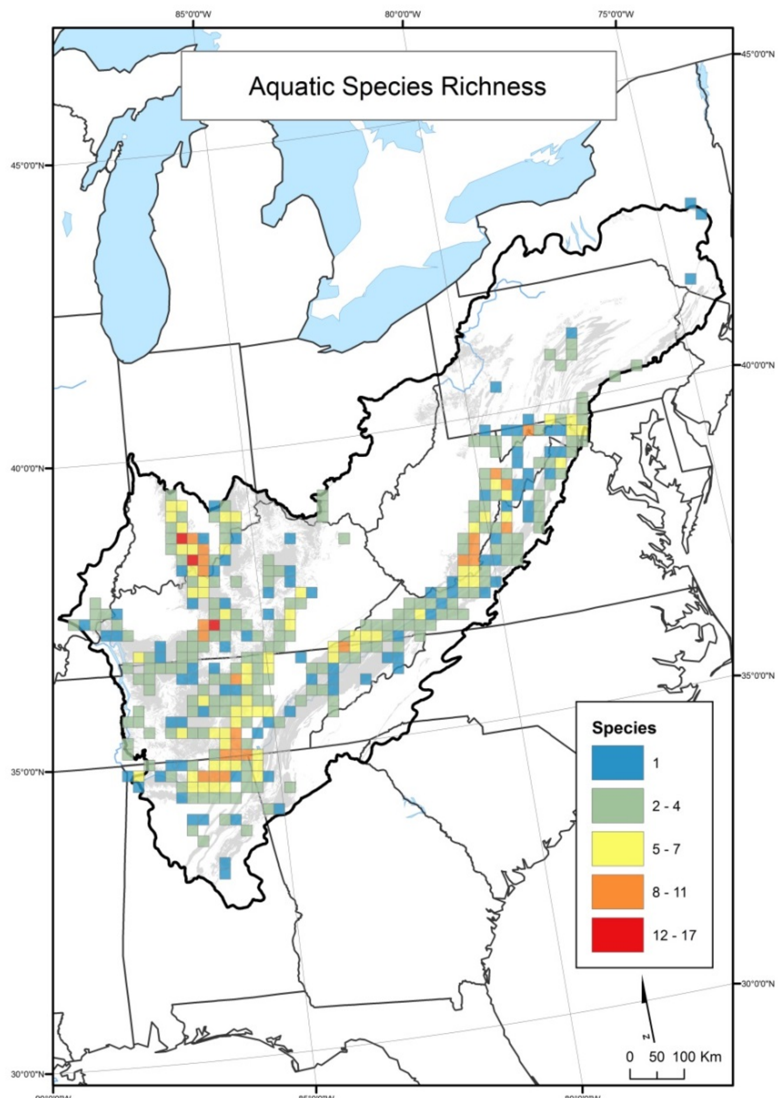


Figure 9.

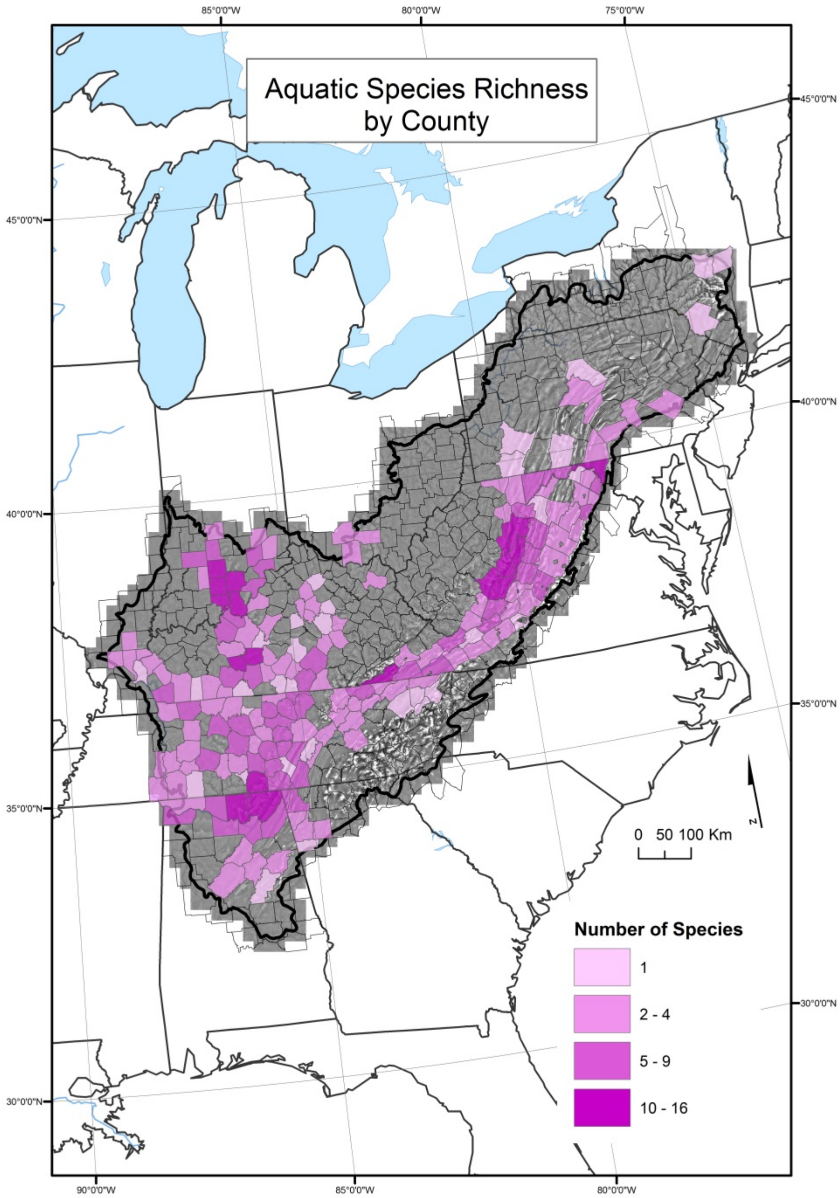


Figure 10.

At the county scale (Figure 10), hotspots are more obvious, occurring in northeast Alabama, Lee County, Virginia, and southern West Virginia, in addition to the two seen at the scale of 20 X 20 km. The number of hotspots depends on the way counties and grid cells are categorized in the color ramps.

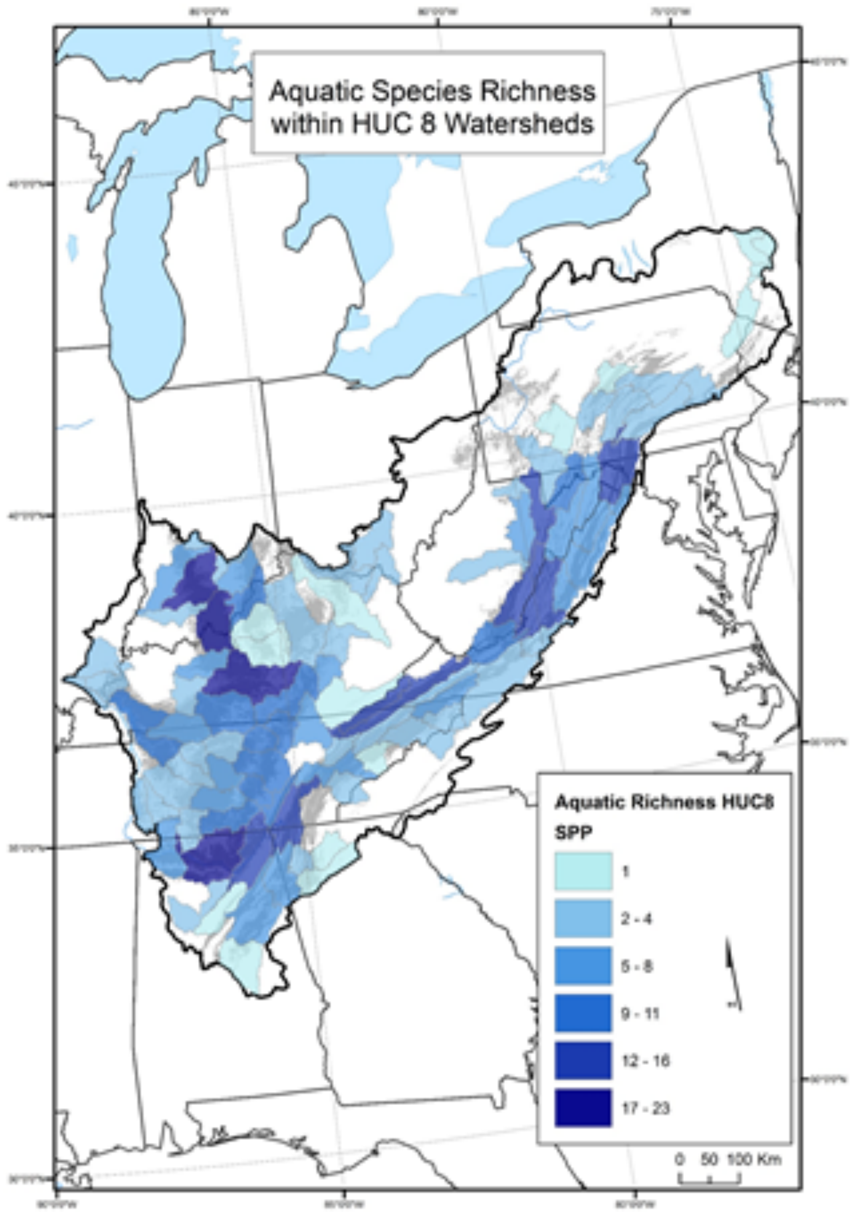


Figure 11.

At the ecoregion level (Figure 11), the pattern is much like that of counties but with the highest species richness in the drainage basins of southern Indiana.

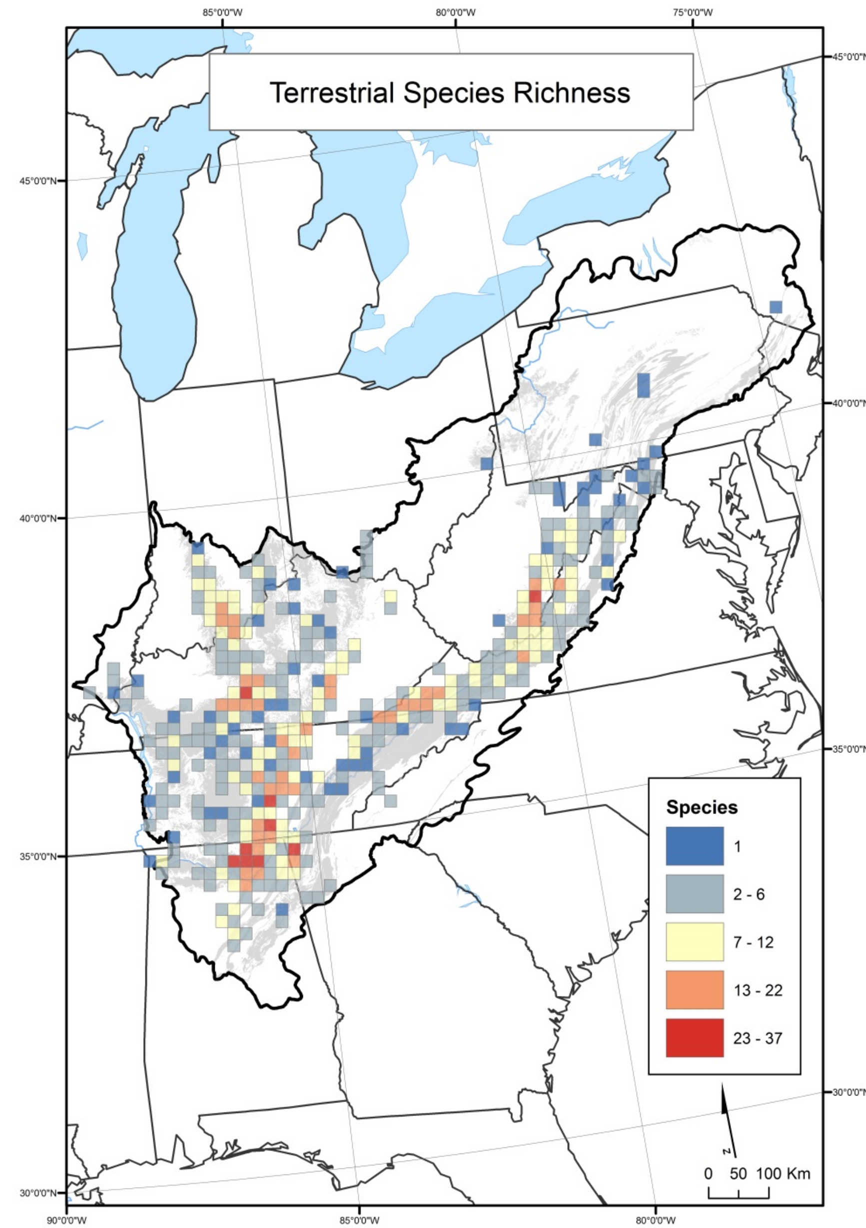


Figure 12.

For terrestrial species (troglobionts), there is a hotspot of species richness in northeast Alabama and southcentral Tennessee, as well as one in the Mammoth Cave area (Figure 12).

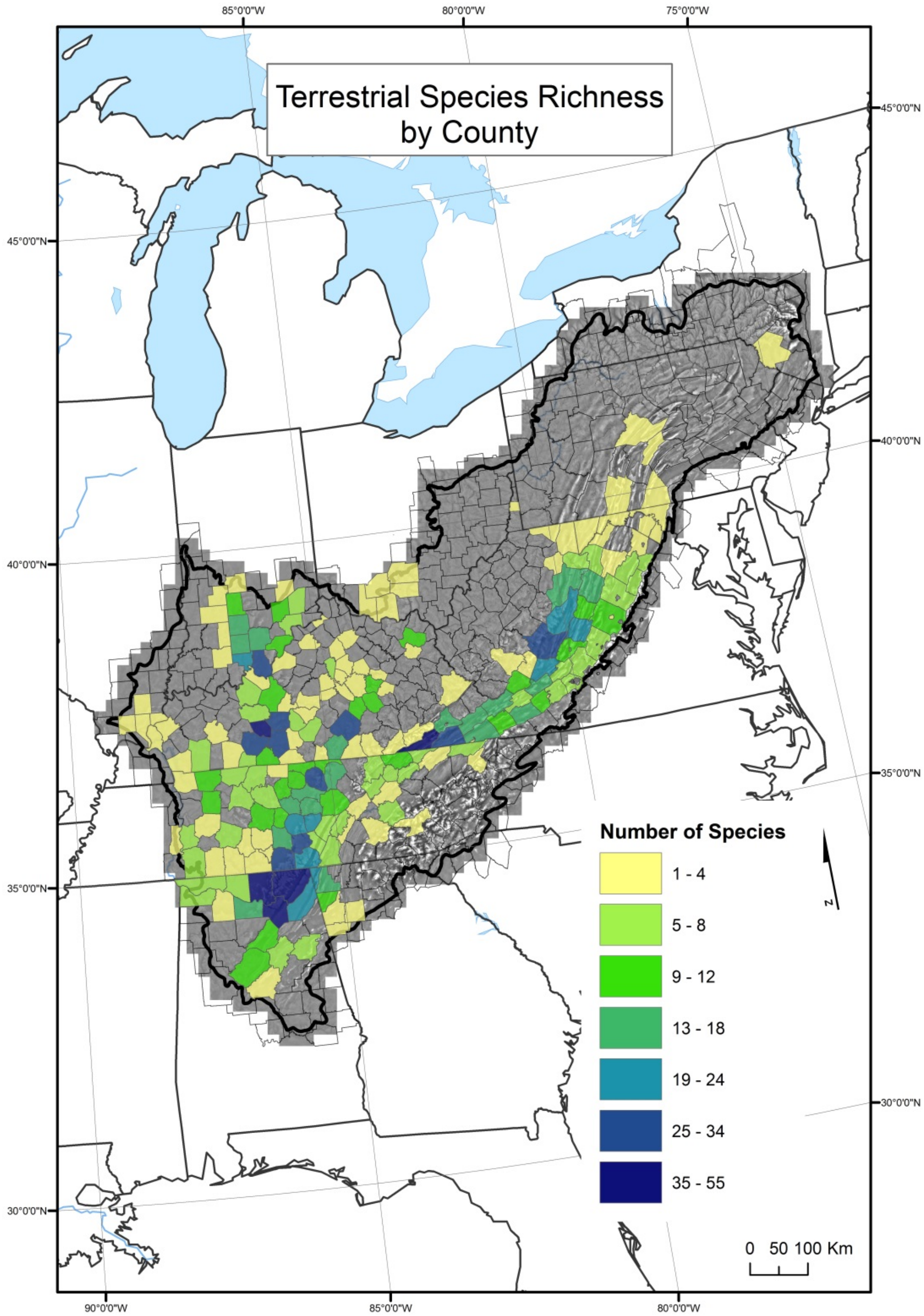


Figure 13.

At the county level, an additional hotspot of terrestrial species richness occurs in southwest Virginia (Figure 13).

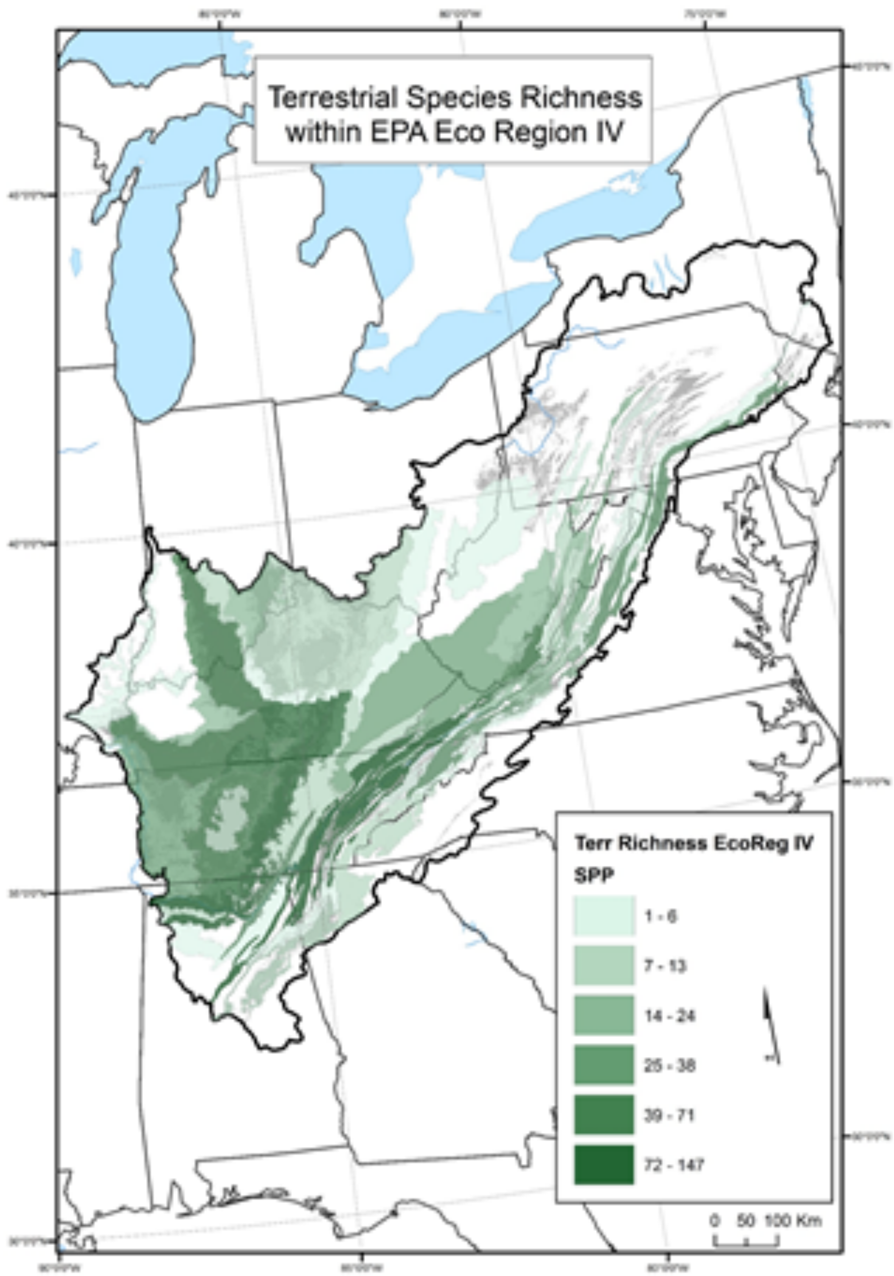


Figure 14.

At the scale of ecoregion IV, the richest ecoregions correspond more or less to the pattern of county hotspots (Figure 14).

A list of the caves with the most aquatic and terrestrial species is potentially misleading because the number of species is highly dependent on sampling intensity, including the number of sampling trips. On the other hand, it is interesting because individual caves are more recognizable than quadrats, basins, or counties.

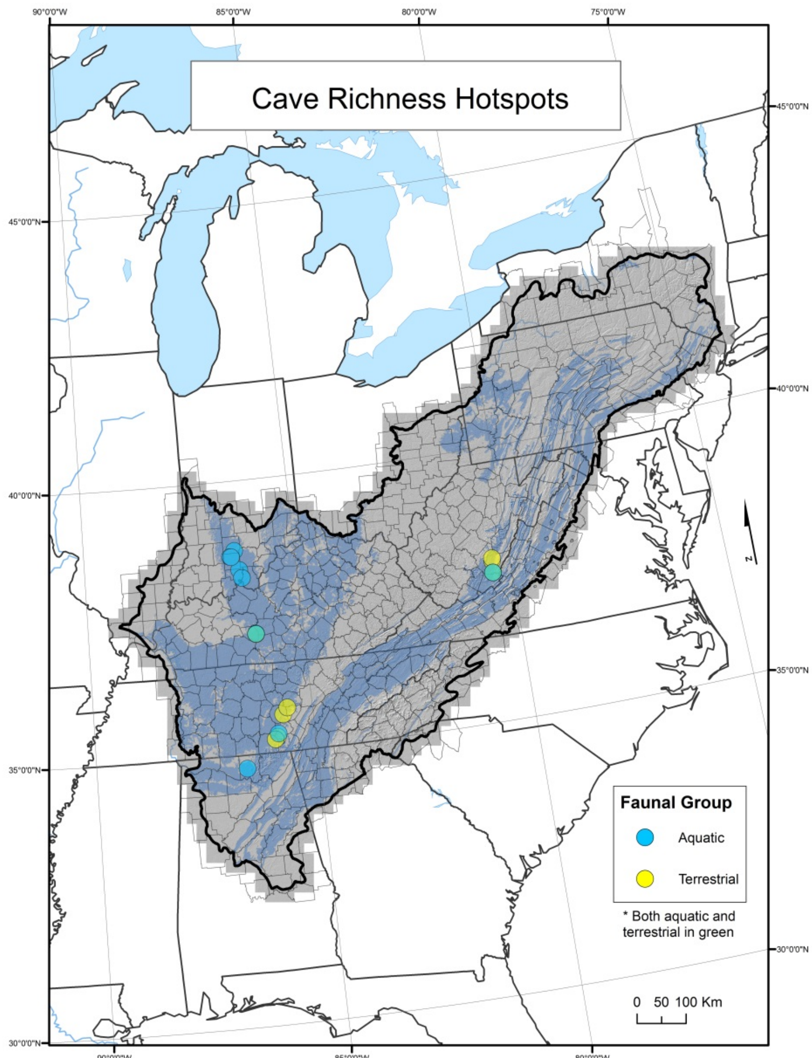


Figure 15.

Not surprisingly, this pattern is rather different, reflecting differing collecting intensities, as well as different relative values for local and regional diversity. For the terrestrial fauna (Figure 15), Tennessee has the most caves (four) with high levels of species richness, followed by West Virginia (three). For aquatic species, Indiana dominates, with six caves out of ten with the most species.

Because many aquatic and terrestrial species are geographically rare, often found in a single cave, we described the geography of endemism (Figure 16). Endemics are scattered throughout the Appalachian LCC region, but especially at the scale of county (Figure 17), there is a concentration of endemism in northeast Alabama. Note that the scale of endemism is different in the next two maps—the first shows the distribution of quadrats with single quadrat endemics (Figure 16) and in the second map shows counties with single county endemics (Figure 17).

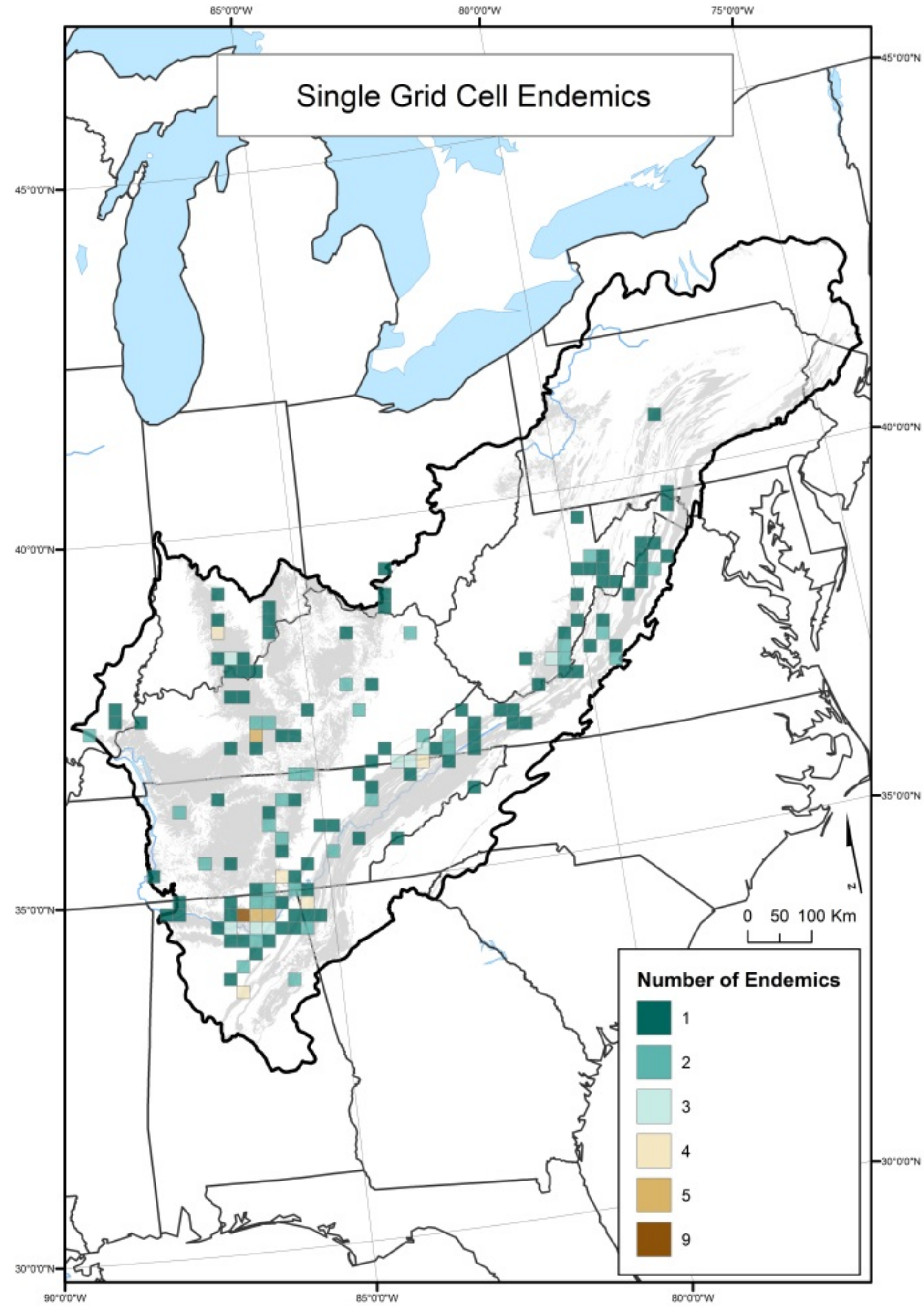
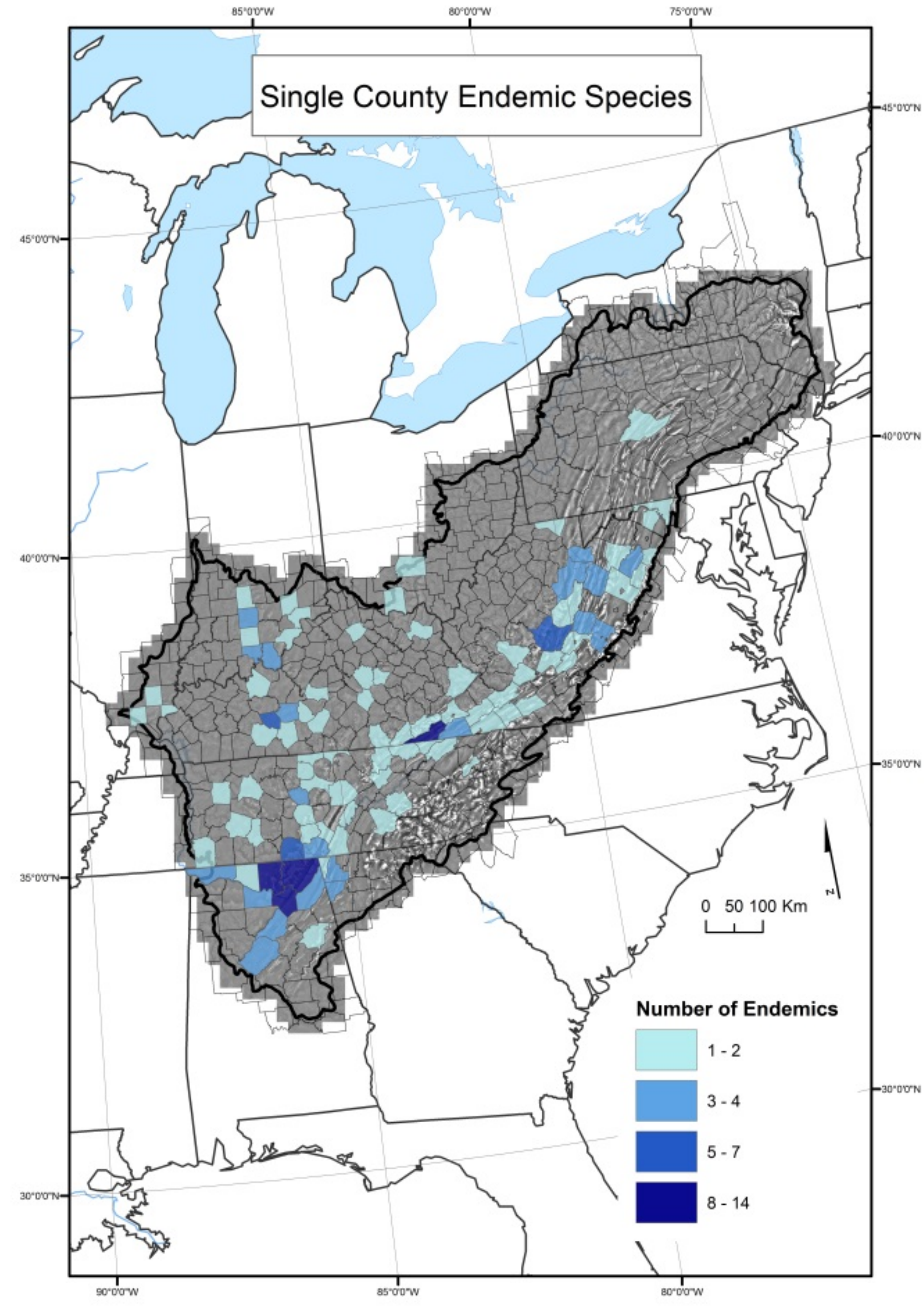

Single Grid Cell Endemics
Number of Endemics
1
2
3
4
5
9
0 50 100 Km
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
90°0'0"W

Figure 16.



Single County Endemic Species
Number of Endemics
1 - 2
3 - 4
5 - 7
8 - 14
0 50 100 Km
85°0'0"W
80°0'0"W
75°0'0"W
90°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N

Figure 17.

Single cave endemics, the ultimate in endemism, is relatively common among the cave fauna but there is an important proviso. In the Appalachian LCC, less than ten percent of the known caves have been sampled and the presence of a species in a second nearby cave does not imply that its range is not highly restricted or that it is not highly vulnerable.

There are a total of 218 single cave endemics of the Appalachian LCC, with Alabama leading the states with 65, followed by Tennessee with 44 (Figure 18). In general, they are scattered throughout the region with only Pennsylvania and New York lacking single cave endemics. Only McClunney Cave in Jefferson County, Alabama, had four endemic species.

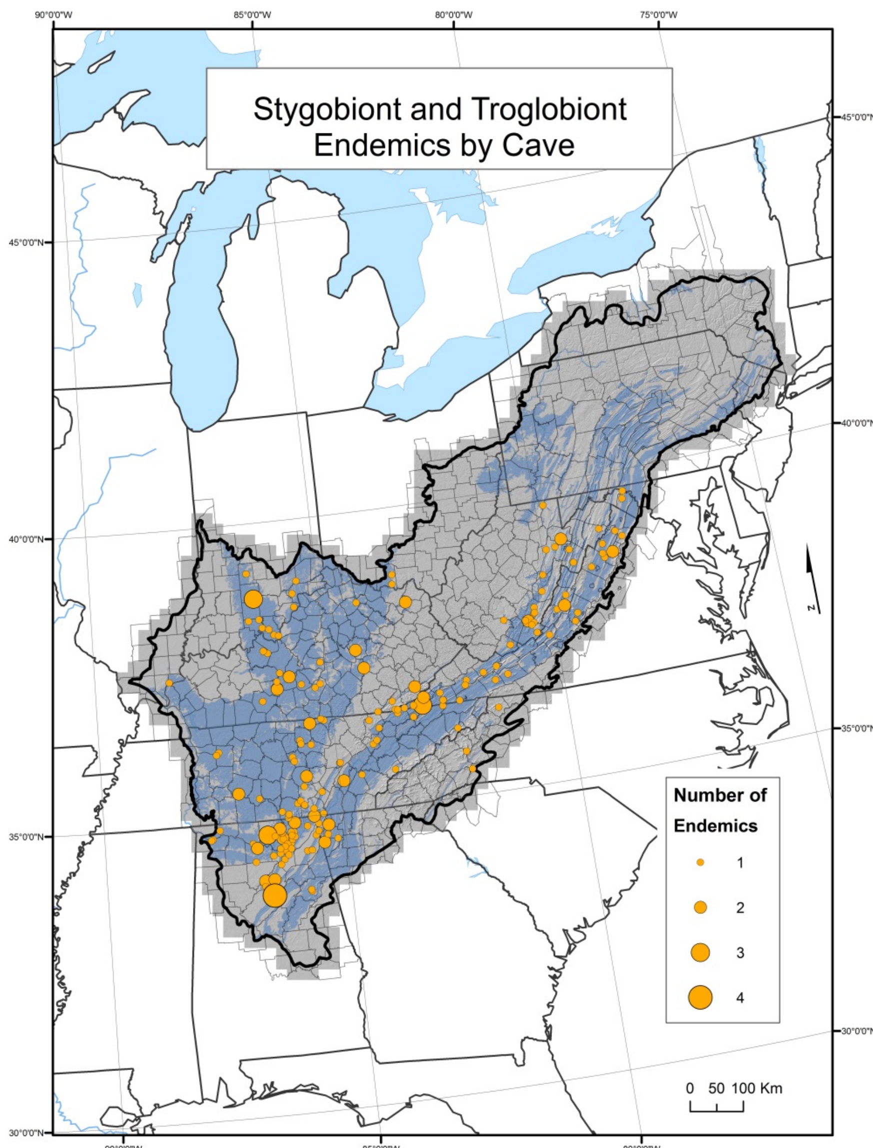


Figure 18.

Since there are far too many species (710) or even genera (131) to analyze within the scope of this project, we took a functional ecological approach. We analyzed the ranges of nine ecological groups—predaceous ground beetles, millipedes, pseudoscorpions, springtails, spiders, amphipods, isopods (Asellidae), crayfish, and fish. Collectively, they are the best studied and most abundant stygobionts and troglobionts. The species within each group have very similar ecological roles, so interesting generalities should emerge about the conditions under which they are found. The number of species in each group ranges from 164 (beetles) to four (fish). Among the terrestrial groups, two are detritivores (millipedes and springtails) and three are predators (ground beetles, pseudoscorpions, and spiders). Among aquatic groups, two are detritivores (amphipods and isopods), one is omnivorous (crayfish), and one is predaceous (fish). The distribution of the nine groups is shown below, using a 1 km^2 grid for display. This shows in more detail the locations of records, but the analysis is at the scale of 20 X 20 km for the statistical reasons given above.

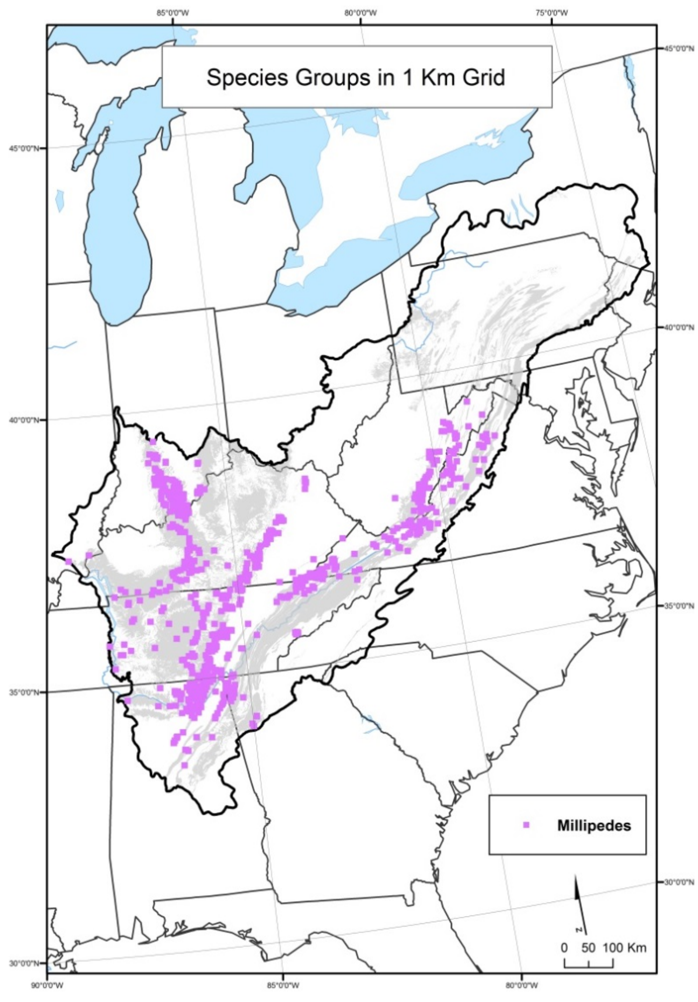


Figure 19.

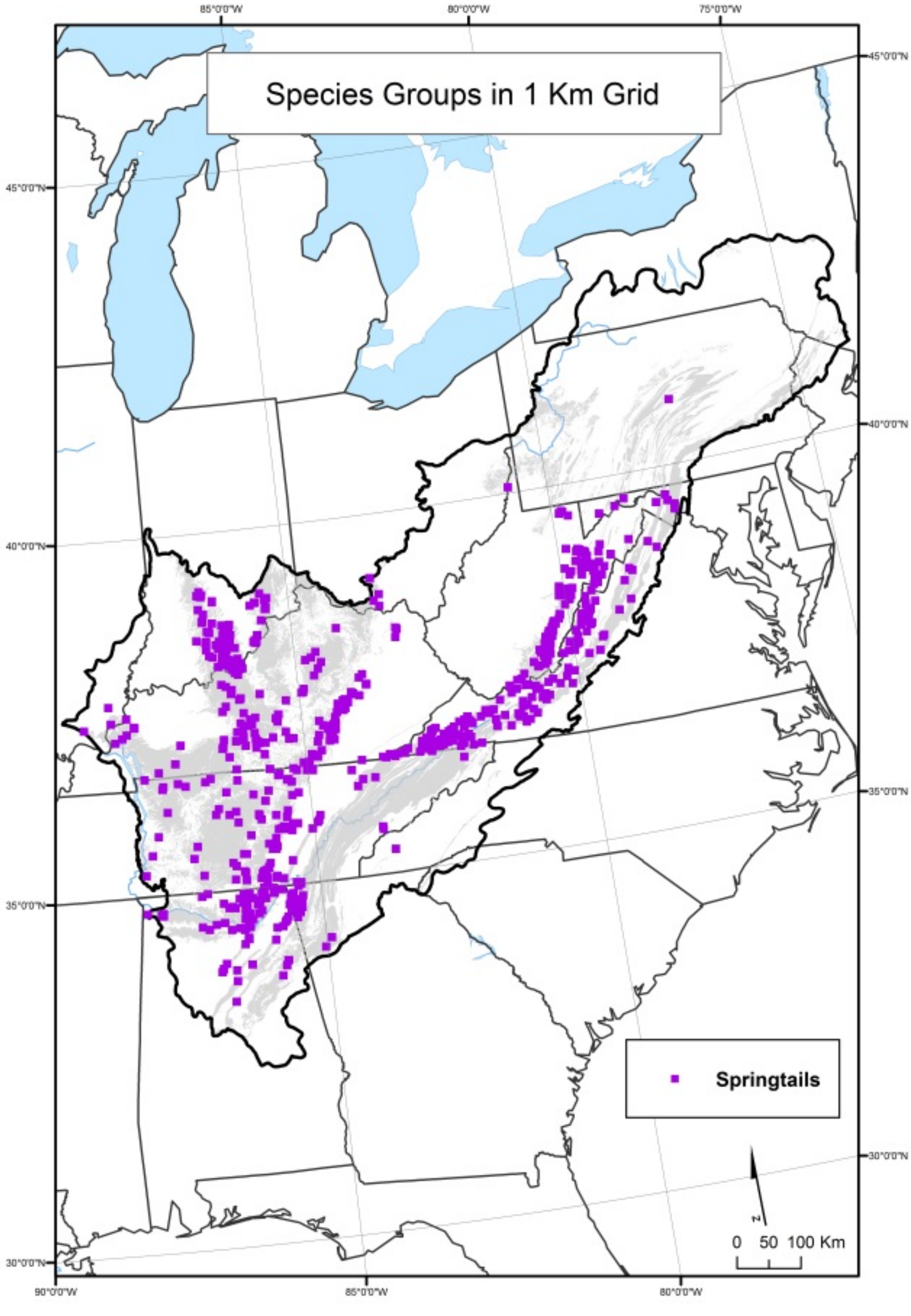

Species Groups in 1 Km Grid
Springtails
0 50 100 Km
85°0'0"W
80°0'0"W
75°0'0"W
90°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N

Figure 20.

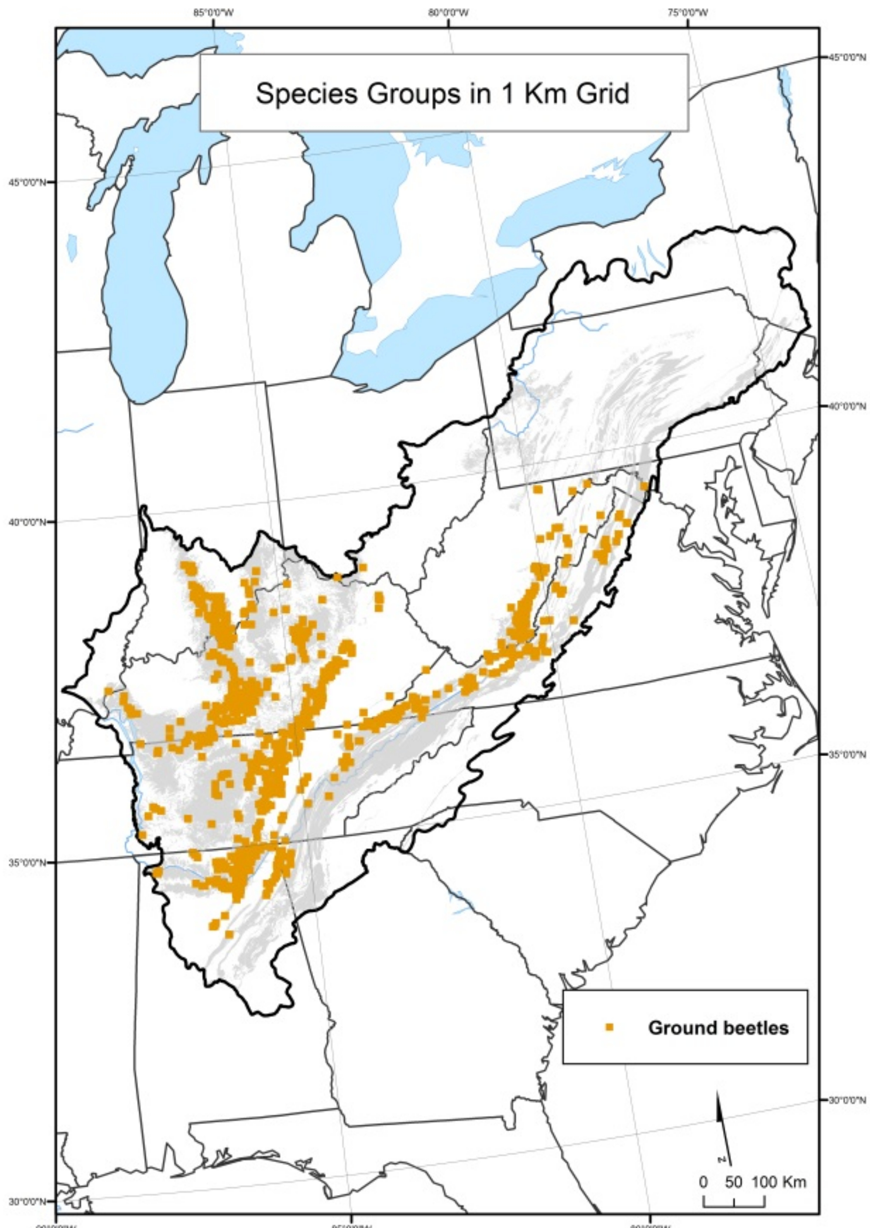
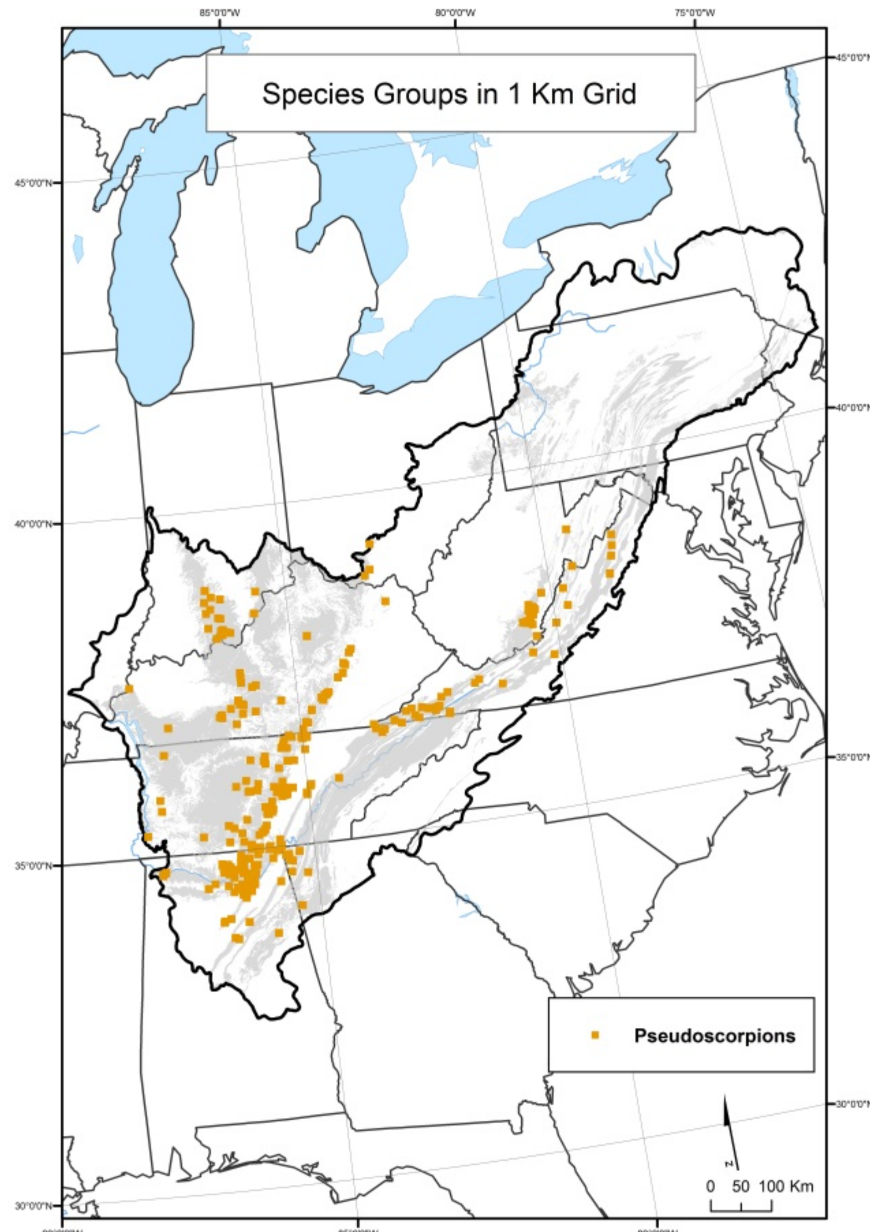


Figure 21.



Species Groups in 1 Km Grid
Pseudoscorpions
0 50 100 Km
85°0'0"W
80°0'0"W
75°0'0"W
90°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N

Figure 22.

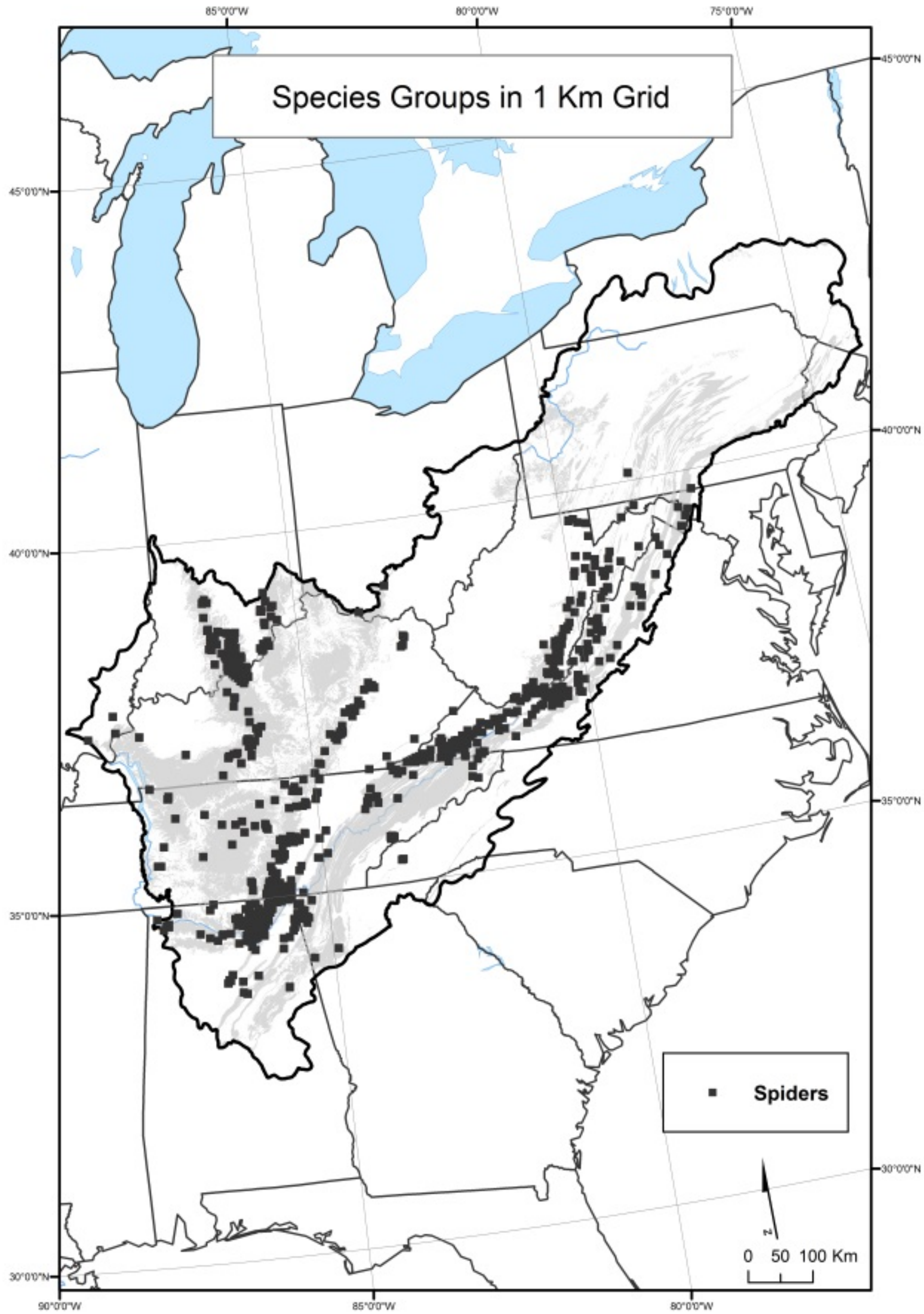
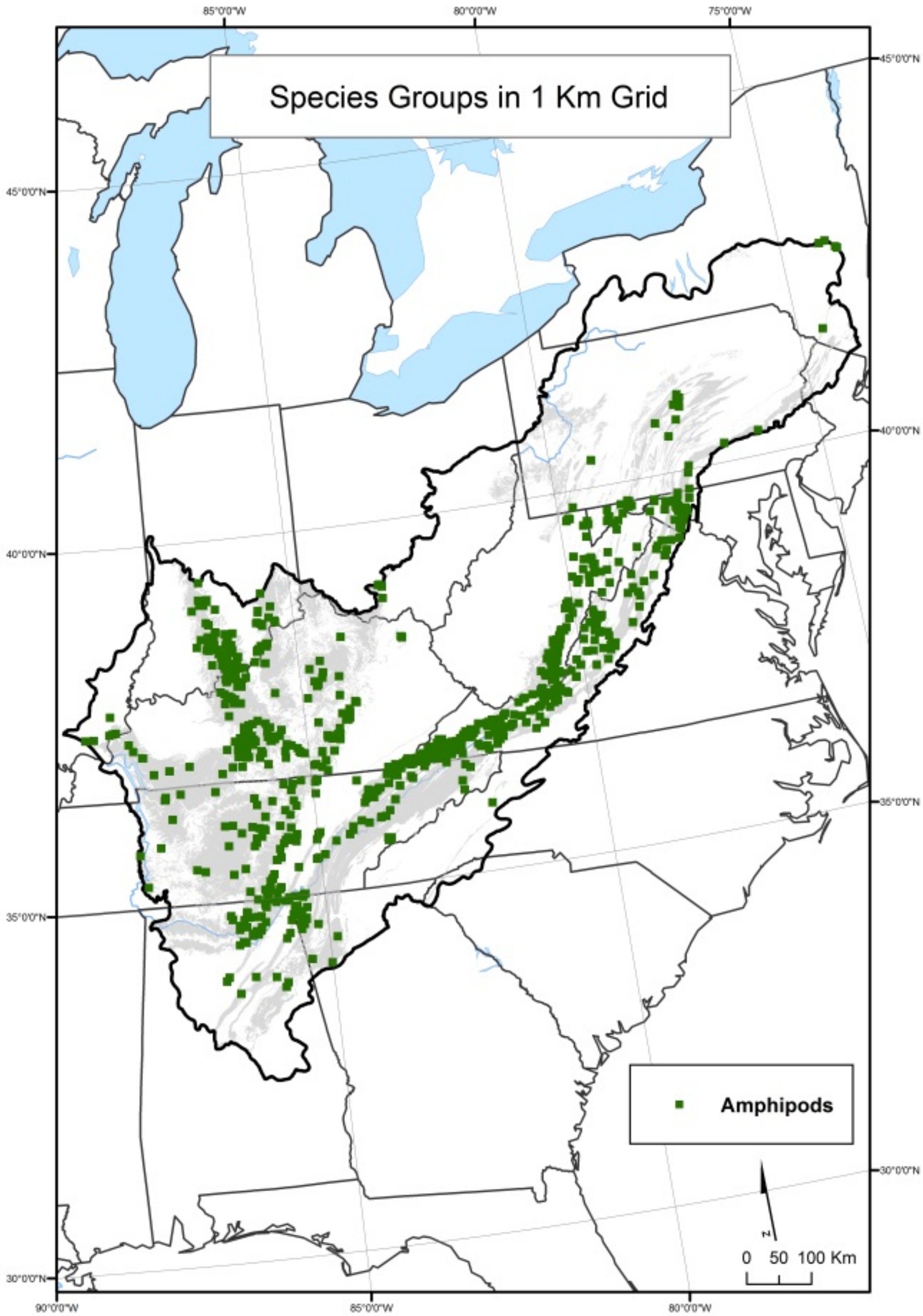


Figure 23.



Species Groups in 1 Km Grid
Amphipods
0 50 100 Km
85°0'0"W
80°0'0"W
75°0'0"W
90°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N

Figure 24.

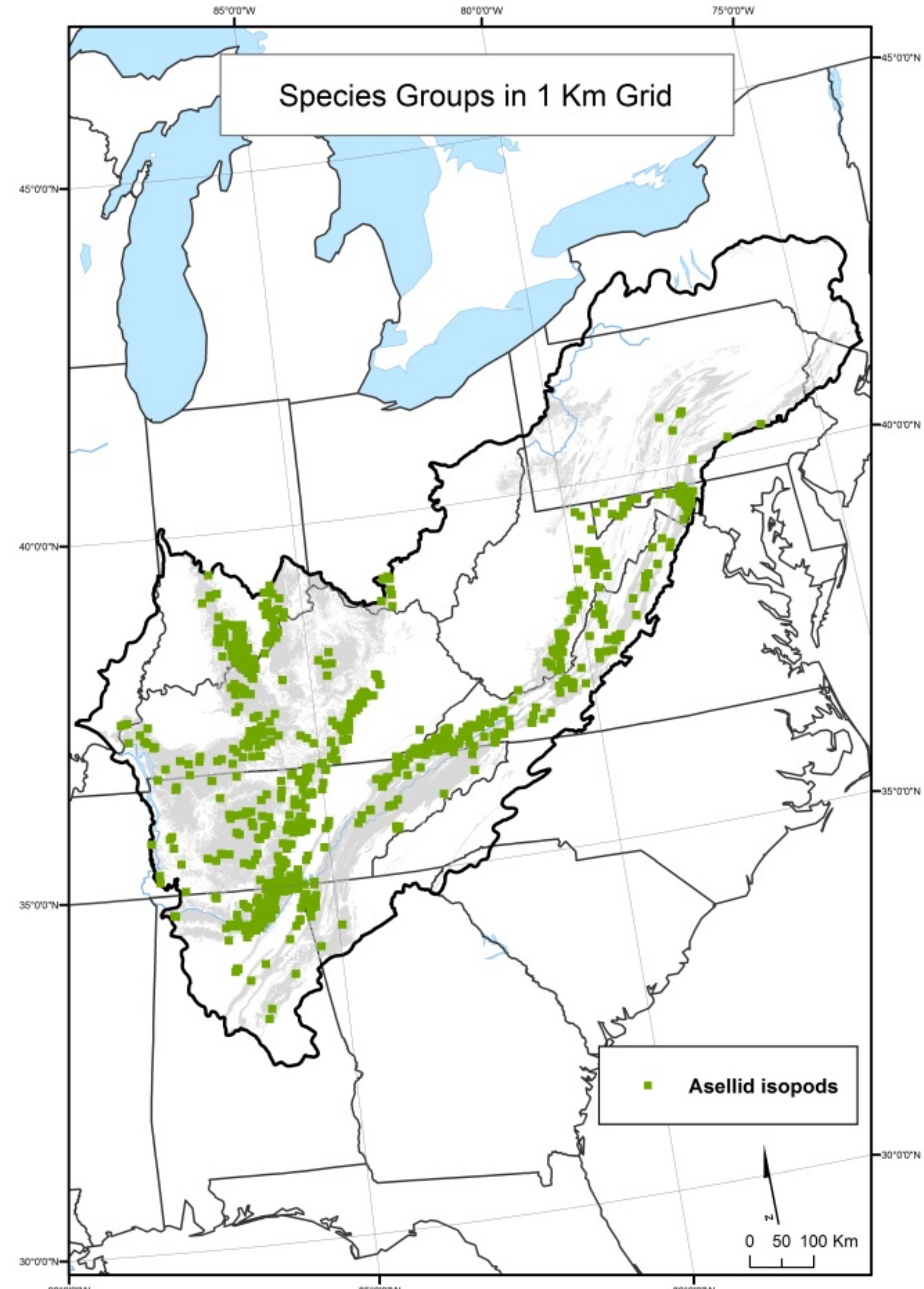
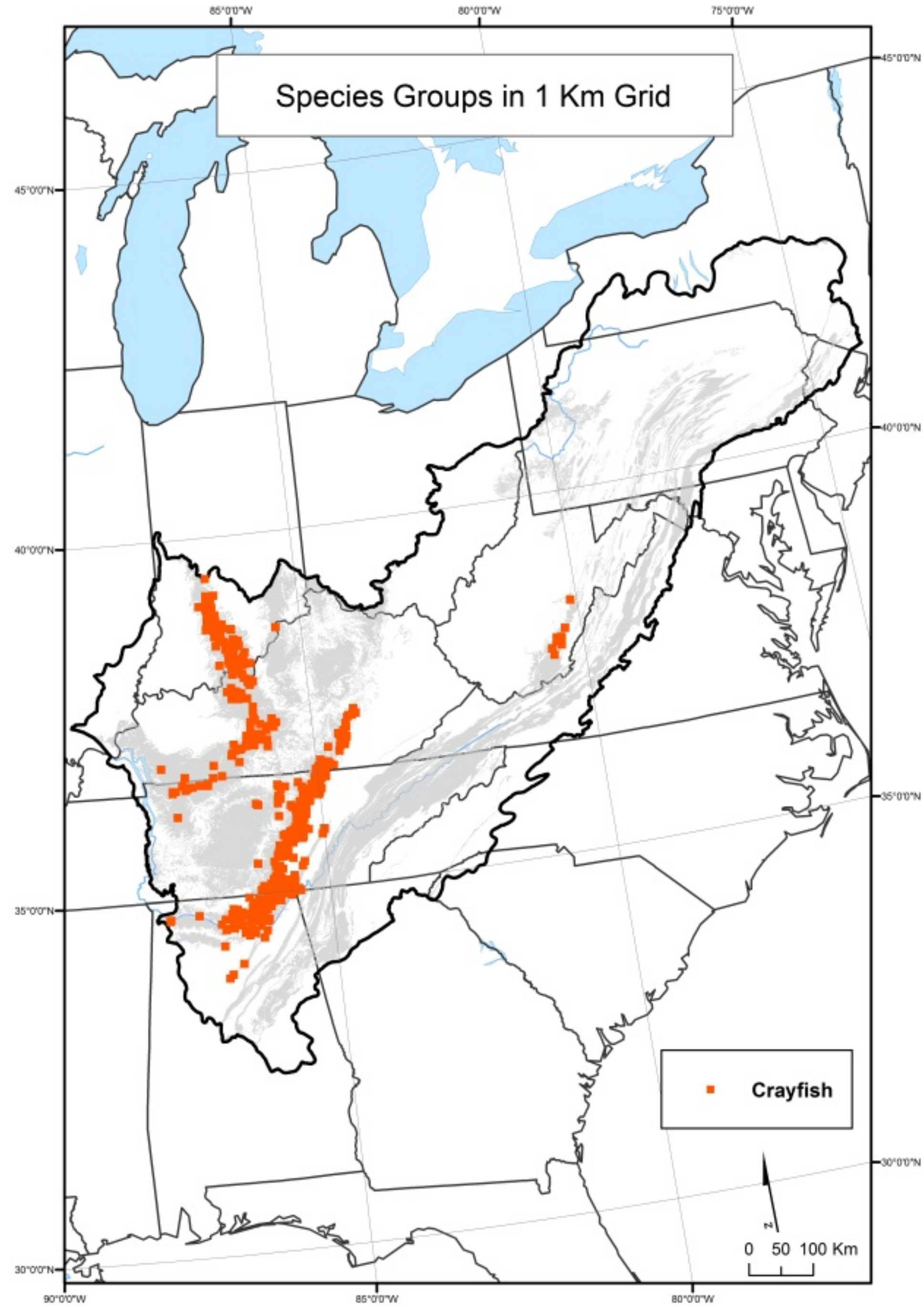


Figure 25.



85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
Species Groups in 1 Km Grid
Crayfish
0 50 100 Km
90°0'0"W
85°0'0"W
80°0'0"W

Figure 26.

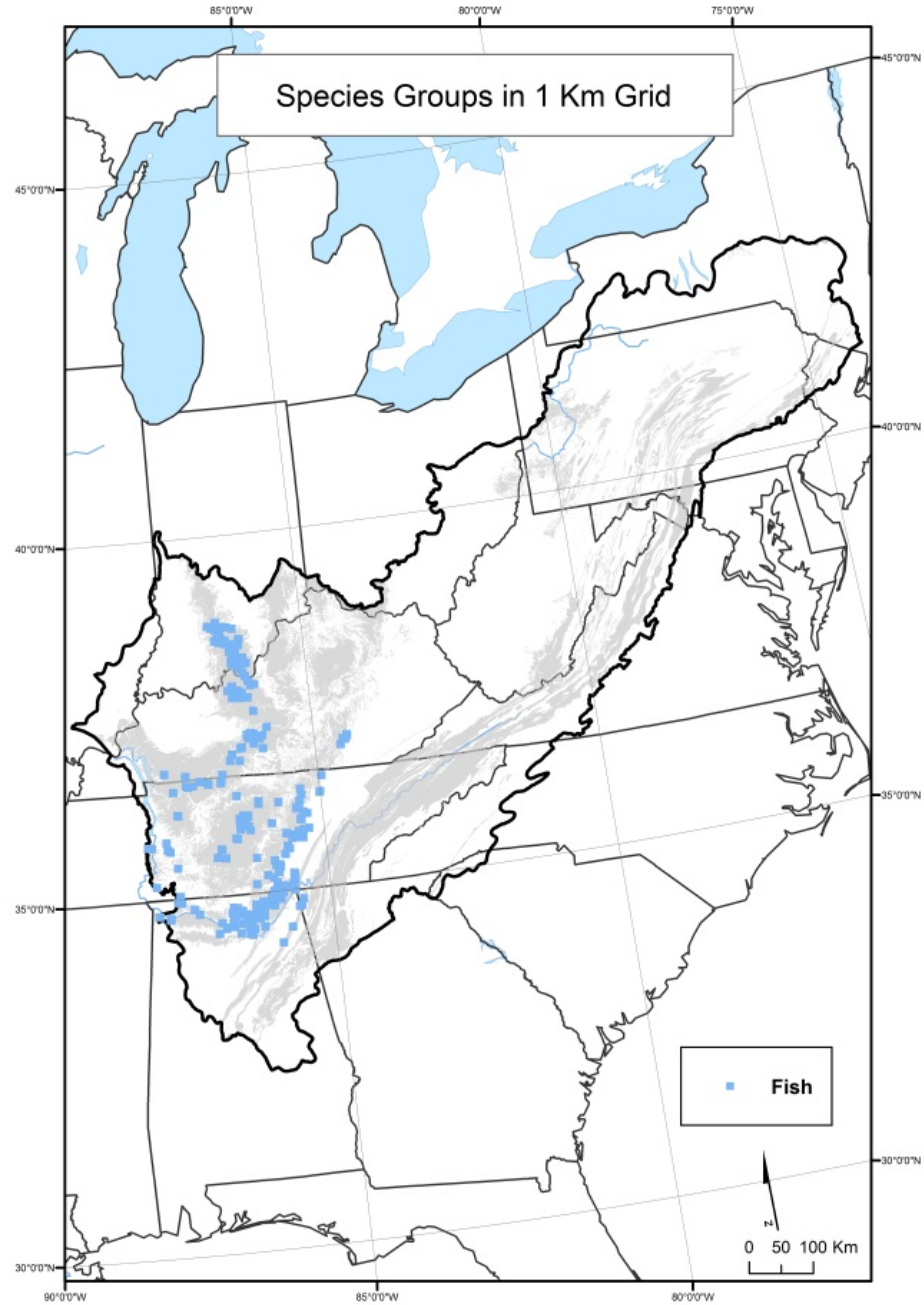


Figure 27.

All the groups are widely distributed except for crayfishes (Figure 26) and fishes (Figure 27), which are mostly (crayfish) or entirely (fish) absent from the Central Appalachians.

Landscape and physical features that are potential predictors of species richness and presence/absence of major groups

A number of physical and physiographic features may influence species richness of stygobionts and troglobionts, as well as the spatial distribution of particular ecological groups, *e.g.* amphipods. Some of these are estimates of available habitat, such as percent karst in an area and number of caves; others are measures of qualitative features of habitat, *e.g.,* length of the contact between carbonate and non-carbonate rocks, sinkhole density, and hydrologic baseflow index (ratio of baseflow to total stream flow). Others are topographic and climate variables that may affect the overall hydrologic regime in caves, amount of detritus and other organic material entering caves. These include elevation, precipitation, and temperature regimes. There are also direct measures of above ground conditions, including several soil characteristics, such as organic content, depth, permeability, etc. Finally, there are landscape units, such as ecoregions and hydrologic units for which there are fundamentally different relationships between physical factors and the cave fauna. These may be correlated with the spatial distribution of cave fauna because they are measures of quality and quantity of above ground habitat. Soil conditions further may impact cave fauna via the transport of organic matter.

In the next section we present the results of logistic regression for predicting the likelihood of the presence of ecological groups based on these physical factors. Here we provide summaries of the factors used in the modeling. These factors are:

PHYSICAL FACTORS FOR KARST MAPPING:

TOPOGRAPHY: Mean elevation, local relief (TPI), 90 m raw data

BEDROCK GEOLOGY: Soluble rock type (carbonate, dolomite, evaporite, etc.), primary lithologies (carbonate, sandstone, shale, etc.)

SURFICIAL GEOLOGY: Glacial deposits

CLIMATE: 1km gridded Precipitation and Temperature (Annual means, min, max, range, seasonality)

SOIL: thickness, water content, permeability, and organic carbon content (1 km grid source data from STATSGO database)

HYDROLOGIC BASE FLOW INDEX (BFI): 1 km grid, Ratio of baseflow to total streamflow

BIOMASS: Total aboveground live forest biomass in units of Mg/ha (http://svinetfc4.fs.fed.us/rastergateway/biomass/index.php)

SURFACE DEPRESSIONS: Density per 1km or 20km grid (available for some States)

CAVES: Density per 1km or 20km grid (available for some States)

SPRINGS (data compilation in progress)

Additional Summary Layers:

ECOREGIONS: EPA (Omernick) Level III or IV
HYDROLOGIC LANDSCAPE REGIONS: (Wolock et al., 2003)

In the figures that follow, we present the spatial distribution of the predictor variables. It is worth noting that the mapping of most of these variables is to the scale of 1km X 1km, so detailed analysis of small regions is possible although not done here. We focused on the Appalachian LCC region as a whole.

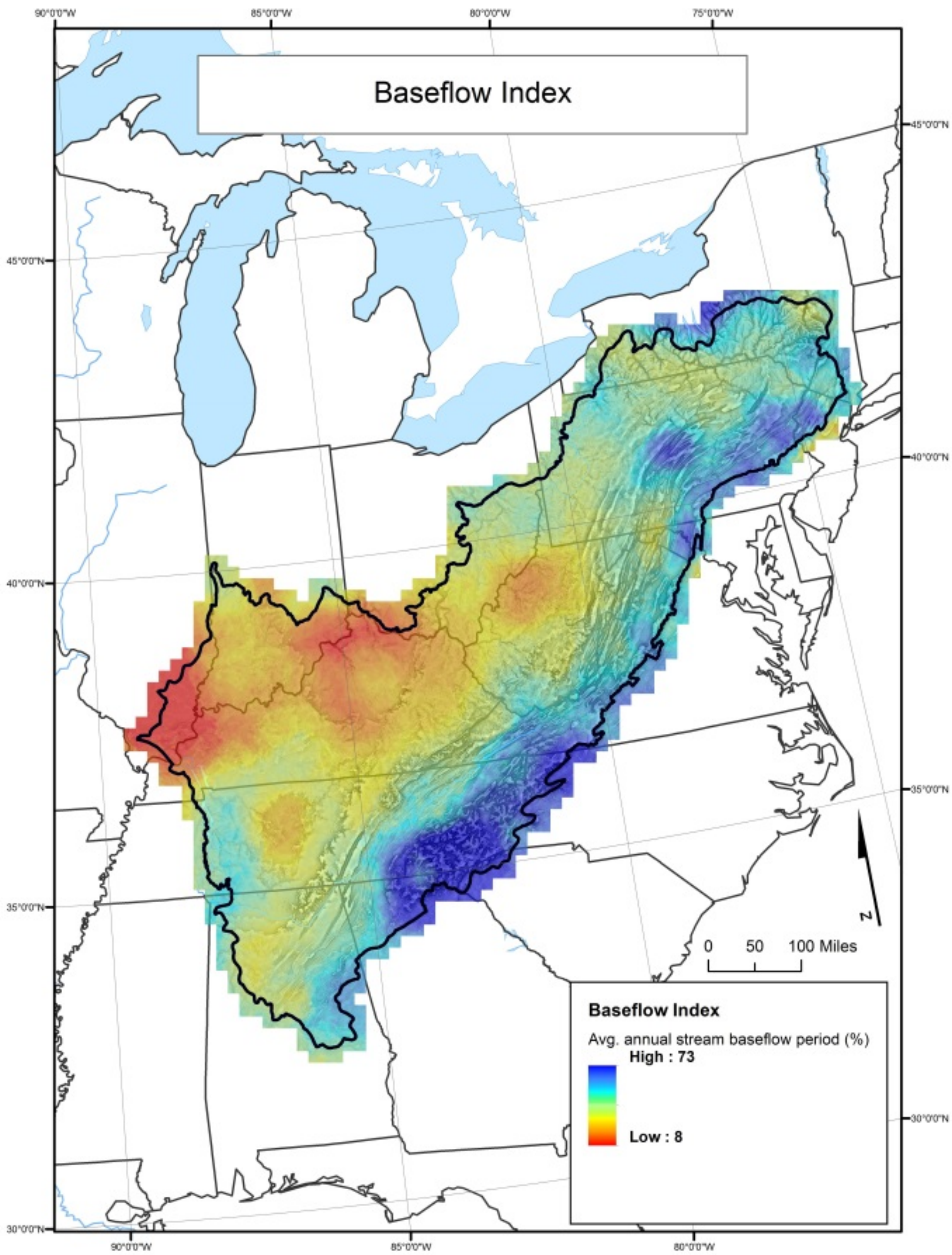


Figure 28.

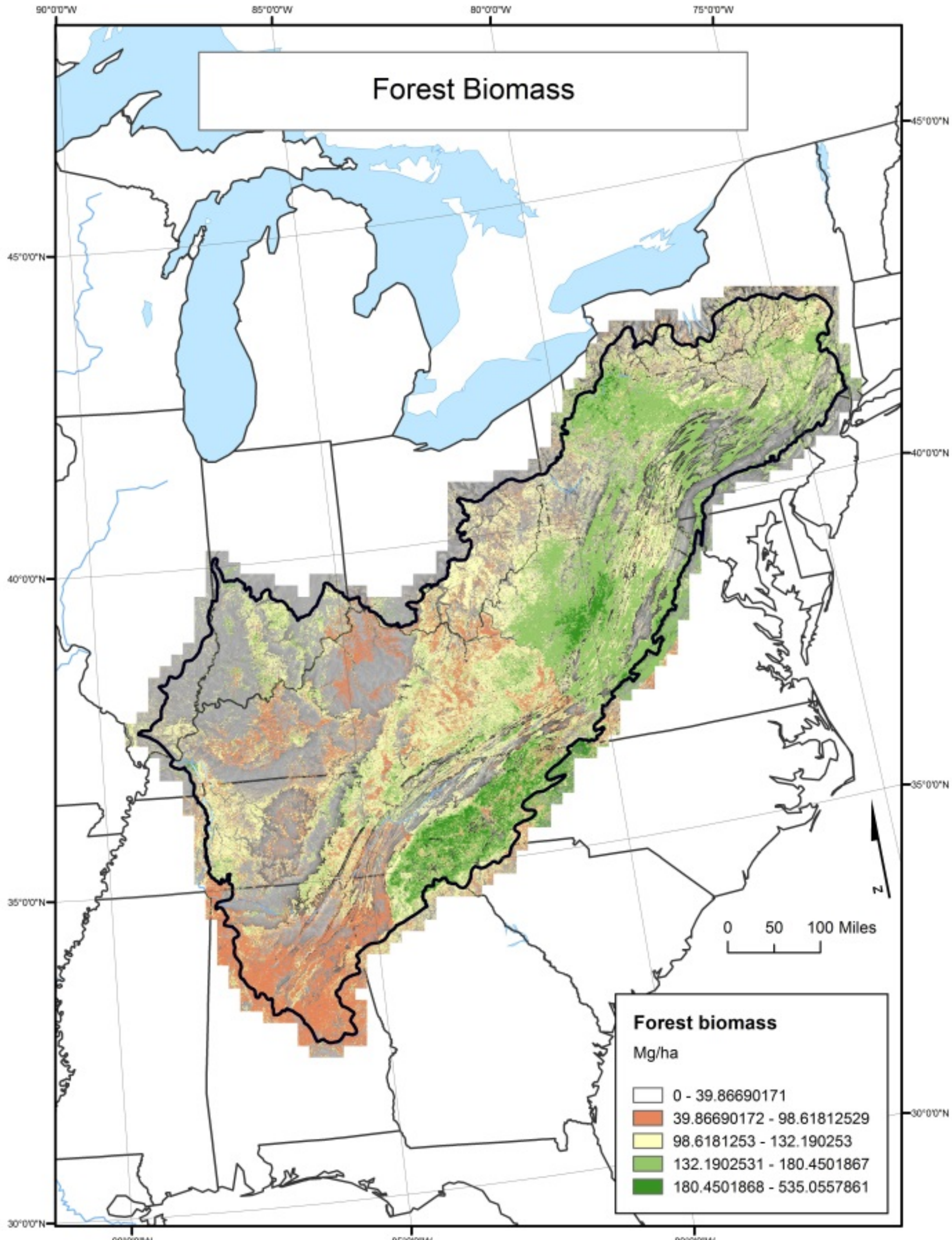

Forest Biomass
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
0 50 100 Miles
N
Forest biomass
Mg/ha
0 - 39.86690171
39.86690172 - 98.61812529
98.6181253 - 132.190253
132.1902531 - 180.4501867
180.4501868 - 535.0557861

Figure 29.

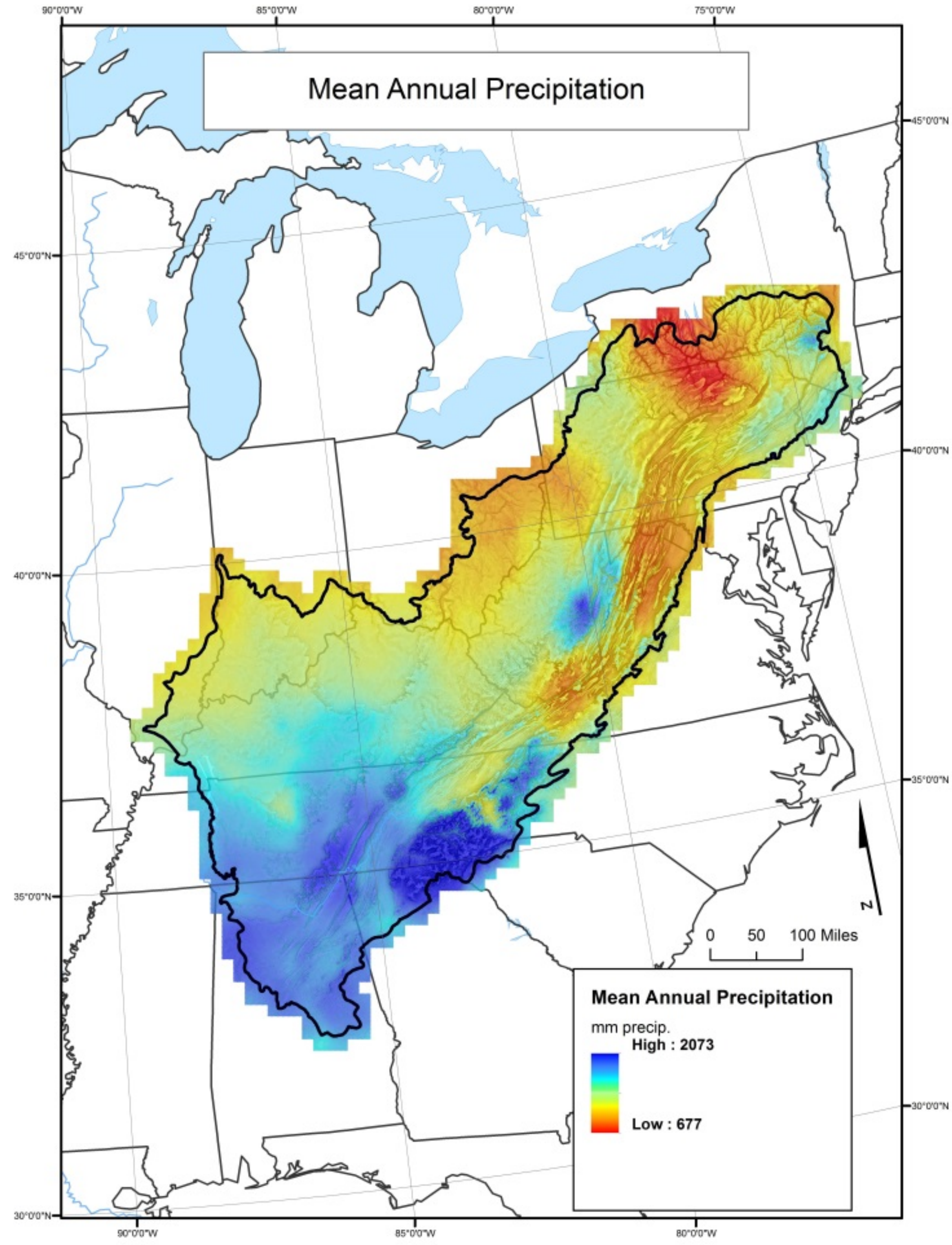

Mean Annual Precipitation
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Mean Annual Precipitation
mm precip.
High : 2073
Low : 677

Figure 30.

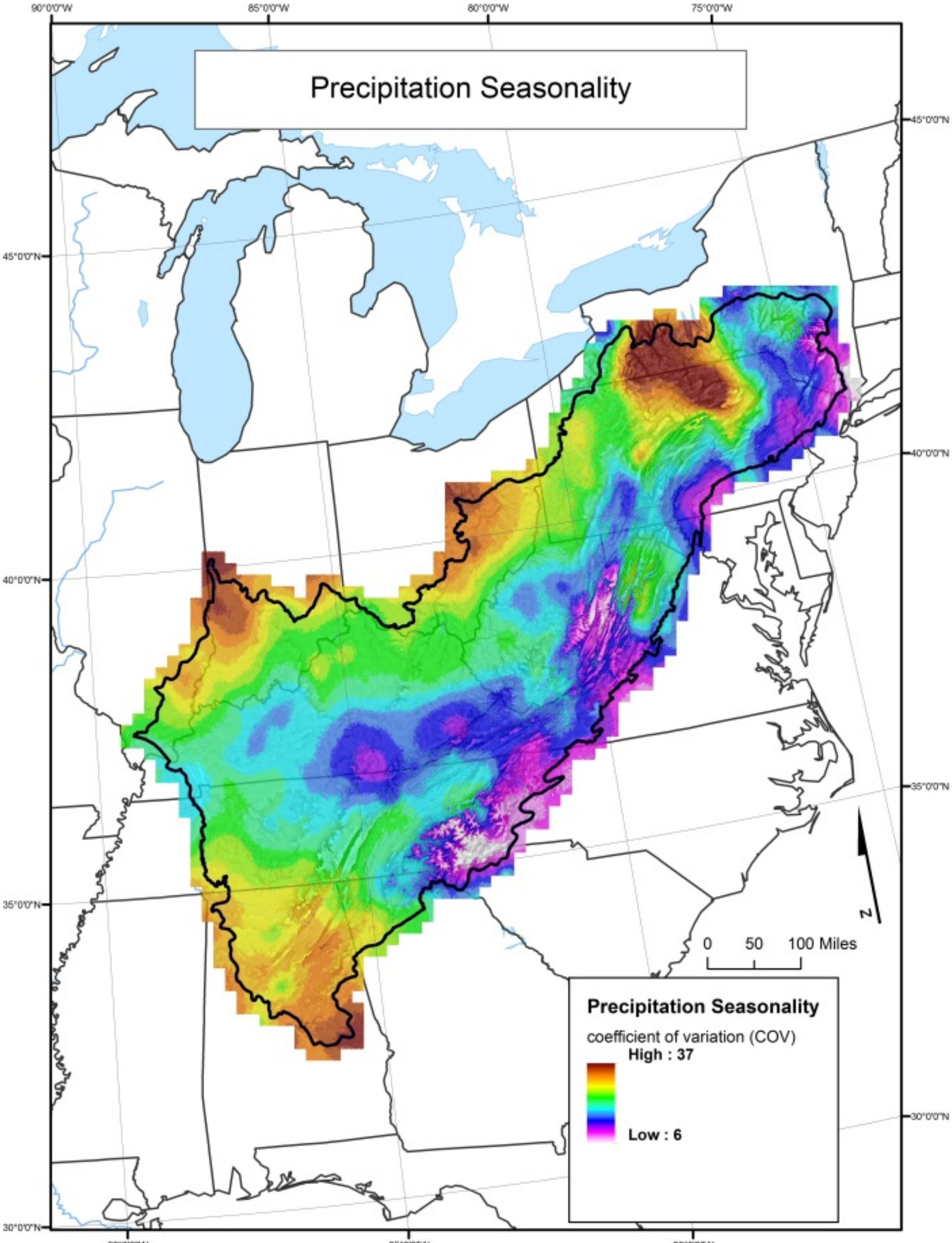

Precipitation Seasonality
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Precipitation Seasonality
coefficient of variation (COV)
High : 37
Low : 6

Figure 31.

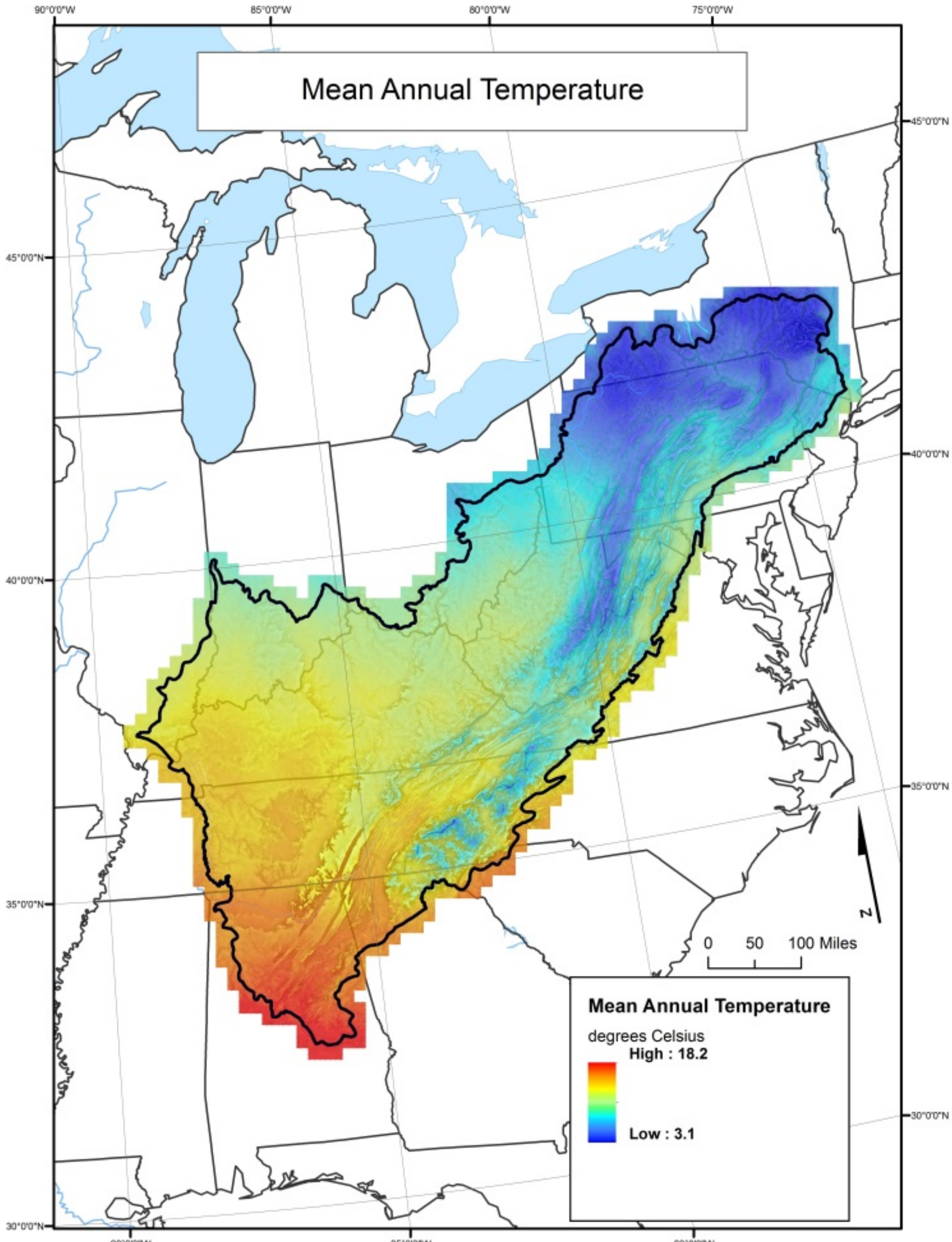

Mean Annual Temperature
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Mean Annual Temperature
degrees Celsius
High : 18.2
Low : 3.1

Figure 32.

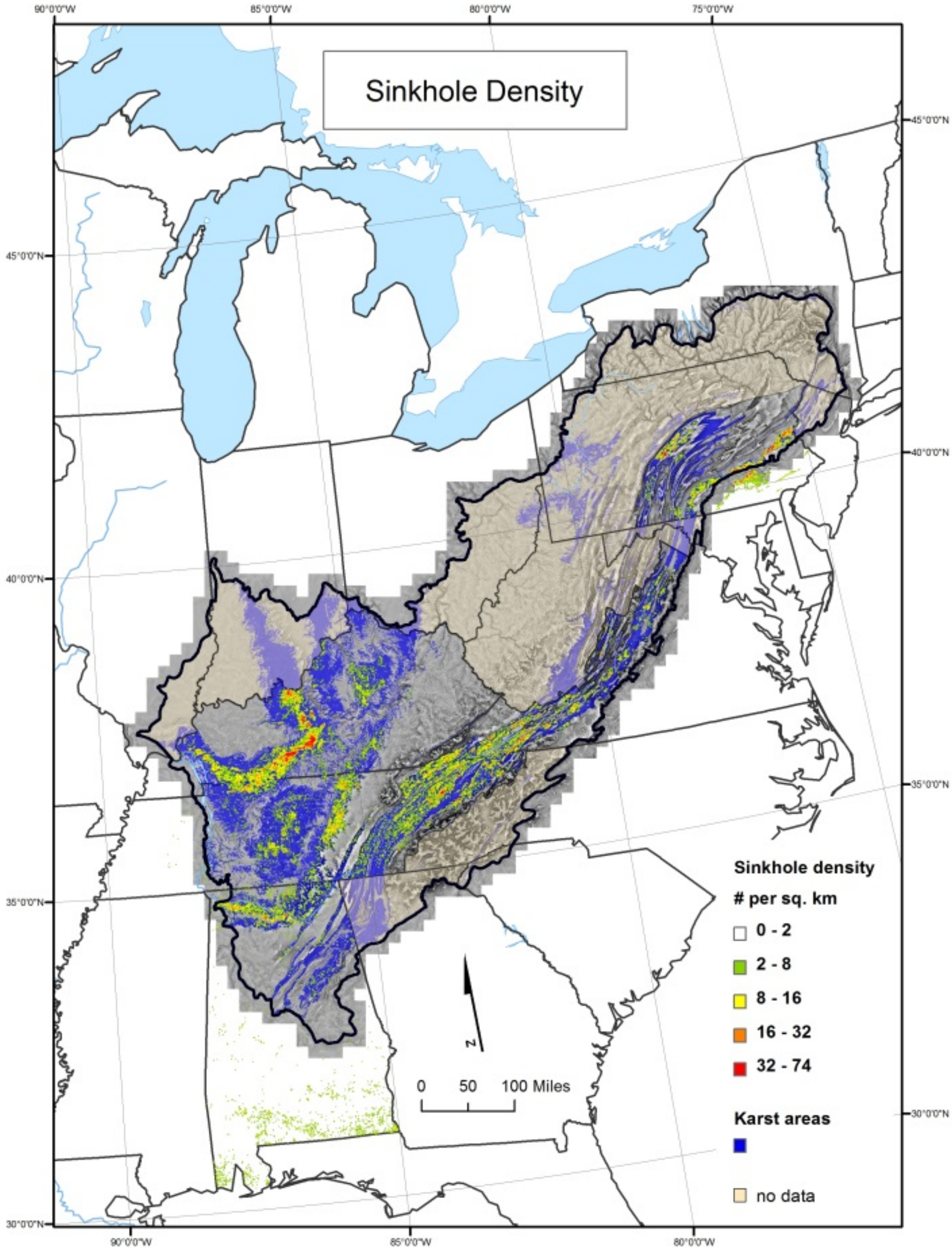

Sinkhole Density
Sinkhole density
per sq. km
0 - 2
2 - 8
8 - 16
16 - 32
32 - 74
Karst areas
no data
0 50 100 Miles
N
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N

Figure 33.

The available soil characteristics are the following:

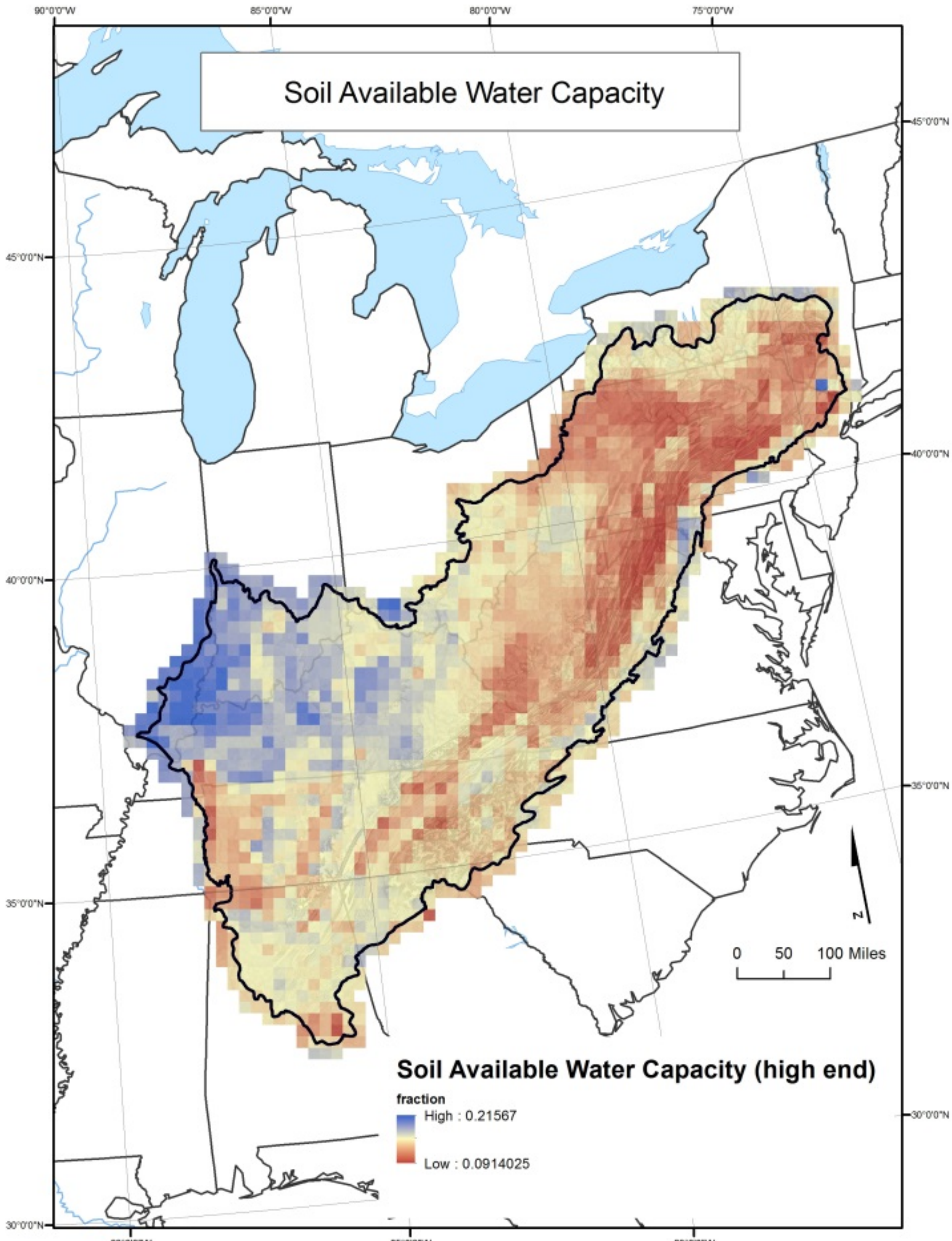


Figure 34.

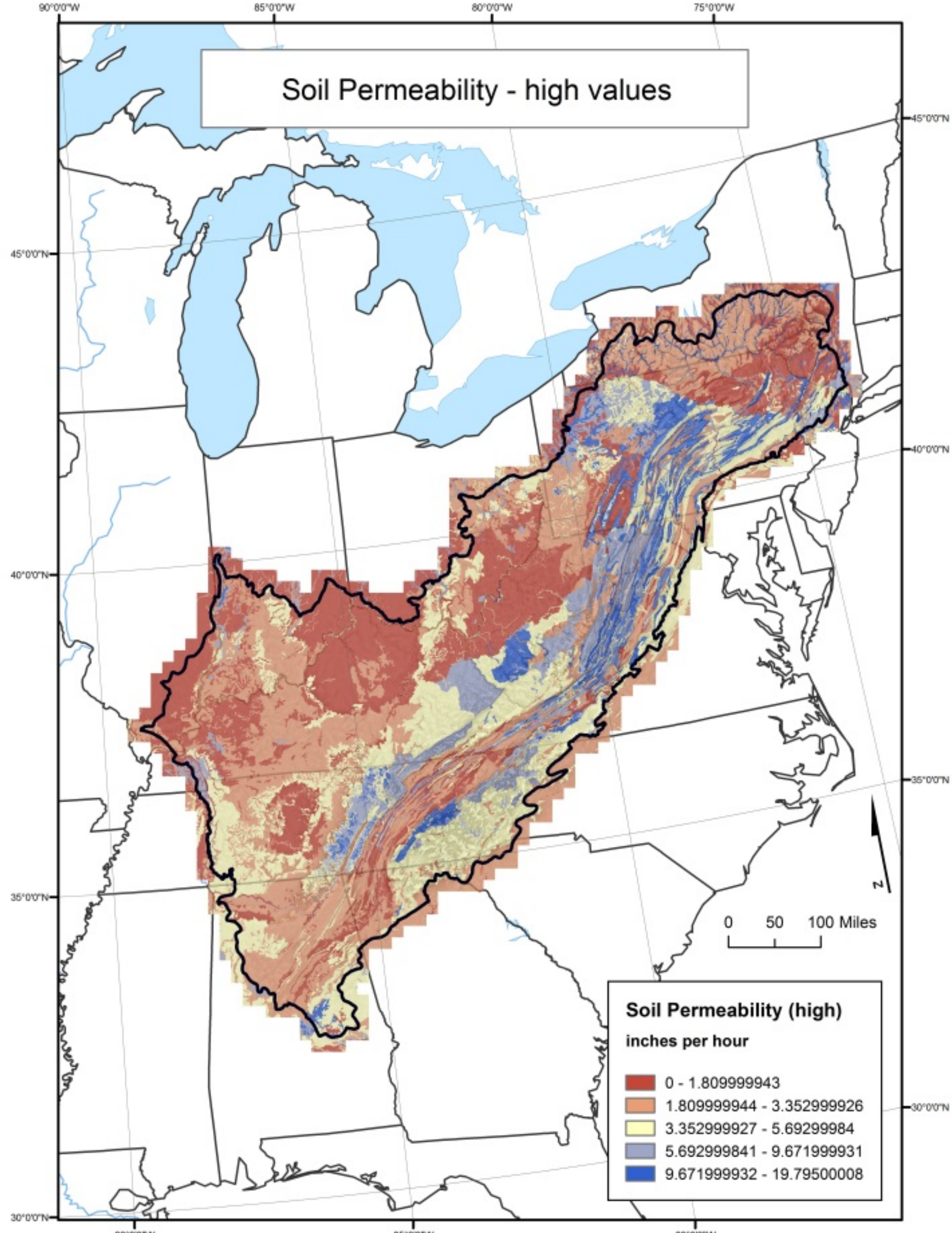
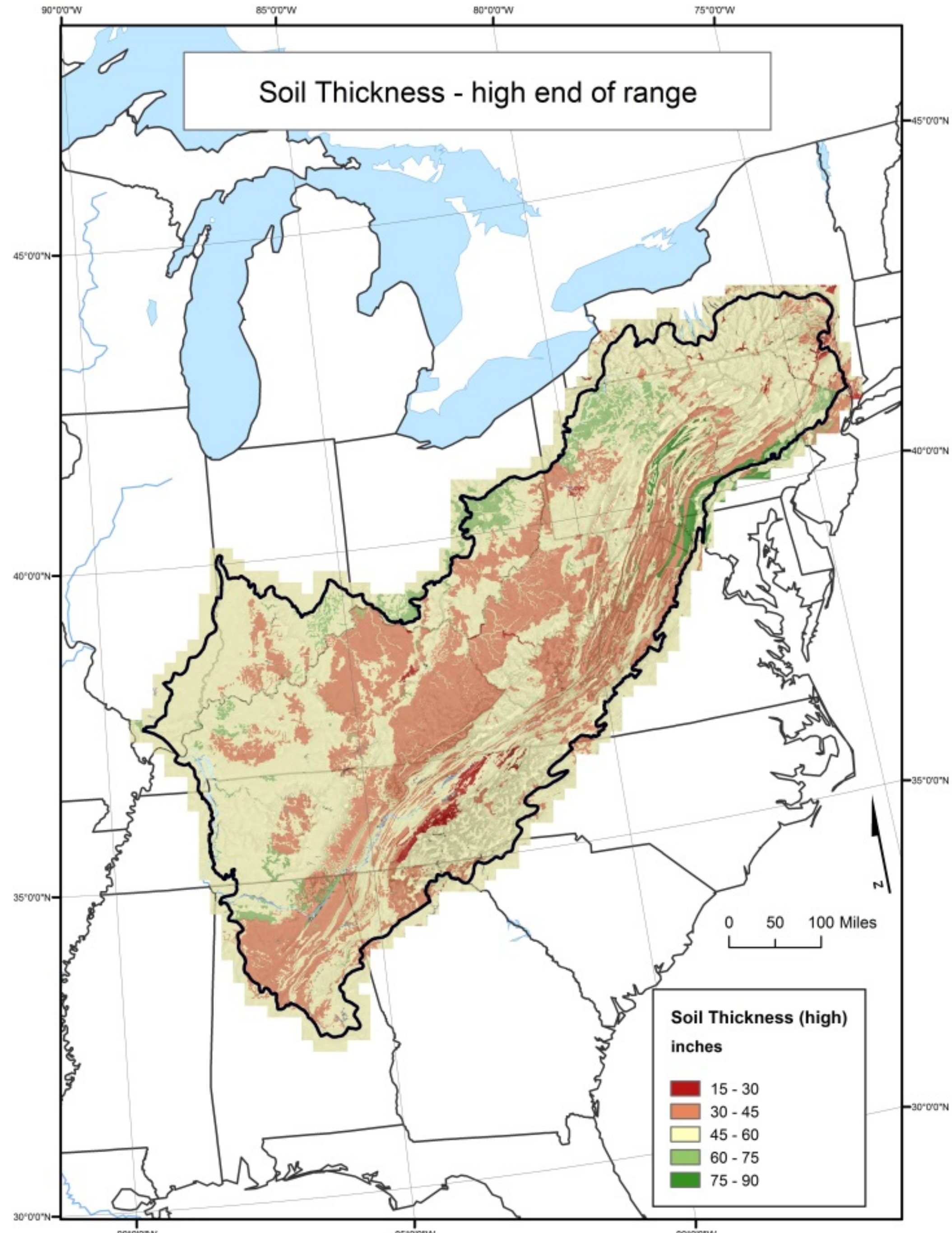

Soil Permeability - high values
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Soil Permeability (high)
inches per hour
0 - 1.809999943
1.809999944 - 3.352999926
3.352999927 - 5.69299984
5.692999841 - 9.671999931
9.671999932 - 19.79500008

Figure 35.



Soil Thickness - high end of range
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Soil Thickness (high)
inches
15 - 30
30 - 45
45 - 60
60 - 75
75 - 90

Figure 36.

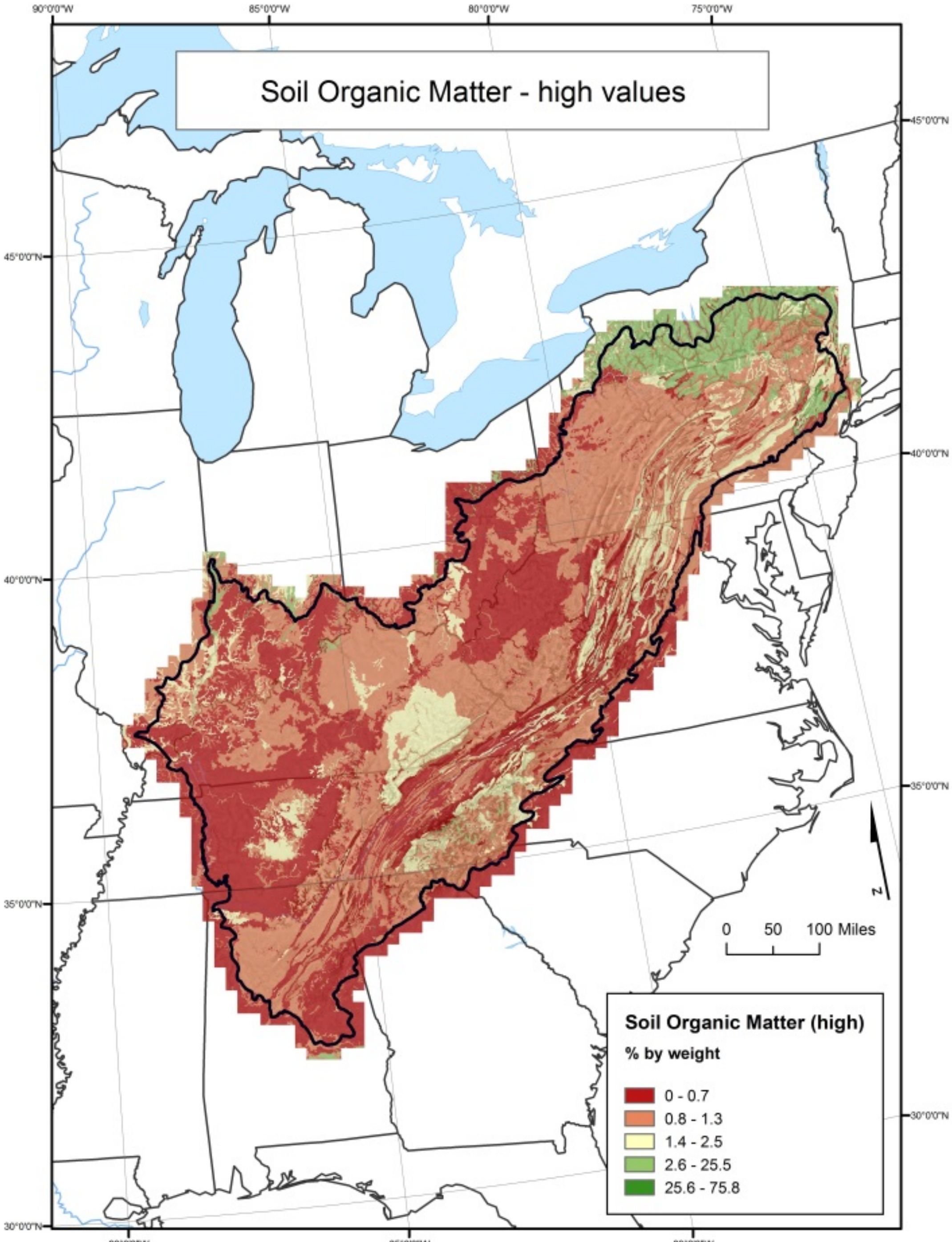

Soil Organic Matter - high values
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Soil Organic Matter (high)
% by weight
0 - 0.7
0.8 - 1.3
1.4 - 2.5
2.6 - 25.5
25.6 - 75.8

Figure 37.

Models to predict the presence or absence of major ecological groups

The basic question we addressed was whether there were physical and topographic variables that could predict the presence or absence of amphipods, asellid isopods, crayfish, fish, pseudoscorpions, spiders, springtails, millipedes, and ground beetles in a 20 km X 20 km quadrat that had karst. The data were modeled using logistic regression which models presence or absence based on a number of continuous variables, *e.g.* precipitation, and provides a prediction as to the probability that a given subterranean group would be found in a particular location.

Each of the three NatureServe regions (Interior Low Plateau, Cumberlands and Southern Blue Ridge, and Interior Low Plateau) were analyzed separately. The geometry of caves differs among the regions, and there are well established faunal differences among them, especially shown by the work of T.C. Barr.

A total of 20 explanatory variables were used in the analysis (see the list below). The predictive power of the models was good, with an overall correct percentage of prediction ranging from 67 to 94 percent. The frequency of false negatives (cells predicted to lack an ecological group but where it was present), another way of judging the effectiveness of the model, ranged from 0 to 34 percent.

Variables used as potential predictors of group presence included mean and standard deviation of: annual precipitation, annual air temperature, elevation, biomass/hectare, base flow index, and TPI; percent of karst in a quadrat as percent of areal coverage; edge length (or natural logarithm of edge length); longitude, latitude, and soil characteristics. The soil variables were combined using principal components analysis into three components describing different independent characteristics of the soil in each quadrat.

Cross-classification results from each model. Prob level = value of the cutoff of the probability of observing presence used to classify each prediction into either an event (presence) or non-event (absence). Correct = number of events and non-events properly classified when comparing predicted to observed. False Negative Percentage: precent of events falsely predicted to be non-events.

Taxon	NS Region	Prob Level	Percentages	
			Correct	False Negative
Amphipod	Central Appalachian	0.22	83.9	.
	Cumberland SBR	0.48	78.8	27.8
	Interior Low Plateau	0.44	73.5	24.4
Asellid Isopod	Central Appalachian	0.44	73.7	29.5
	Cumberland SBR	0.4	75.9	33.3
	Interior Low Plateau	0.36	72.4	18.2
Crayfish	Central Appalachian	0.2	94.1	2.7
	Cumberland SBR	0.22	93.4	1.1
	Interior Low Plateau	0.48	78.5	17.8
Fish	Cumberland SBR	0.26	86.1	6.9
	Interior Low Plateau	0.4	74	18.6
Pseudoscorpion	Central Appalachian	0.44	83.9	12.3
	Cumberland SBR	0.62	73.7	26.3
	Interior Low Plateau	0.4	74.6	21
Spider	Central Appalachian	0.5	83.1	18.2
	Cumberland SBR	0.34	71.3	26.7
	Interior Low Plateau	0.56	69.6	32.2
Springtail	Central Appalachian	0.66	78	33.3
	Cumberland SBR	0.3	67.2	26.3
	Interior Low Plateau	0.46	68.5	39.3
Millipede	Central Appalachian	0.2	82.2	2.1
	Cumberland SBR	0.46	80.3	20.5
	Interior Low Plateau	0.58	70.2	34.9
Ground Beetle	Central Appalachian	0.56	73.7	24.3
	Cumberland SBR	0.28	77.4	18.2
	Interior Low Plateau	0.32	75.7	23.8

Which variables were most predictive of the likelihood of presence varied from group to group and among NatureServe regions. Those variables that had explanatory power for the most groups and in most regions were (in descending order);

- Percent karst (18 of 26 models)
- Standard deviation of TPI, a measure of local relief (14 of 26)

- Standard deviation of temperature (13 of 26)
- Longitude (11 of 26)
- Principal Component I of soil variables

Explanatory variables in the final model for each combination of taxonmic group and Nature Serve region--CA=Central Appalachians, CSBR=Cumberland/Southern Blue Ridge, and ILP=Interior Low Plateau.

Taxon	Region	Mean Precipitation	SD Precipitation	Mean Temperature	SD Temperature	Mean Elevation	SD Elevation	Mean Mg/ha	SD Mg/ha	Mean BFI	SD BFI	Mean TPI	SD TPI	% Karst	Edge Length	log(Edge Length)	Longitude	Latitude	Soil PCA1	Soil PCA2	Soil PCA3
Amphipod	CA											x	x						x		x
	CSBR		x	x			x						x	x	x						
	ILP	x					x				x			x			x	x			
Asellid Isopod	CA	x					x						x	x			x		x	x	
	CSBR				x					x				x					x	x	
	ILP						x	x						x					x		
Crayfish	CA	x												x		x			x		
	CSBR		x			x				x		x					x				x
	ILP	x	x				x			x	x	x		x			x	x			
Fish	CSBR				x	x	x			x				x			x			x	
	ILP	x		x	x	x								x	x		x	x			
Pseudoscorpion	CA		x											x					x		x
	CSBR	x	x						x	x			x		x					x	
	ILP		x							x	x		x	x							
Spider	CA		x				x						x			x		x			
	CSBR		x	x		x						x				x	x	x			
	ILP							x	x				x	x					x		
Springtail	CA		x				x					x	x					x			
	CSBR	x	x				x						x				x			x	x
	ILP				x			x	x			x	x	x							
Millipede	CA		x	x										x			x	x	x		
	CSBR								x	x			x	x	x				x		
	ILP			x						x	x		x	x			x				
Ground Beetle	CA		x				x					x	x	x					x		x
	CSBR	x	x					x		x			x					x			
	ILP			x							x	x		x			x	x	x	x	
	TOTAL	8	13	6	4	4	10	4	4	9	5	8	14	18	4	3	11	9	11	6	5

There are two big take home messages from this analysis. The first is that surface features can effectively predict the likelihood of presence of subterranean species groups. If there ever was any doubt that cave fauna could be protected with little regard to activities on the surface, this study should put that to rest. Second, the most important determinants are available habitat and cave heterogeneity (measured by landscape heterogeneity).

Below we display the prediction maps for each of the nine groups. These are potentially important both to predict areas where to find particular groups and to determine regions of overall high habitat quality where species richness is expected to be high.

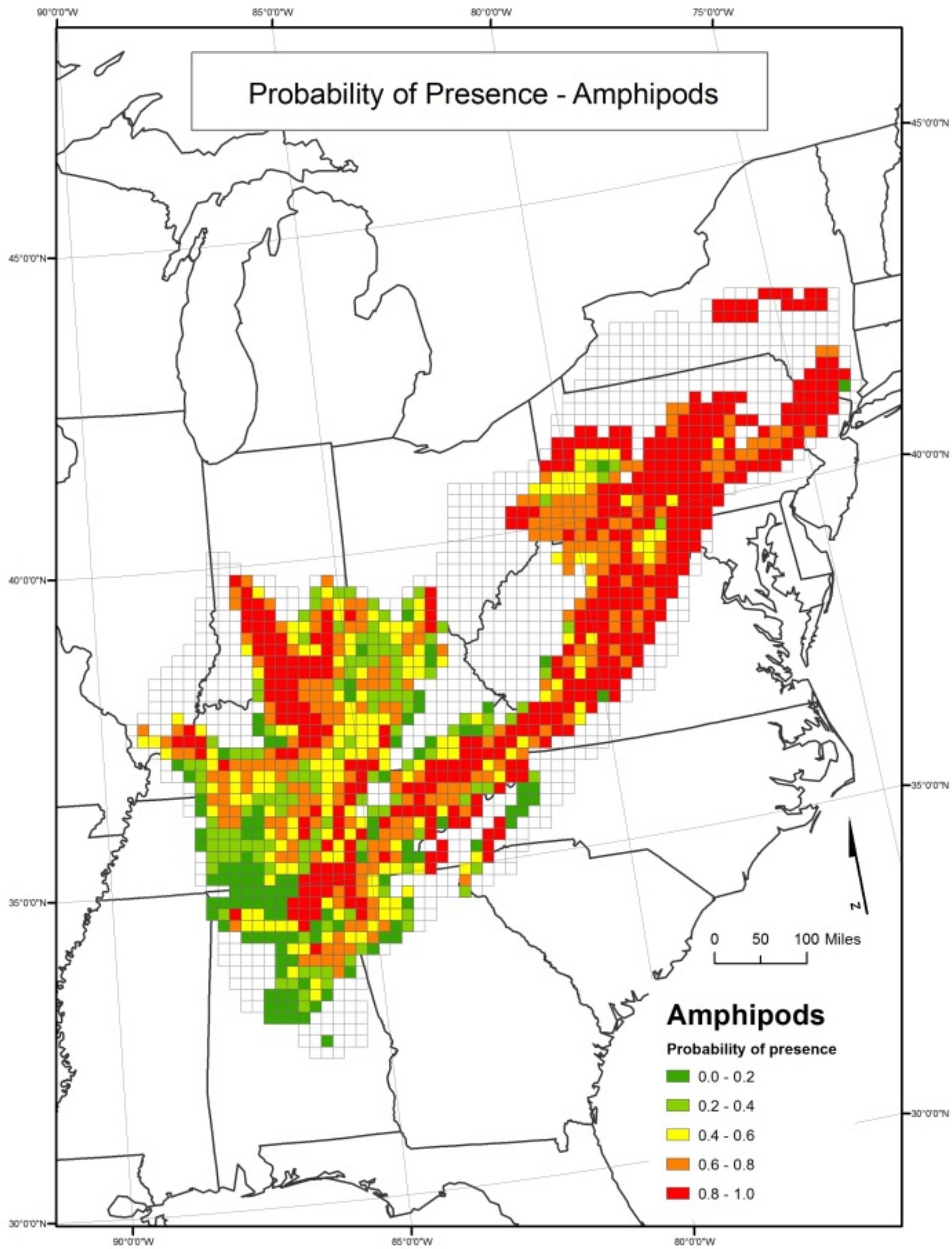


Figure 38.

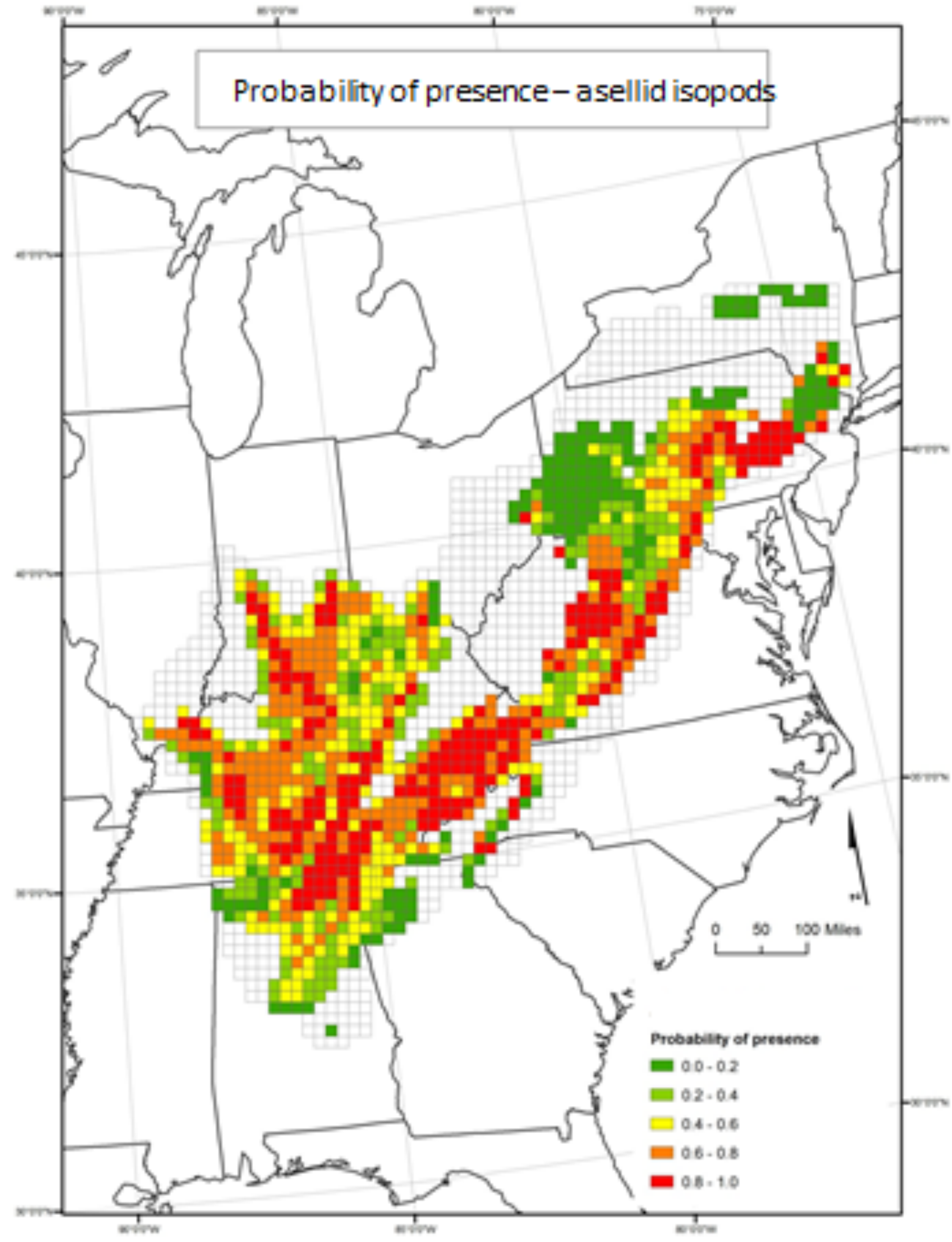
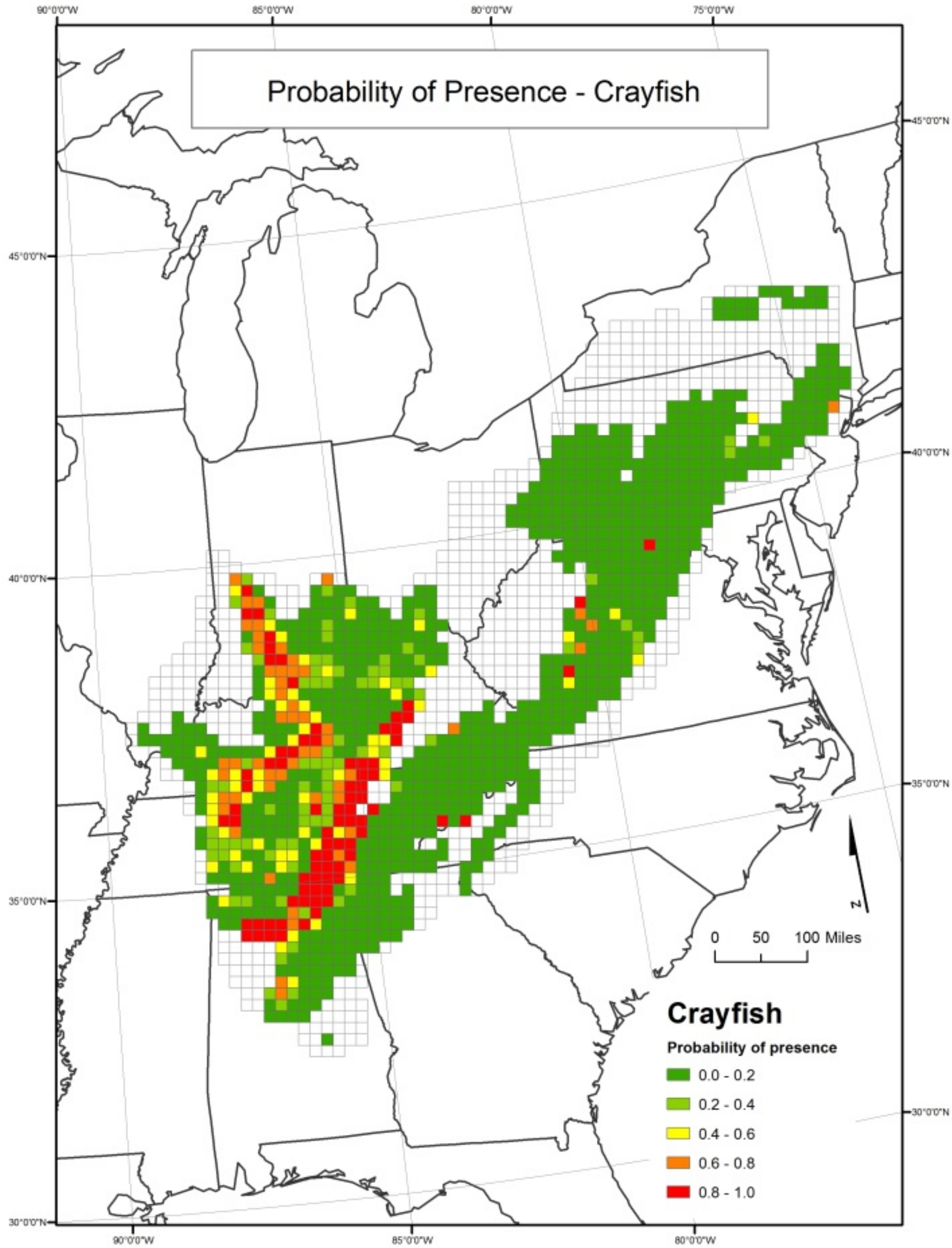
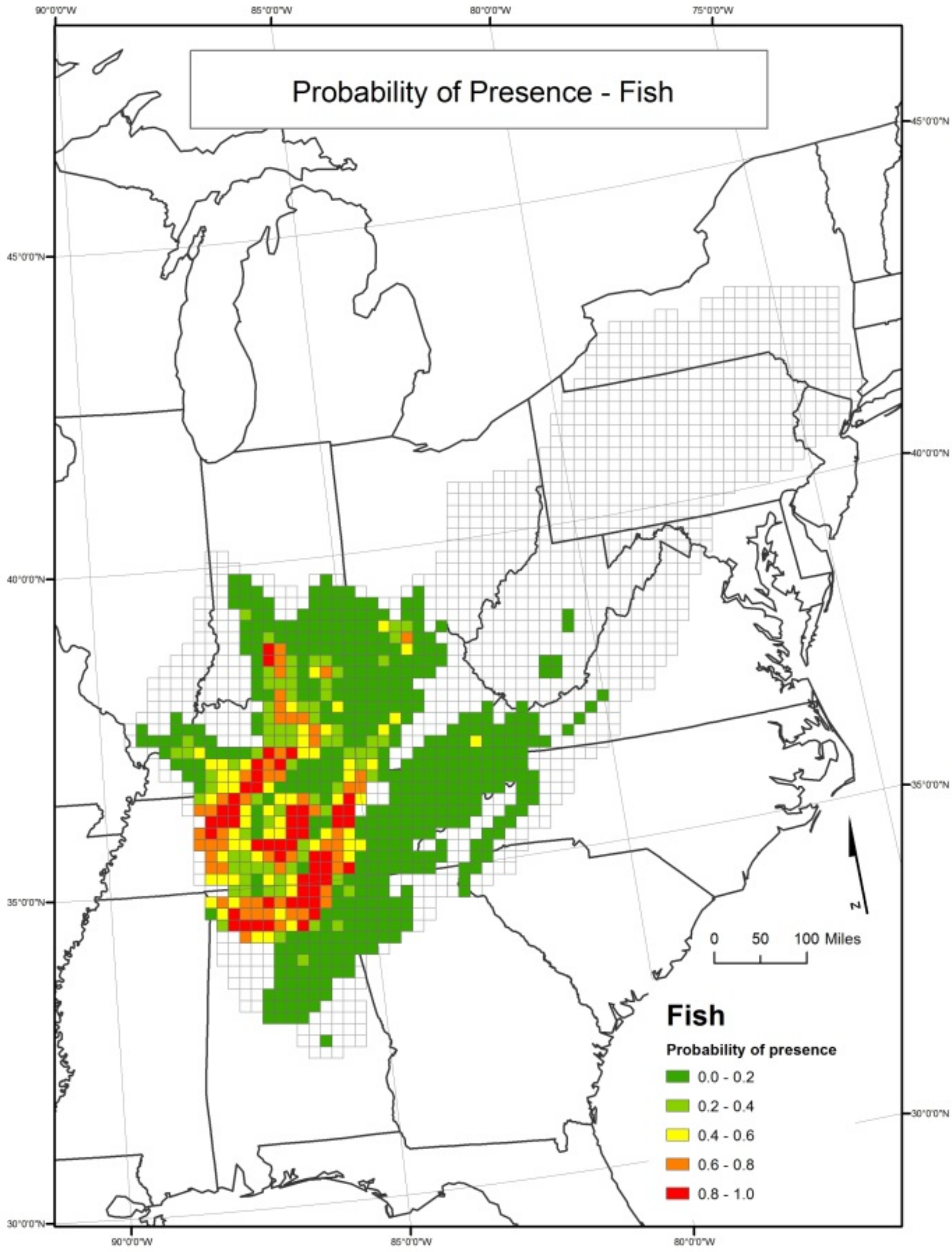

Probability of presence – asellid isopods
0 50 100 Miles
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 39.



Probability of Presence - Crayfish
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Crayfish
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 40.



Probability of Presence - Fish
0 50 100 Miles
N
Fish
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 41.

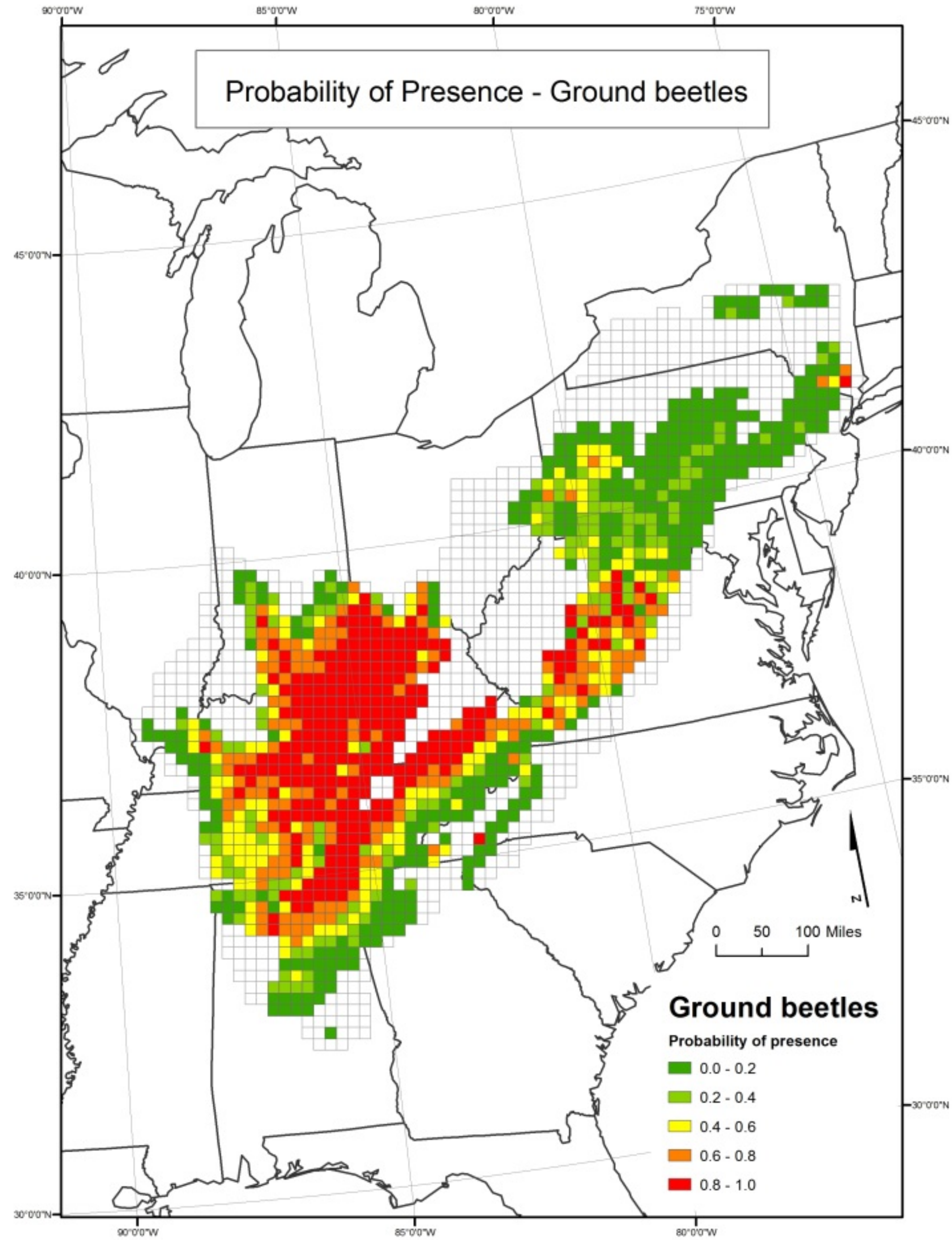

Probability of Presence - Ground beetles
0 50 100 Miles
N
Ground beetles
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 42.

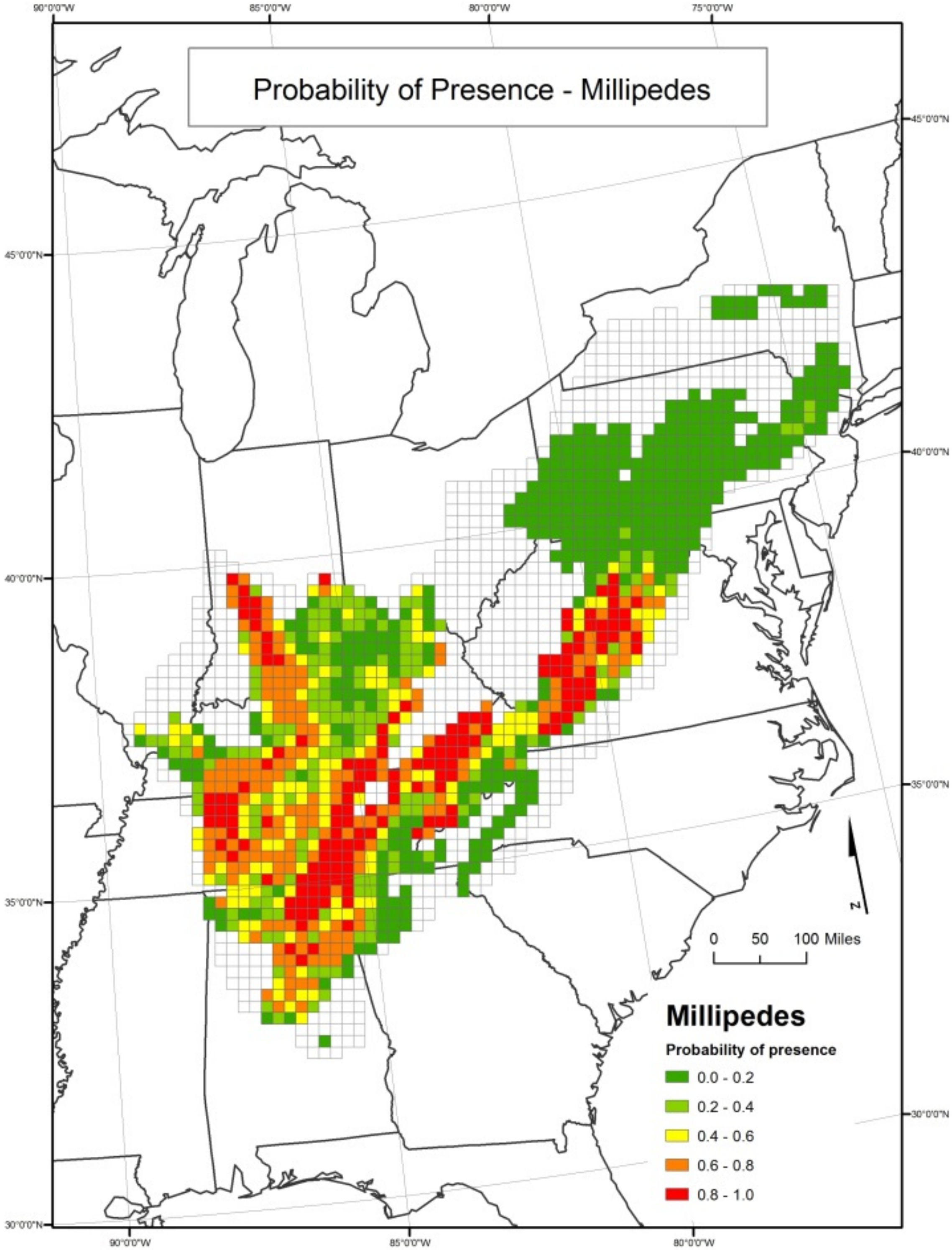
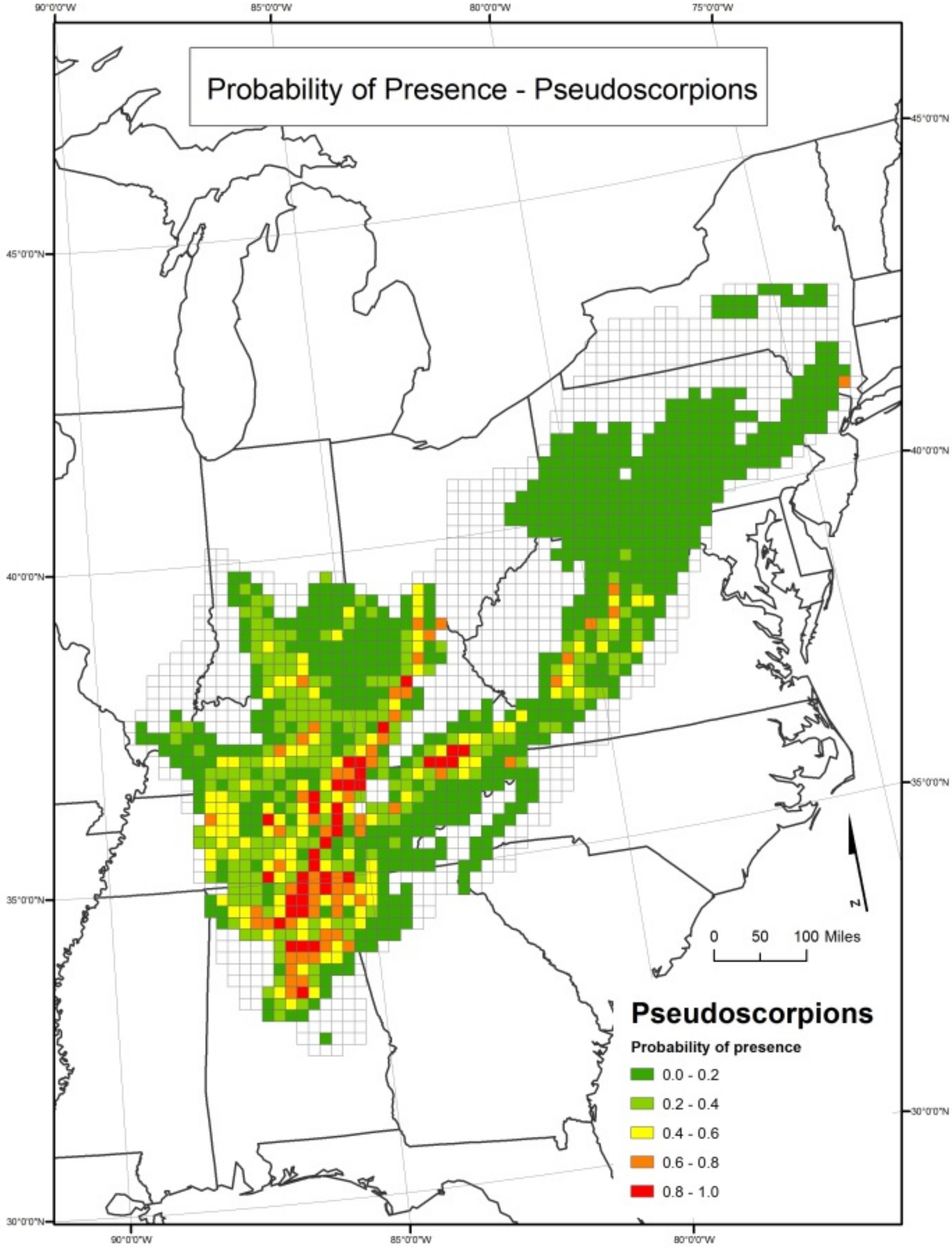
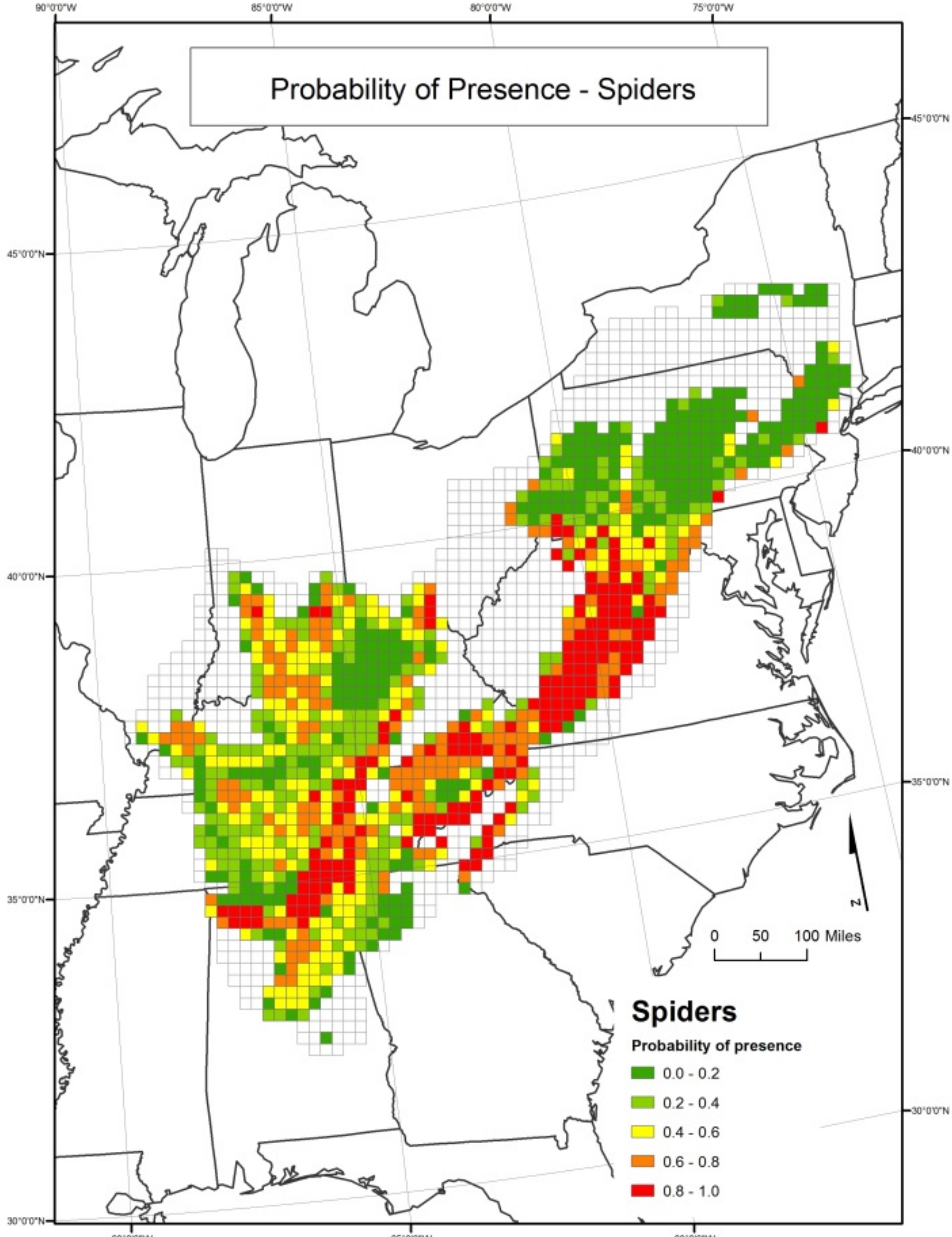

Probability of Presence - Millipedes
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Millipedes
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 43.



Probability of Presence - Pseudoscorpions
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Pseudoscorpions
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 44.



Probability of Presence - Spiders
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
0 50 100 Miles
N
Spiders
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 45.

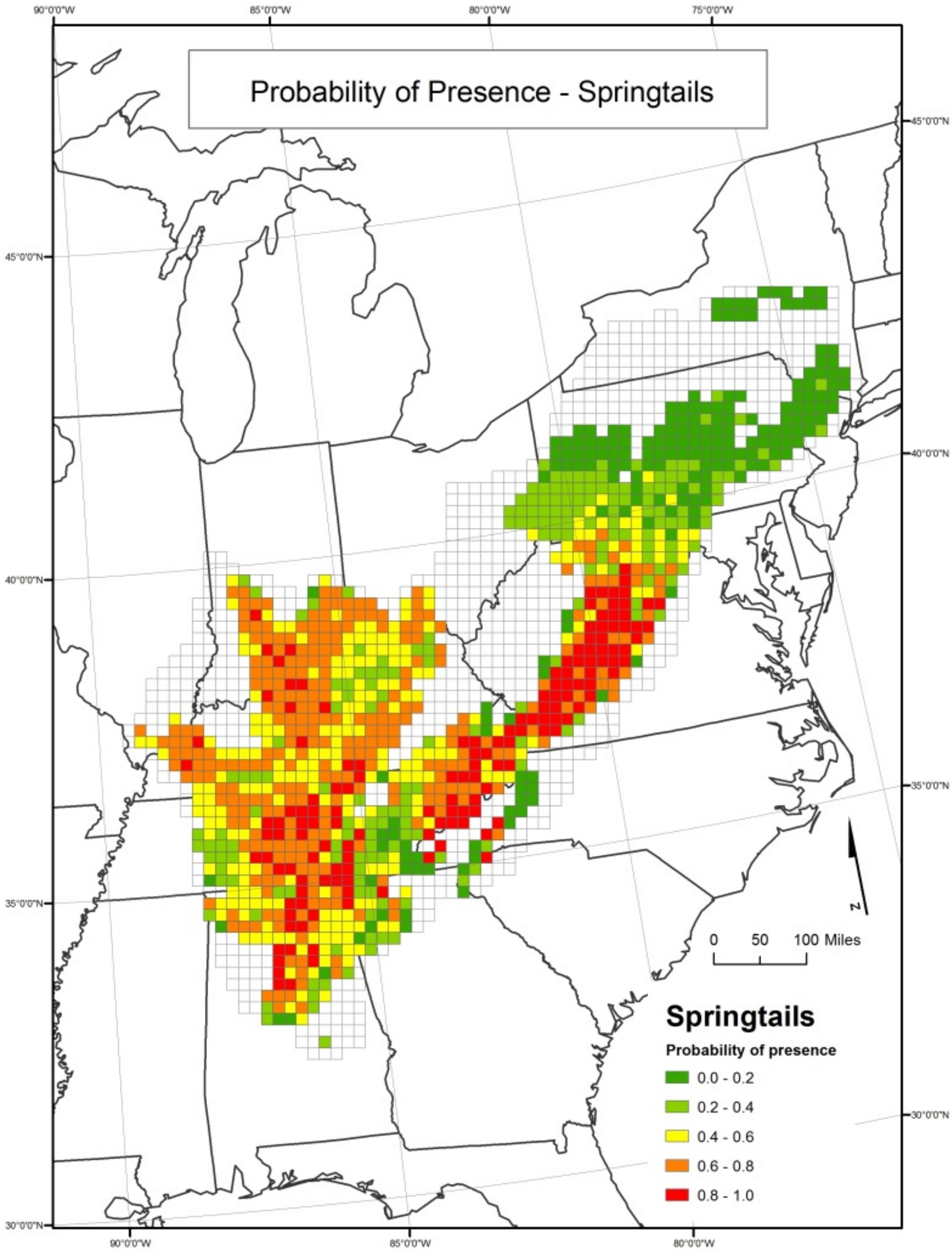

Probability of Presence - Springtails
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N
N
0 50 100 Miles
Springtails
Probability of presence
0.0 - 0.2
0.2 - 0.4
0.4 - 0.6
0.6 - 0.8
0.8 - 1.0

Figure 46.

As a first step toward a predictive model of hotspots of species richness based on the predictive variables outlined above, we summed the probabilities of each group within each grid cell (excluding fish which do not occur at all in the Central Appalachians, making predictions impossible). We summed probabilities to indicate locations that have one or more of the species groupings. Higher values indicate that more species are likely to be found. Multiplying the probabilities would provide the likelihood of all groupings being present which is more rare than the event that at least one species group is found.

For the five terrestrial groups (Figure 47), the major hotspot is in northeast Alabama and south central Tennessee, mimicking the observed data. However, there are also hotspots in southwest Virginia, and central West Virginia that do not appear on the map of species richness.

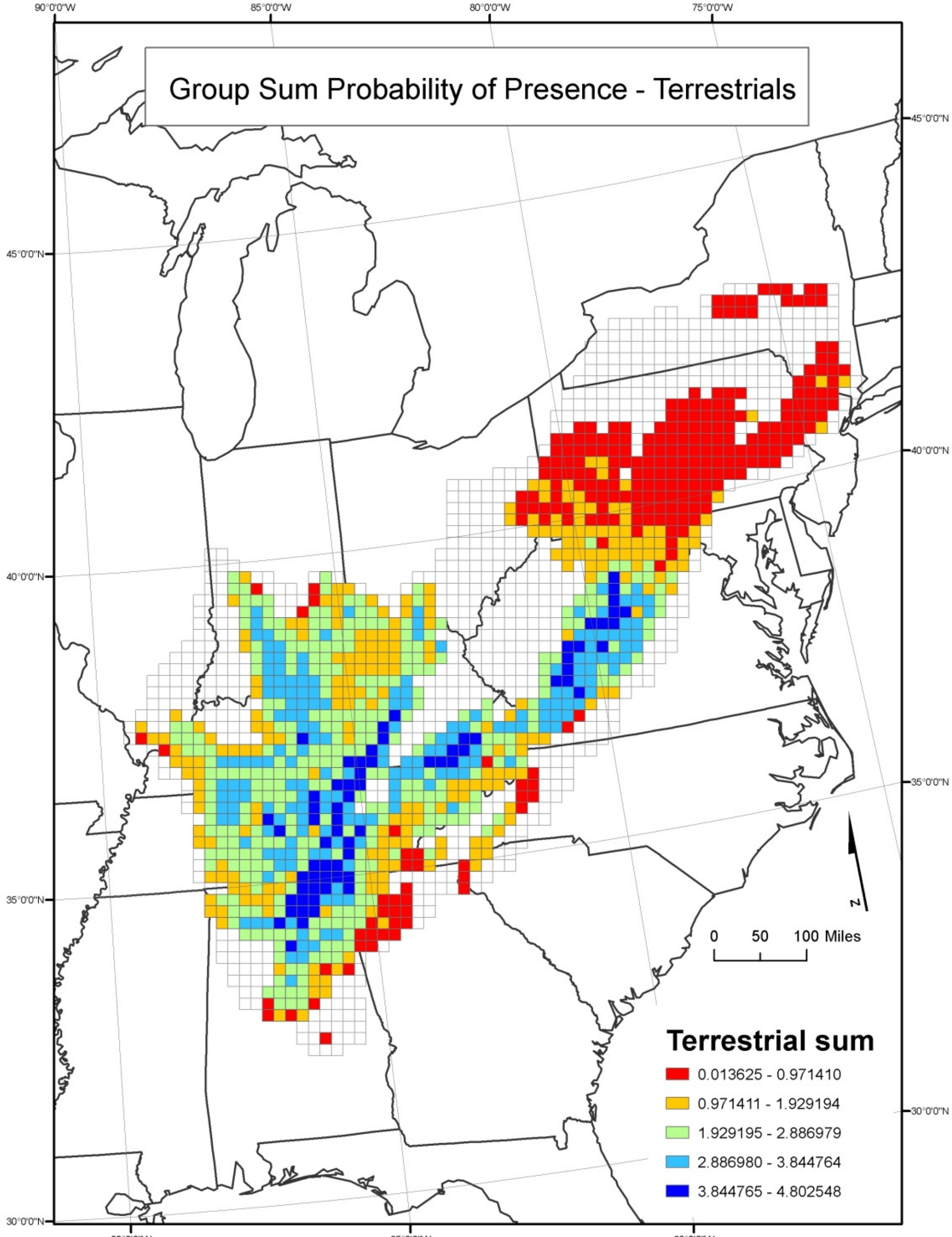

Group Sum Probability of Presence - Terrestrials
Terrestrial sum
0.013625 - 0.971410
0.971411 - 1.929194
1.929195 - 2.886979
2.886980 - 3.844764
3.844765 - 4.802548
0 50 100 Miles
90°0'0"W
85°0'0"W
80°0'0"W
75°0'0"W
45°0'0"N
40°0'0"N
35°0'0"N
30°0'0"N

Figure 47.

The map of predicted aquatic species richness has broader swaths of species richness, especially in the Interior Low Plateau (Figure 48).

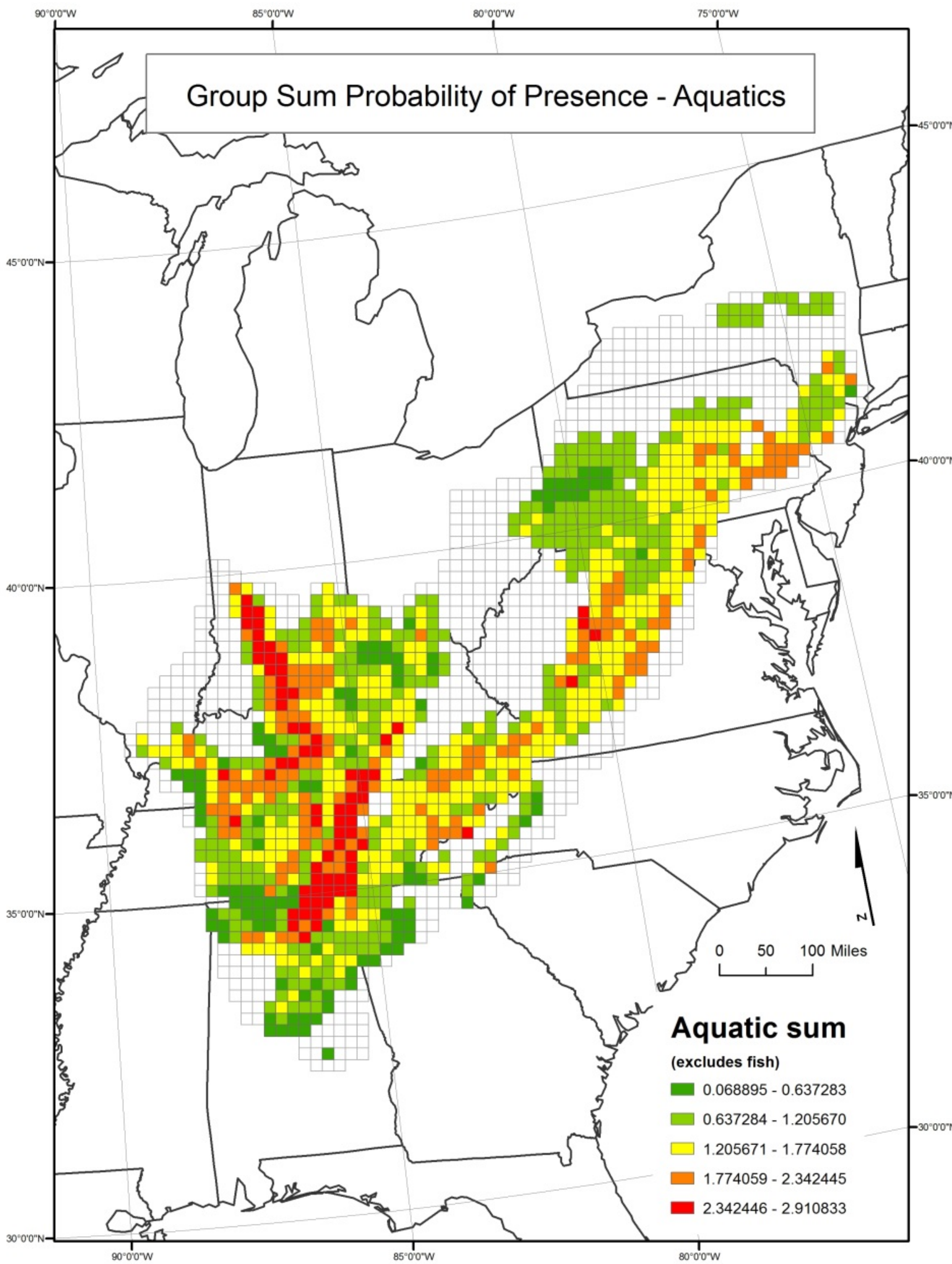


Figure 48.

Geography of risk to the subterranean fauna

It is probable that most risk to the cave fauna is local, through factors of direct destruction (quarrying, road construction, etc.), groundwater contamination or extraction (sinkhole dumping, spills, wells, etc.), and other development.

To many conservationists, a core cause of environmental problems and risk to biota is population growth (Figure 49). The study area shows an interesting pattern in this regard. Two areas—, the Nashville region, and the eastern panhandle of West Virginia have shown strong population growth in the past ten years, while many of the mountain counties of the Appalachians have shown declines.

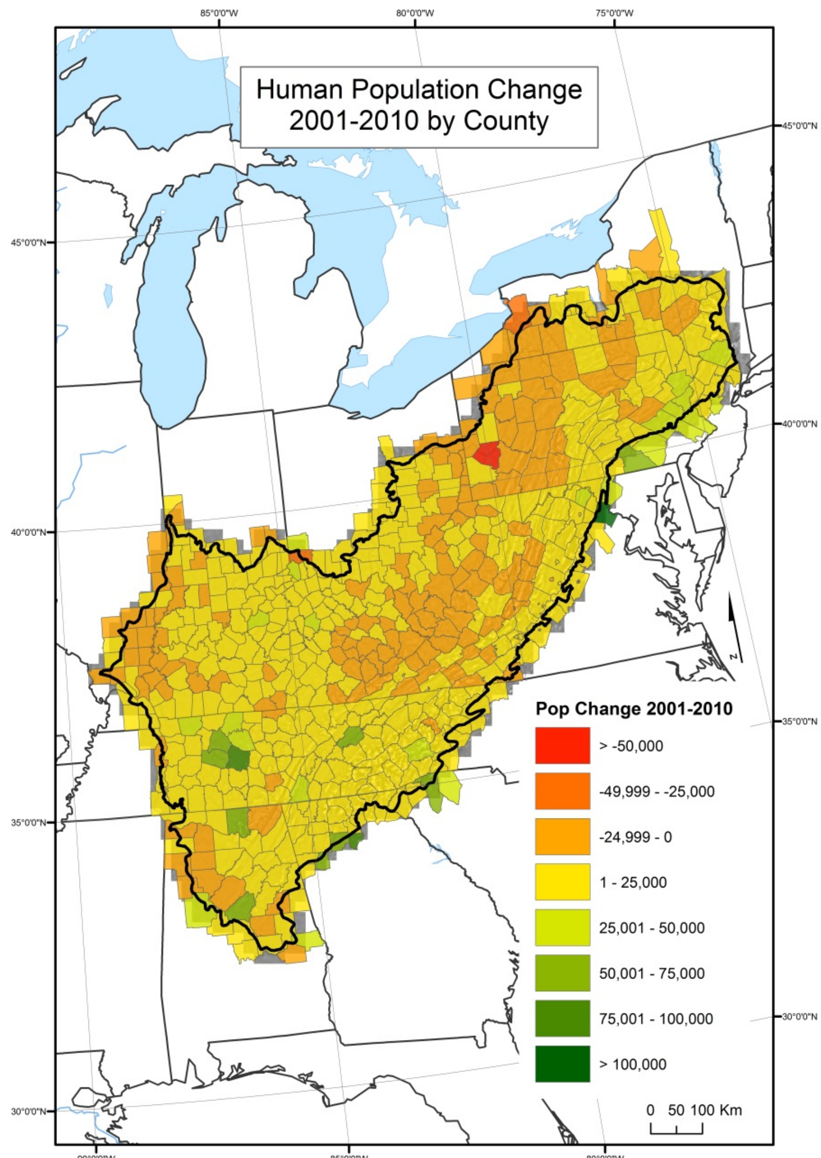


Figure 49

However, there are some regional risks larger than metropolitan zones. For example, one newly arising risk is the construction of natural gas pipelines through entire states that have the potential of directly destroying vulnerable habitat and indirectly by increasing the risk of spills and contamination. A macro-scale risk that is long-term and national if not global is climate change.

Connected with the geography of risk is the geography of protection. The map below shows the various categories of protected lands in the Appalachian LCC area (Figure 50).

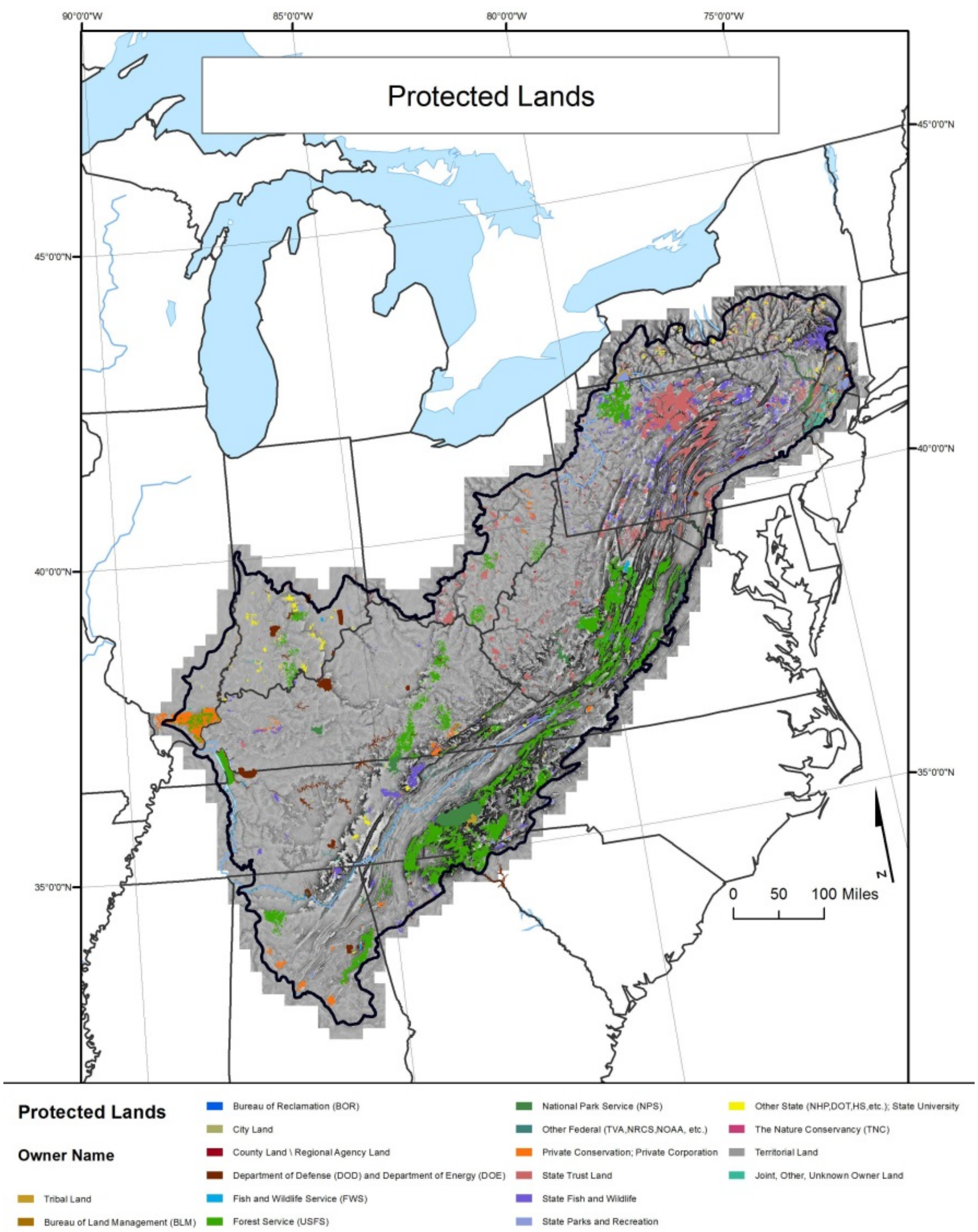


Figure 50

Geographic patterns of bat utilization of caves

The utilization of caves by bats is quite different than that of obligate cave-dwelling species. Of course, no bat spends its entire life in a cave, and during the summer, those species that roost in caves leave at night to forage for food, primarily insects. Some species also hibernate in caves, and overall there is a varying degree of dependency on caves as a physical habitat. Many species are also found in mines, presumably because some mines and caves are very similar habitats to bats. In the study area, there are ten species of bats that depend on caves and mines:

- *Eptesicus fuscus* – Big Brown Bat
- *Perimyotis subflavus* – Tri-Colored Bat
- *Corynorhinus rafinesquii* – Rafinesque's Big-Eared Bat
- *C. townsendii virginianus* – Virginia Big-Eared Bat
- *Myotis austroriparius* – Southeastern Myotis
- *M grisescens* – Gray Bat
- *M. leibii* – Eastern Small-Footed Bat
- *M. lucifugus* – Little Brown Bat
- *M. septentrionalis* – Northern Long-Eared Bat
- *M. sodalis* – Indiana Bat

Because of habitat destruction (both foraging areas and hibernacula), as well as the impact of White Nose Syndrome, six of these bats are on or are candidates for the federal endangered species list:

Federal status of these bats

Some of these taxa are listed as endangered or have been considered for listing:

1. *M. sodalis* – Endangered (1967)
2. *M. grisescens* – Endangered (1976)
3. *C. townsendii virginianus* – Endangered (1979)
4. *M. septentrionalis* – Proposed for listing as endangered (2013)
5. *M. leibii* – Considered for listing, but listing not warranted (2013)
6. *P. subflavus* – Will be considered for listing shortly

The ranges of all ten species, by county, are shown below in Figures 51–60. Due to problems of data coverage, only county data are complete. Data are available from 1093 sites.

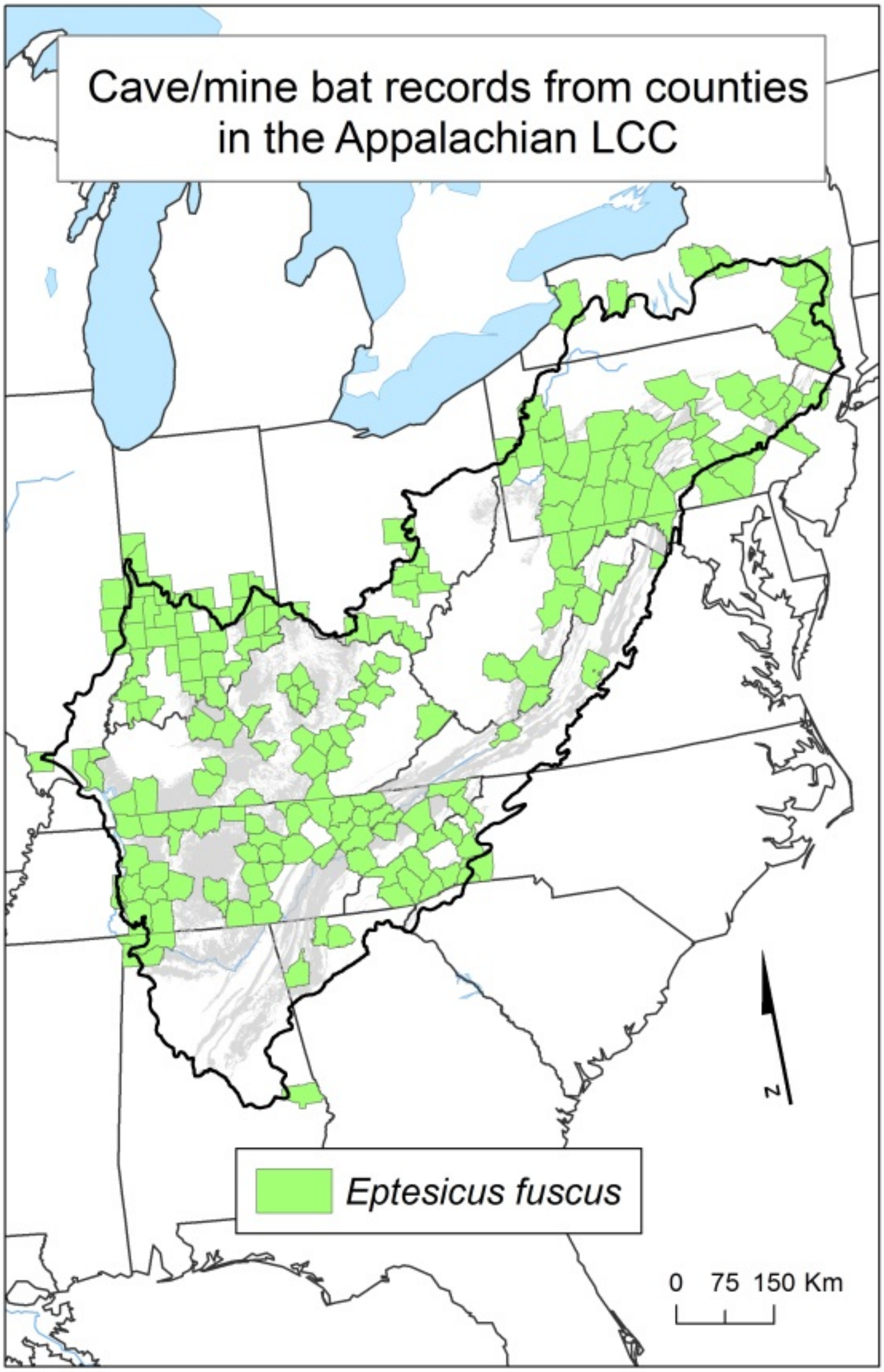


Figure 51

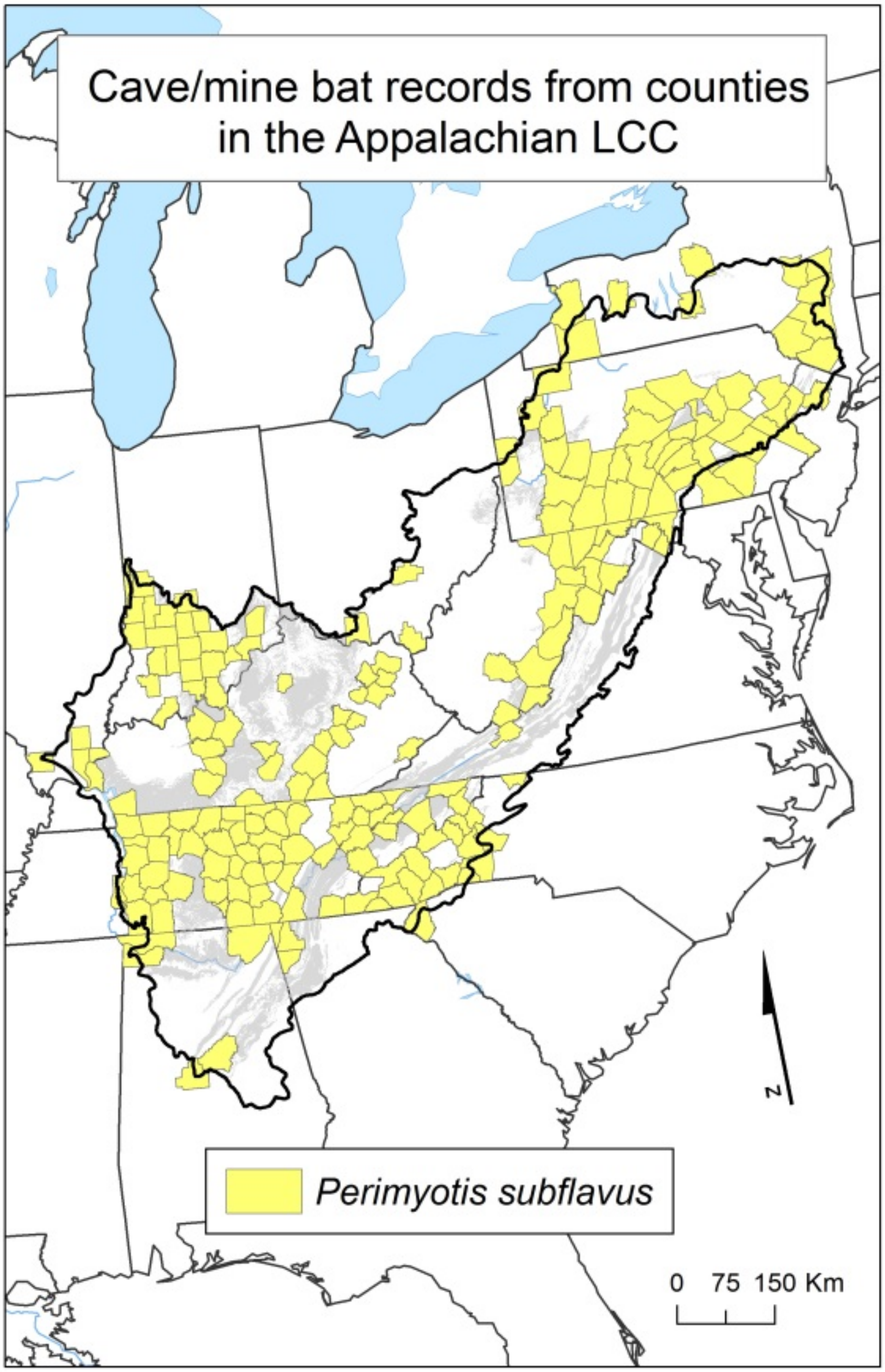

Cave/mine bat records from counties in the Appalachian LCC
Perimyotis subflavus
N
0 75 150 Km

Figure 52

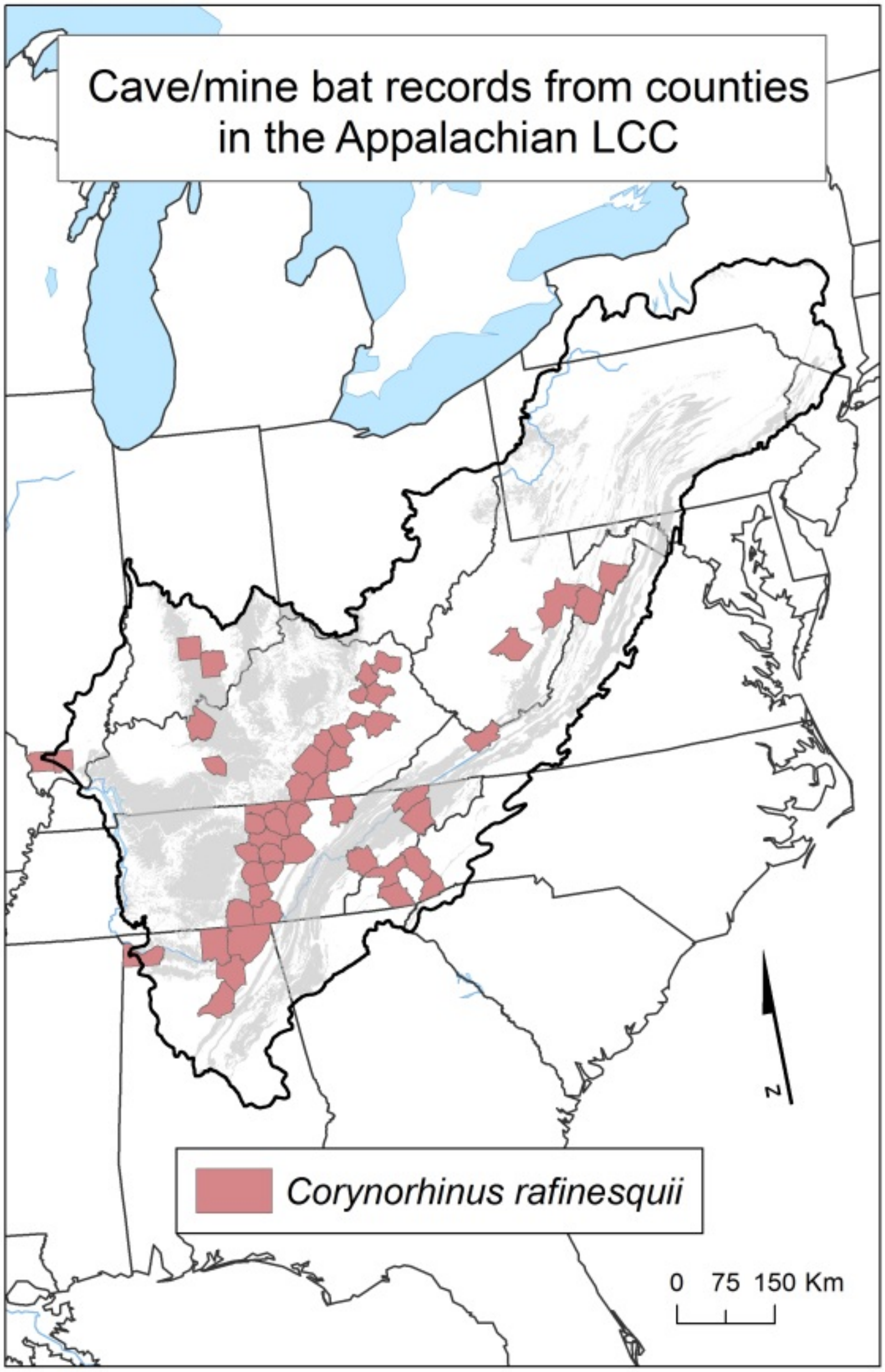

Cave/mine bat records from counties in the Appalachian LCC
Corynorhinus rafinesquii
N
0 75 150 Km

Figure 53

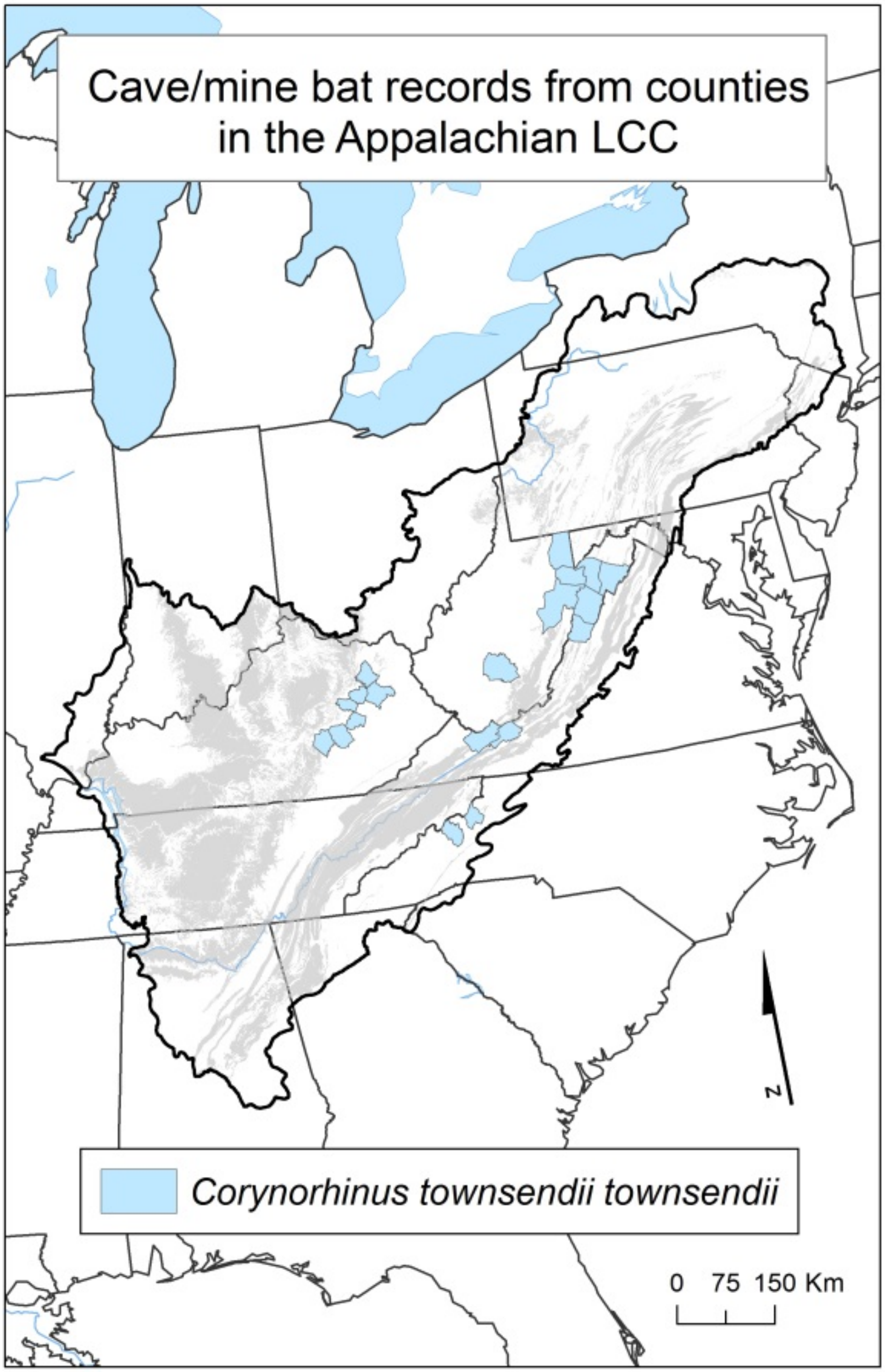

Cave/mine bat records from counties in the Appalachian LCC
Corynorhinus townsendii townsendii
N
0 75 150 Km

Figure 54

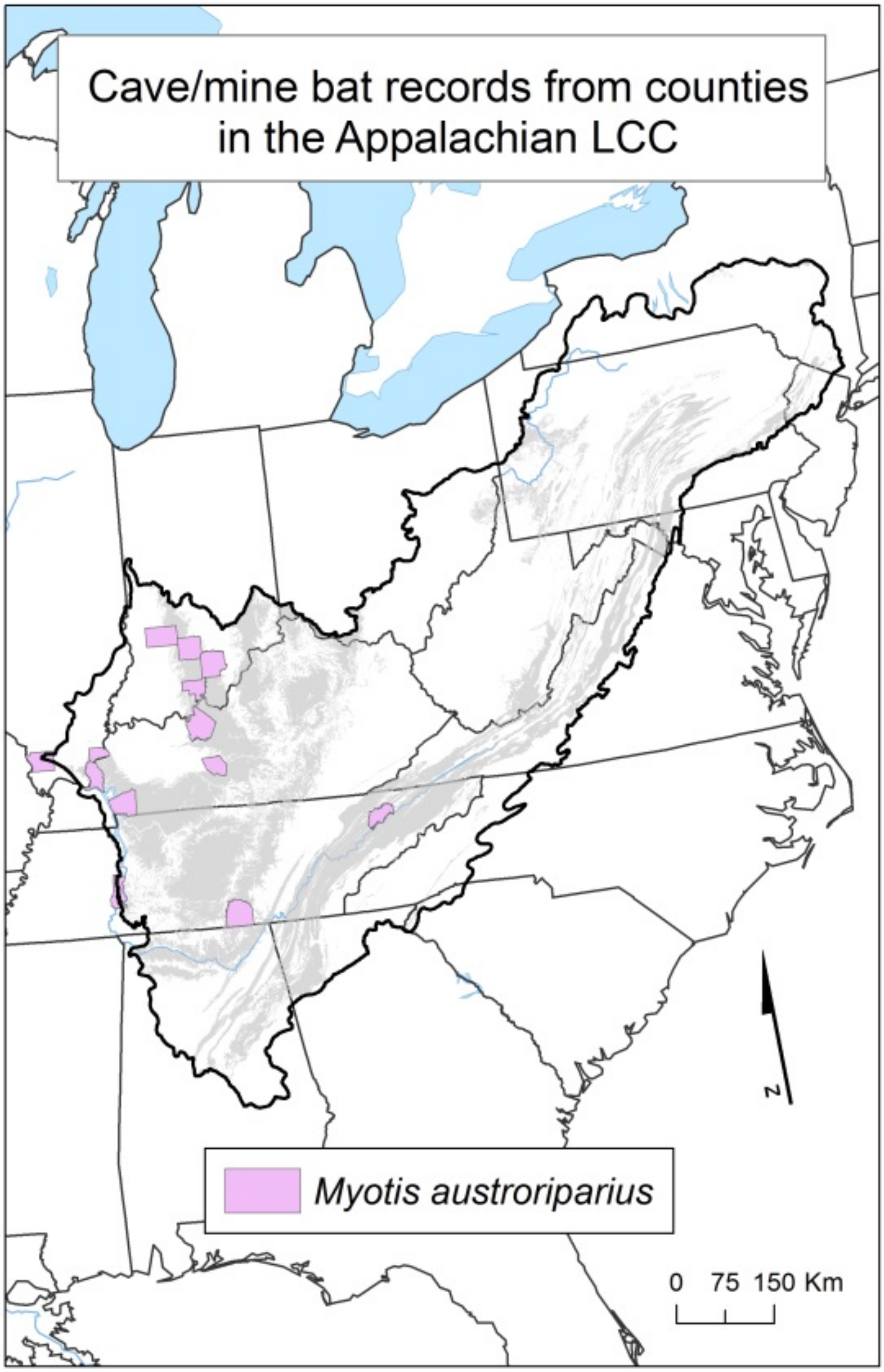

Cave/mine bat records from counties in the Appalachian LCC
Myotis austroriparius
0 75 150 Km
N

Figure 55

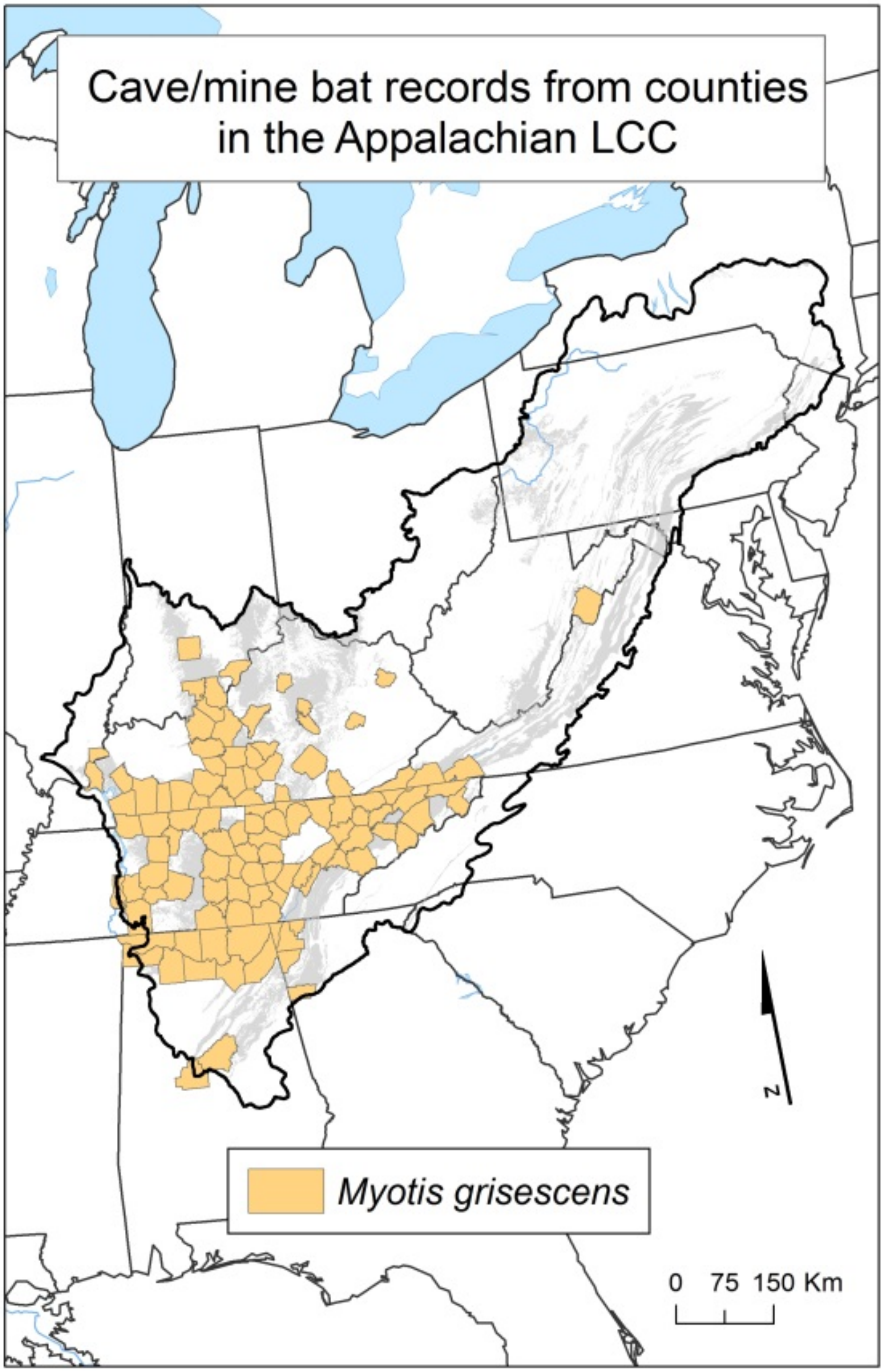

Cave/mine bat records from counties
in the Appalachian LCC
Myotis grisescens
N
0 75 150 Km

Figure 56

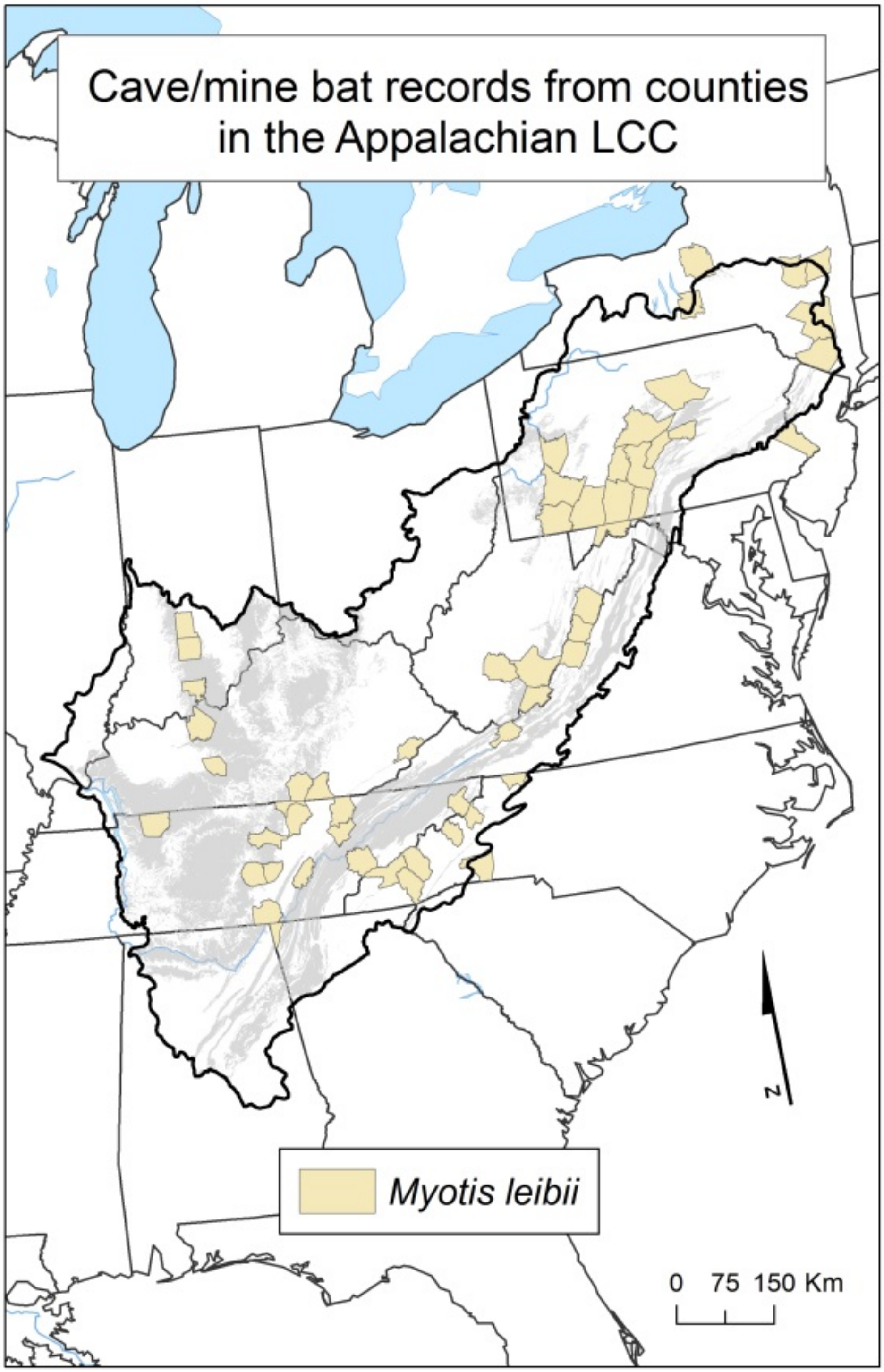

Cave/mine bat records from counties in the Appalachian LCC
N
Myotis leibii
0 75 150 Km

Figure 57

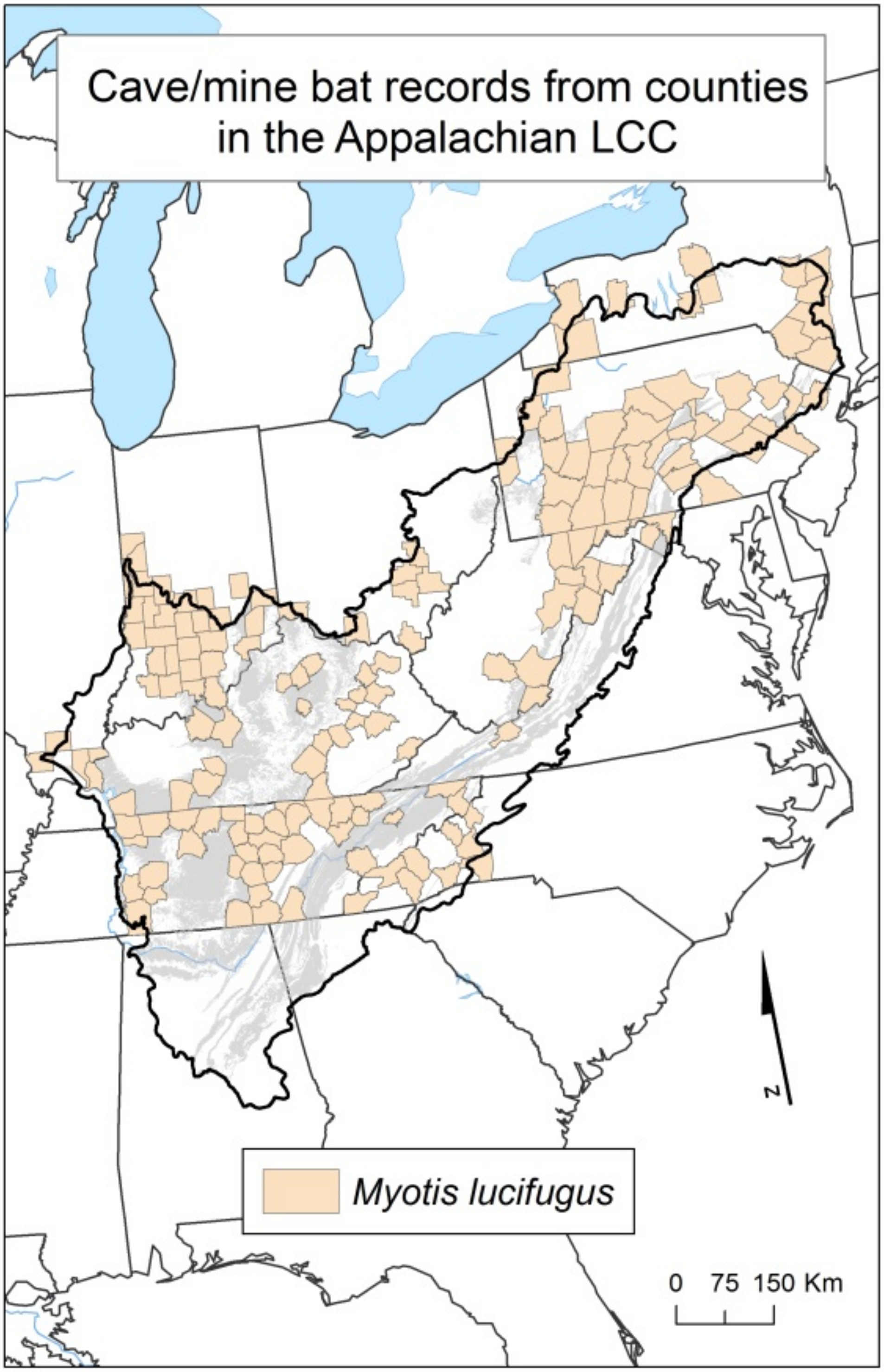

Cave/mine bat records from counties
in the Appalachian LCC
Myotis lucifugus
0 75 150 Km
N

Figure 58

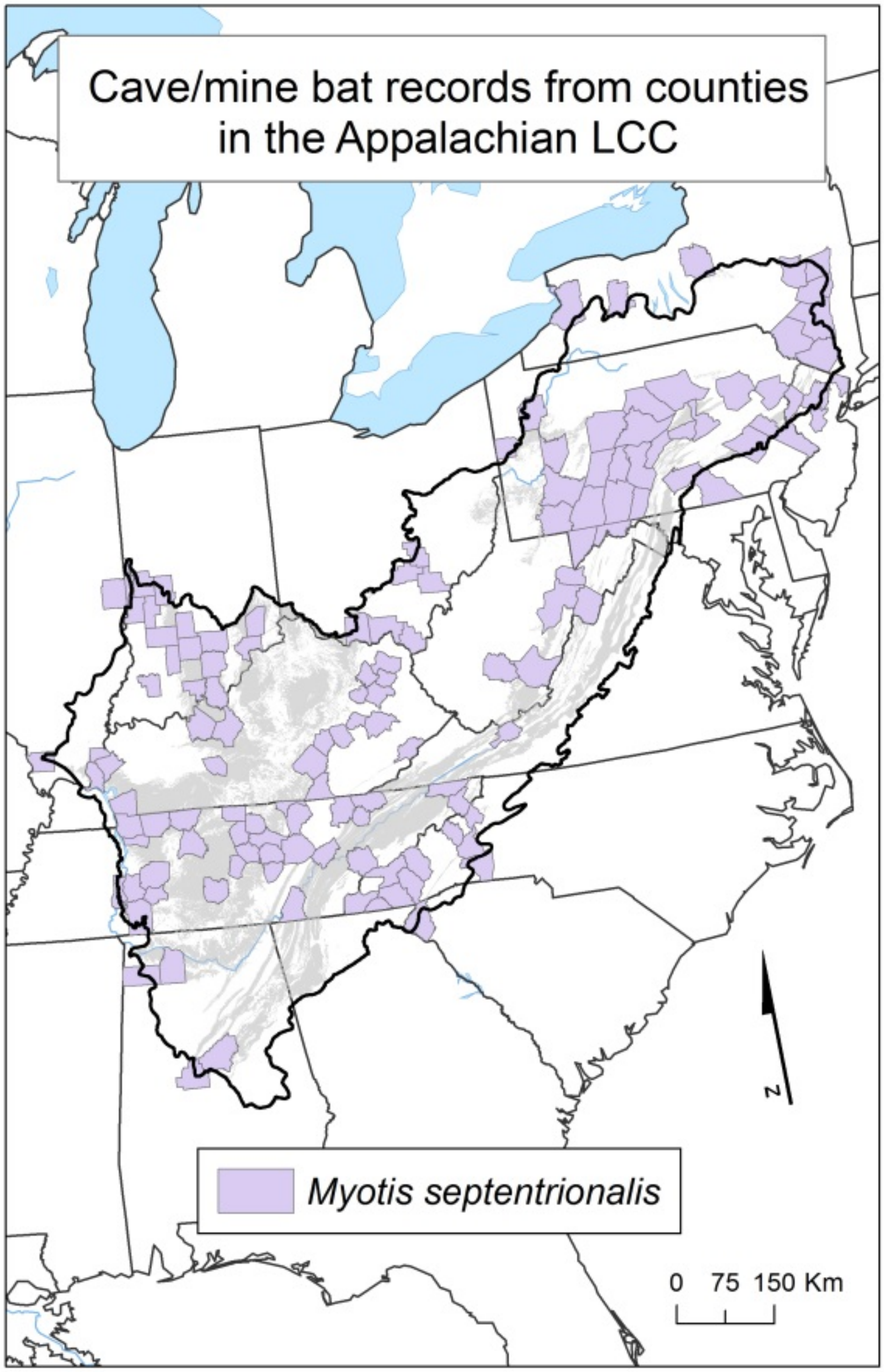

Cave/mine bat records from counties in the Appalachian LCC
Myotis septentrionalis
N
0 75 150 Km

Figure 59

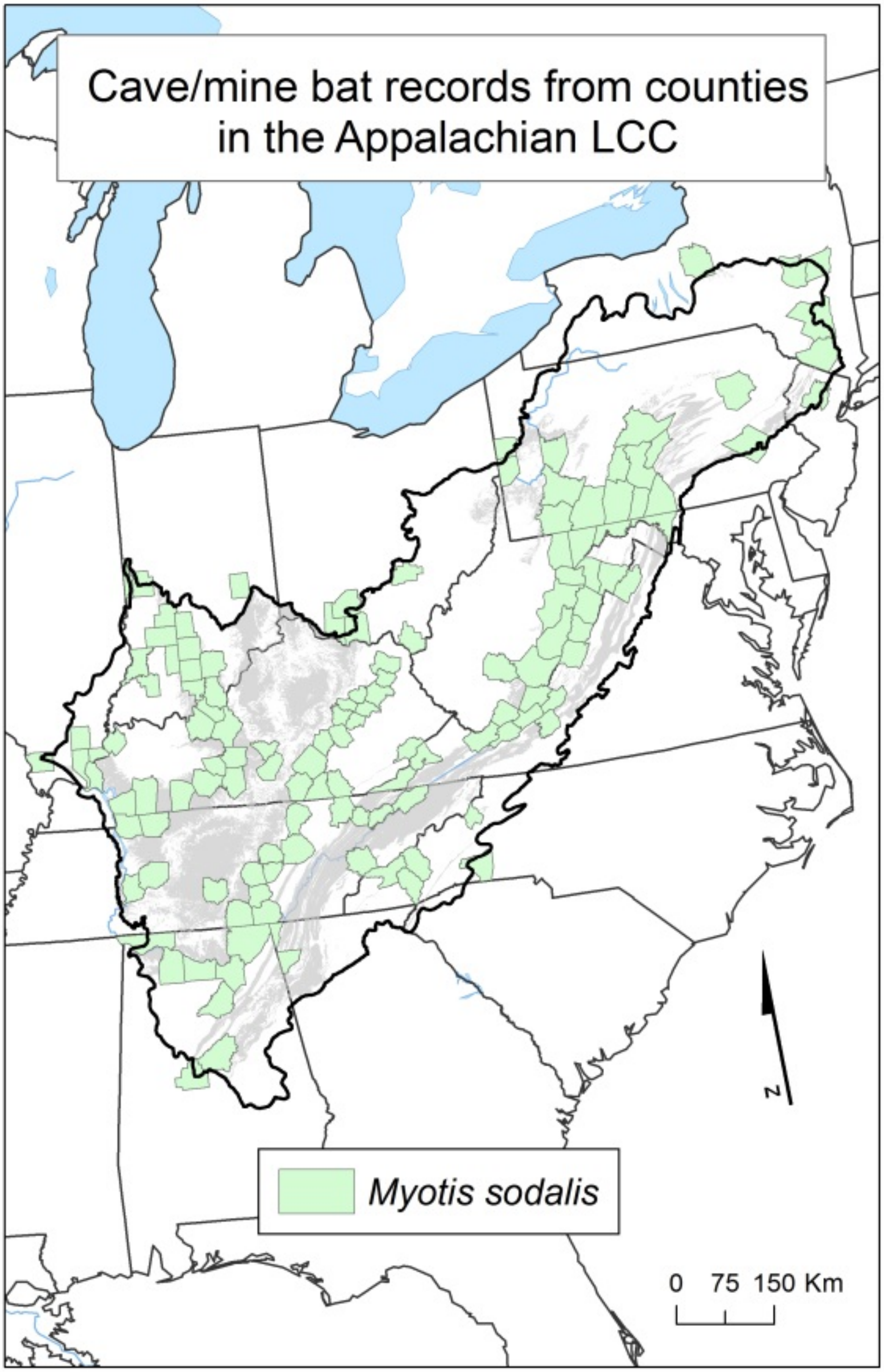

Cave/mine bat records from counties in the Appalachian LCC
Myotis sodalis
N
0 75 150 Km

Figure 60