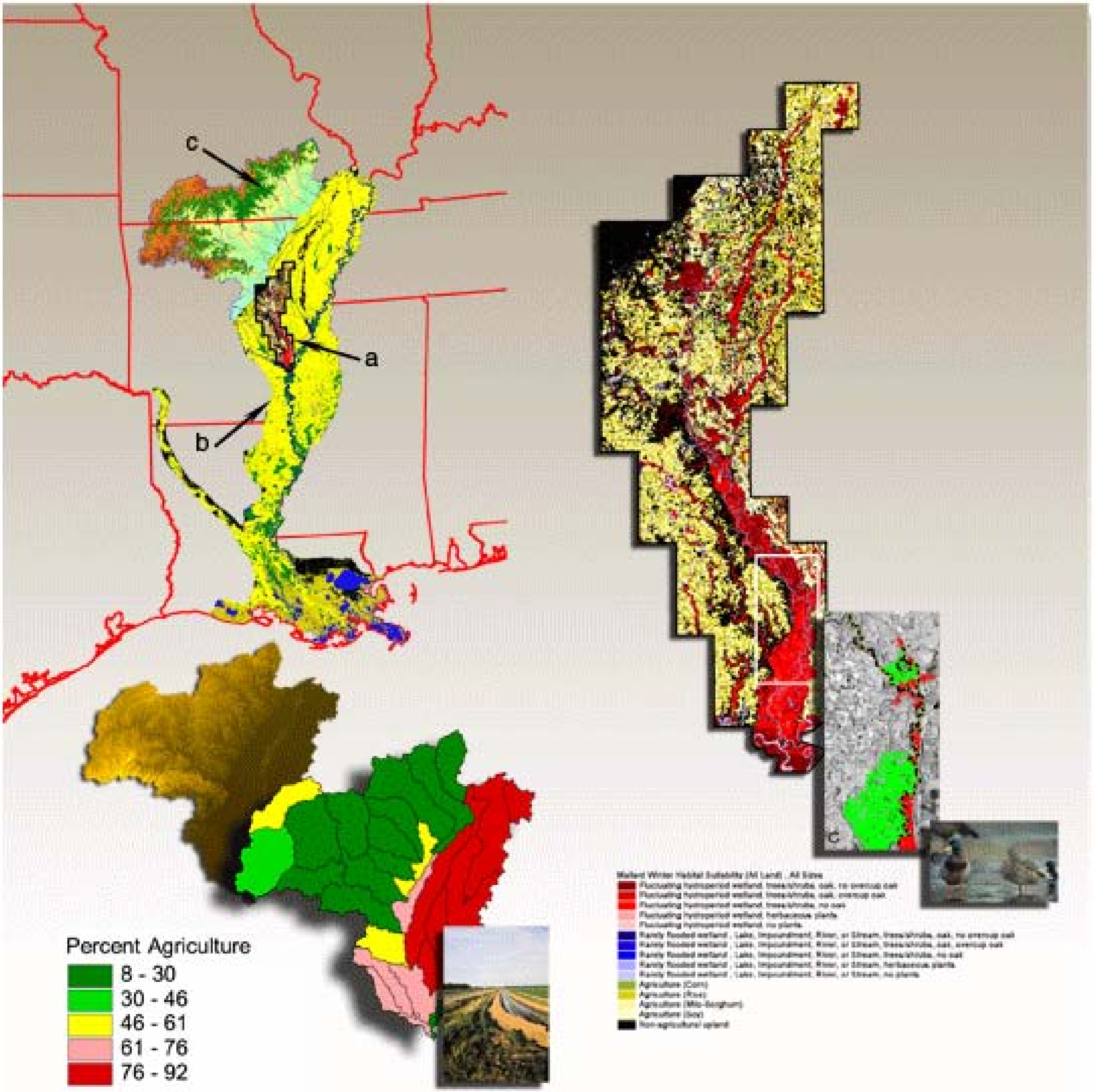
United States Environmental Protection Agency

A Landscape Atlas of Ecological Vulnerability:

Arkansas' White River Watershed and the Mississippi Alluvial Valley Ecoregion



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A LANDSCAPE ATLAS OF ECOLOGICAL VULNERABILITY: ARKANSAS' WHITE RIVER WATERSHED AND THE MISSISSIPPI ALLUVIAL VALLEY ECOREGION

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NOTICE

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COVER IMAGE DESCRIPTION

Selected study results showing mallard duck habitat suitability models in the (a) Lower White River Region, mallard duck habitat suitability models in the (b) Mississippi Alluvial Valley Ecoregion, and water quality vulnerability models in the (c) White River Watershed. (Right) The Lower White River Region mallard duck winter habitat suitability model with an overlay map of the mallard duck habitat Unified Vulnerability Index for the South Unit of the White River National Wildlife Refuge. (Lower left) Hillshaded digital elevation model of the White River Watershed, overlaid with a water quality vulnerability model based on percent agriculture.

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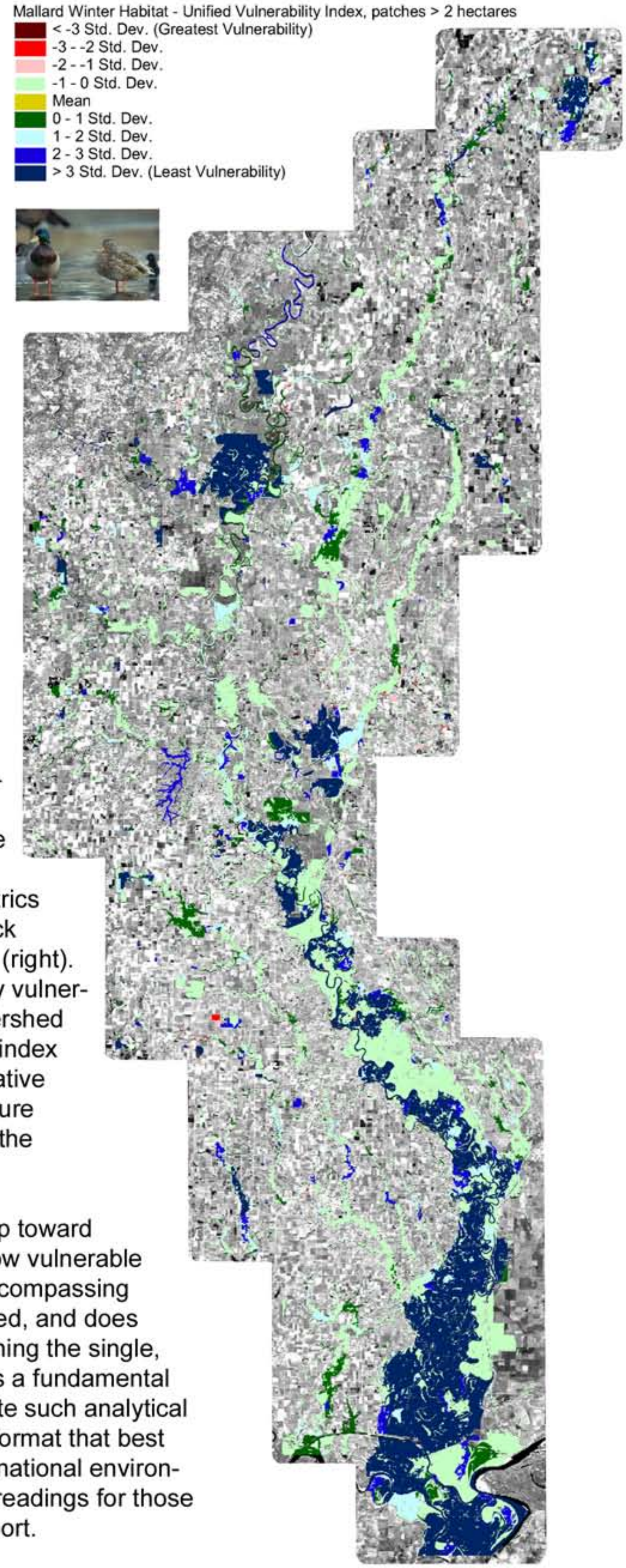
DEDICATION

From Mark Twain's, *Life on the Mississippi* - 1883

Now when I had mastered the language of this water and had come to know every trifling feature that bordered the great river as familiarly as I knew the letters of the alphabet, I had made a valuable acquisition. But I had lost something, too. I had lost something which could never be restored to me while I lived. All the grace, the beauty, the poetry had gone out of the majestic river! I still keep in mind a certain wonderful sunset which I witnessed when steamboating was new to me. A broad expanse of the river was turned to blood; in the middle distance the red hue brightened into gold, through which a solitary log came floating, black and conspicuous; in one place a long, slanting mark lay sparkling upon the water; in another the surface was broken by boiling, tumbling rings, that were as many-tinted as an opal; where the ruddy flush was faintest, was a smooth spot that was covered with graceful circles and radiating lines, ever so delicately traced; the shore on our left was densely wooded, and the somber shadow that fell from this forest was broken in one place by a long, ruffled trail that shone like silver; and high above the forest wall a clean-stemmed dead tree waved a single leafy bough that glowed like a flame in the unobstructed splendor that was flowing from the sun. There were graceful curves, reflected images, woody heights, soft distances; and over the whole scene, far and near, the dissolving lights drifted steadily, enriching it, every passing moment, with new marvels of coloring.

Executive Summary

This report presents the potential for loss or damage to ecosystems in Arkansas' White River Watershed and the Mississippi Alluvial Valley, where approximately 90% of wetlands and a substantial percent of other natural areas have been destroyed. The report is a synopsis of results to date and subsequent updates to this information, including other presentations, publications, and data can be obtained at our web site: http://www.epa.gov/nerlesd1/land-sci/whiteriver.htm.



This research synthesizes the theoretical foundations of ecological function with landscape-ecological analyses, such that the potential interactions between the ecology and human land use of the region can be depicted. Several technical approaches are discussed, each of which involve the use of geographic information systems. The technical approach in this report interlinks a tremendous amount of ecological information, which is used to address the question of ecological vulnerability. Future work includes (a) a comparative discussion of developing habitat assessment techniques such as those in the report, (b) further exploration of selected habitat suitability/vulnerability parameters used in the study areas, and (c) further exploration of selected water quality parameters in the White River Watershed.

Chapter 1 discusses the ecological and societal bases of this research. Chapter 2 describes the approach of using landscape metrics to assess habitat vulnerability for several taxa, using patch size, patch shape, road, and human population density metrics throughout the entire Lower White River Region and Mississippi Alluvial Valley Ecoregion. An example of the mapped results in this report is the unified vulnerability index, which combines patch size and shape vulnerability metrics with human-induced disturbance metrics to depict mallard duck foraging habitat vulnerability in the Lower White River Region (right). The use of other "landscape" metrics to measure water quality vulnerability is discussed and applied to the entire White River Watershed in Chapter 3. Specific applications of the unified vulnerability index are discussed in Chapter 4, specifically demonstrating the relative vulnerability of wildlife refuges and the potential impacts of future landscape change on habitat vulnerability in riparian areas of the White River.

The systems approach taken in this report is a substantial step toward better understanding the systemic answer to the question, "how vulnerable is the ecology of the White River region?" However, an all-encompassing answer to the question of ecological vulnerability is multifaceted, and does not take the form of a single answer. The problem of determining the single, most important vulnerability factor within ecological systems is a fundamental 'system-level analysis' problem, not unique to ecology. Despite such analytical complexities, the authors have created this report in a digital format that best conveys their results, in consultation with local, regional, and national environmental professionals. Chapter 1 includes several suggested readings for those who choose to explore the special topics discussed in this report.

Chapter 1. Landscape Analysis Overview

Project Overview and Summary of Regional Environmental Issues

The White River begins in mountainous northwestern Arkansas, flows through southwestern Missouri, reenters north central Arkansas, and flows down from the Ozark Mountains into Arkansas' agricultural plain, where it meanders to its confluence with the Mississippi River (Figure 1). The catchment area of the White River Watershed (WRW; Figure 2a) extends from the Fayetteville, Arkansas in the western Ozark Mountains to the Mississippi River, and drains from a wide range of landscapes containing farmland, upland forests, wetlands, lakes, streams, and urban areas (Figure 3). There are seven major dams that maintain large reservoirs along the White River, and a National Scenic River (Figure 1). Along the banks of the White River and its tributaries there are two National Wildlife Refuges, two National Forests, and a National Scenic River. The Cache River (a tributary to the White River; Figure 1) and its wetlands have been designated as Ramsar Wetlands of International Importance (Ramsar, 2002), along with 1,235 other wetlands around the world. The "Lower White River Region" (Figure 2a and Figure 2b) contains most of the White River channel that flows through Arkansas' agricultural plain, which is a region currently dominated by row-crop agriculture (Figure 3) but also contains a large proportion of the Mississippi River Valley's last-remaining bottomland hardwood wetland 'swamps' (Dahl, 1990; Figure 4). Thus, the Lower White River Region (LWRR) was used in this project, in addition to the entire Mississippi Alluvial Valley Ecoregion (MAVE), to assess the ecological vulnerability of habitat throughout the region (Figure 2a).

The LWRR is unusual because (a) it provides suitable habitat for the largest winter concentration of mallard ducks (*Anas platyrhynchos*) in North America, (b) provides necessary habitat for recovering populations of black bears (*Ursus americanus*), (c) provides critical shore habitat for the endangered populations of least terns (*Sterna antillarum*), and (d) provides some of the last-remaining habitat for wetland plants in the region (Carreker, 1985; Allen, 1987; Rogers and Allen, 1987). The White River aquatic ecosystems also support an important riverine fishery, including sturgeon (*Scaphirhynchus albus* and *S. platorynchus*) and paddlefish (*Polyodon spathula*), and aquatic plant communities within the bottomland hardwood swamps, which represent some of the most biologically diverse and productive ecosystems of the world (Mitsch and Gosselink, 1993). The White River and the surrounding landscape also contain valuable resources for the people living and working in the region because they provide people with plentiful irrigation water, clean drinking water, flood control, transportation for agricultural commerce, recreation, commercial shelling and fishing products, and tourism.

Although the predominant land cover in the LWRR and MAVE is currently agriculture, forest land-cover predominates in the Ozark Mountain region of the WRW (Figure 3). Closer inspection of the land cover throughout the WRW reveals that the landscape is a mosaic of many different discernable land cover types, such as dry “upland” forests, wetlands, human-built and populated areas, pastures, and row-cropped land. This mixture of land cover occurs, for example, as a gradient (i.e., a gradual change in the relative proportions) of land cover types from the northwestern corner of the WRW to the southeastern corner of the WRW (Figure 3). Similar gradients to this are used in this assessment to predict habitat suitability (i.e., the applicability of land cover to organismal requirements) for mallard ducks, black bears, least terns, and wetland plants; to predict habitat vulnerability (i.e., the risk of loss or damage of suitable habitat) for mallard ducks, black bears, least terns, and wetland plants; and to predict the vulnerability of surface water to impairment from runoff. Vulnerability predictions were performed with the use of currently available land cover data for the Lower White River Region, the Mississippi Alluvial Valley Ecoregion (Omernik, 1987), and the White River Watershed (Figure 2; U.S. GS, 1994).

Historically, the Lower White River Region, the Mississippi Alluvial Valley Ecoregion, and the White River Watershed have all undergone substantial alterations in land cover (Dahl, 1990; Figure 4), particularly the conversion of wetlands (Figure 5) to agricultural land (Figure 6). Consequently, there has been tremendous biological and hydrologic change throughout the landscape of the region (Dahl, 1990; Mitsch and Gosselink, 1993), particularly in riparian wetlands (Figure 7; Figure 8). Although the majority of wetland losses in the region occurred prior to the 1970s, the trend has continued in Arkansas, Mississippi, and Louisiana as a result of wetland conversion (Johnston, 1989; Dahl and Johnson, 1991; The Nature Conservancy, 1992; Kress et al., 1996; Heggem et al., 2000; NRI, 2000). In particular, seventy-percent of Arkansas' wetlands have been destroyed since the late nineteenth century (Dahl, 1990), a loss of approximately 28,000 square kilometers of wetland, with greater than 4,000 square kilometers of wetland loss occurring in Arkansas during the first half of the twentieth century (Shaw and Fredine, 1956). The ongoing losses of wetlands in the region have been positively correlated with regional and local losses of biological diversity (Gosselink and Turner, 1978; Ewel, 1990; Kilgor and Baker, 1996; Smith, 1996; Wakeley and Roberts, 1996); an increase in frequency, severity, and duration of flood events (Hopkinson and Day, 1980a; Hopkinson and Day, 1980b; Brown, 1984); and the degradation of downstream water quality (Kitchens et al., 1975; Day et al., 1977; Hupp and Morris, 1990; Hupp and Bazemore, 1993; DeLaune et al., 1996; Dortch, 1996; Kleiss, 1996; Long and Nestler, 1996; Walton et al., 1996a; Walton et al., 1996b; Wilber et al., 1996). This study is a first step towards determining how landscape scale (i.e., broad scale) land-cover changes may have influenced habitat loss or degradation, and surface water quality. This map-based "atlas" geographically depicts and quantifies some of the aforementioned relationships, and endeavors to provide information for future land use planning in the Lower Mississippi River region. This atlas focuses primarily on the loss and degradation of wetlands because future development in the vicinity of the White River has great potential for altering wetland and aquatic ecosystem habitat conditions, regional hydrology, and water quality. The results in this atlas are timely because there are several land development projects and human activities in the vicinity of the White River that are planned or ongoing, each of which has the potential to damage or destroy a substantial portion of the remaining wetlands in the area. In general, planned or ongoing development activities in the area include: construction of dikes or channel modifications to increase river flow rates (personal communications with U.S. Fish and Wildlife Service and U.S. Army Corps of Engineers, 2001); agricultural irrigation projects that involve increasing the removal of surface water from the White River to supplement agriculture irrigation shortages (Jehl, 2002); modification of reservoir release schedules (personal communication with U.S. Fish and Wildlife Service, 2000); and road construction projects (Arkansas State Highway Commission, 2002).

The White River has never before undergone a landscape-scale ecological assessment of this kind despite the fact that it contains important and rare habitat, is one of the major tributaries to the Mississippi River, and contributes a large amount of nutrients to the Mississippi River and the Gulf of Mexico (Presely et al., 1980; Meade, 1996; Rabalais et al., 2002). Thus, an ecological vulnerability assessment of the White River and surroundings is warranted to understand better the landscape-scale ecological relationships in the region and to contribute to the decision-making processes during future land development planning. To this end, this atlas was completed using readily available geographic information system (GIS) data, provides several forms of maps, and uses simple model calculations that consist of understandable components. Thus, the results in this atlas may be easily browsed (in the digital version of the report) and analyses may be reconstructed, recalculated, or applied to other data sets in the future.

Objectives

This atlas addresses two project objectives: (1) determining the risks of habitat damage or loss within the LWRR and the MAVE (i.e., habitat vulnerability) and (2) determining the risks of water quality impairment within the WRW (i.e., water quality vulnerability). The GIS-based habitat models are applied to the entire MAVE and to the LWRR using similar techniques, but with different data sets because the larger MAVE does not have the full coverage of GIS data that is available for the LWRR (see Approach and Methods). The results depicted in this atlas further the goals of U.S. EPA's Landscape Sciences Program [e.g., see Jones et al., 2000a] by specifically contributing to the progressive strategy of (i) detecting cross-sectional landscape change by comparing thematic data sets in a GIS environment; (ii) quantifying landscape change; (iii) investigating landscape metrics (e.g., percent forest cover); and (iv) developing landscape indicators (e.g., forest cover as a indicator of surface water total phosphorus concentration).

Approach and Methods

Habitat Vulnerability Assessment

Mallard ducks, black bears, least terns, and wetland plants were selected for the GIS-based habitat vulnerability modeling in this atlas because: (a) sufficient habitat suitability literature was available for all taxa; (b) GIS data coverages were available and sufficient to represent published habitat requirements for all taxa; (c) the selected taxa require either wetland or shoreline conditions during at least a portion of the year; (d) the selected taxa have either undergone a population decline at some time in the study region, are recovering, or are presently listed as endangered; and (e) the selected taxa are of special interest to local, regional, or national natural resource professionals.

The habitat vulnerability assessment objectives of this project were met by addressing five landscape-ecological hypotheses within the relatively fine-scale LWRR and relatively broad-scale MAVE (Figure 2). For clarity, the hypotheses are stated below as questions:

Question 1. What are the gradients of land cover in the LWRR (Table 1a) and the MAVE (Table 1b)?

Question 2. How do the observed gradients of land cover in the LWRR and the MAVE affect the suitability of habitat for mallard ducks (Table 2a), black bears (Table 2b), least terns (*Sterna antillarum*; Table 2c), and regional wetland plants (Reed, 1988; Table 2d) based on basic organismal requirements?

Question 3. How do the observed gradients of patch size, patch shape, and human-induced disturbance within the LWRR and the MAVE (Table 3a) affect the vulnerability of mallard duck, black bear, least tern, and wetland plant habitat?

Question 4. How is mallard duck habitat suitability (from question 2) and mallard duck habitat vulnerability (from question 3) distributed among the seventy-two refuge areas that comprise the White River National Wildlife Refuge (NWR), Cache River NWR, and Bald Knob NWR (Figure 9a)?

Question 5. What mallard habitat losses are likely to occur in the South Unit of the White River NWR, given current habitat vulnerability and a hypothetical decrease in flooding of river-adjacent riparian wetlands (Figure 9a)?

Water Quality Vulnerability Assessment

The water quality vulnerability assessment objectives of this project were met by addressing two landscape-ecological hypotheses within the WRW (Figure 2). For clarity, the hypotheses are stated below as additional questions:

Question 6. What are the landscape gradients among twenty-five 8-digit hydrologic unit code (U.S. GS, 1994) 'HUC subwatersheds' (Figure 2a) based on current land cover (Table 1c)?

Question 7. How do the observed landscape gradients of land cover potentially affect surface water quality in the study areas, based on previously published correlations and validation with 1990s National Water Quality Assessment (NAWQA) Program surface water physio-chemical data (U.S. GS, 2001)?

Water quality vulnerability assessments were performed by measuring land cover within a given 8-digit hydrologic unit code (HUC) subwatershed and within cumulative 30 m riparian zones to a maximum of 300 m from shorelines within a HUC. The land-cover-derived metrics (Table 1c and Table 3b) within each 30 m riparian zone (Figure 10) and within each complete HUC were then compared among HUCs to compare the scale-dependency of such measurements (Figure 11).

The Landscape-Ecological Perspective

This study makes use of ecological indicators, landscape metrics, and landscape indicators. For the purposes of this atlas an 'ecological indicator' is a sample measurement of an ecological resource (Bromberg, 1990; Hunsaker and Carpenter, 1990; Hunsaker et al., 1990), typically from field sampling (e.g., a total phosphorus concentration at a single gauging station on the Cache River). When measured at a relatively broad 'landscape scale' (Forman, 1995), 'landscape metrics' (e.g., percent forest cover) that are characteristic of the environment, as measured by a sufficient sample size of ecological indicators can provide quantitative information about ecological resources at broad scales, and are referred to as 'landscape indicators' (Jones et al., 1997). In this atlas we selected landscape metrics (Table 3a and Table 3b) that are correlated with ecological indicators at several scales, i.e., at relatively broad scales (e.g., Riitters et al., 1995; Jones et al., 2000b; Jones et al., 2000c; Jones et al., 2001), at moderate scales (e.g., van der Valk and Davis, 1980; Roth et al., 1996; Nagasaka and Nakamura, 1999; Fauth et al., 2000; Lopez et al., 2002; Lopez and Fennessy, 2002), and at single-site or mesocosm scales (e.g., Peterjohn and Correll, 1984; Murkin and Kadlec, 1986; Ehrenfeld and Schneider, 1991; Willis and Mitsch 1995; McIntyre and Wiens, 1999a; Luoto, 2000). The combined use of these previously observed correlations, GIS mapping techniques, and statistical analysis techniques across the LWRR, MAVE, and WRW study areas facilitated the determination of correlations between land cover gradients and ecological vulnerability at each scale, further aided by relatively rapid computing rates and large computer memory storage space available on currently available personal computers (Scott et al., 1993; Jones et al., 1997).

This atlas makes use of different landscape gradients. Each gradient is a range of a condition, which is observed across a selected landscape unit (e.g., across the LWRR) or among reporting units (e.g., among HUCs or among wildlife refuges). Thus, the two important selection criteria for study areas in a landscape gradient assessment are a sufficient range of conditions along each landscape gradient of interest within a study area, and a sufficient number of sites to compare among reporting units (Green, 1979; Karr and Chu, 1997). Accordingly, this atlas uses a complete coverage of GIS data (i.e., a "wall-to-wall" coverage of land cover data) to produce maps in the LWRR, MAVE, and WRW study areas. An initial visual analysis of available GIS and remote sensing data (Table 1a, Table 1b, and Table 1c), and meetings with local experts from the Arkansas Game and Fish Commission, the Arkansas Natural Heritage Commission, the Arkansas Soil and Water Conservation Commission, The Nature Conservancy, the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency; and the U.S. Fish and Wildlife Service also indicated sufficient land cover variability within each study area to conduct valid gradient analyses.

There is an inherent trade-off between conducting site-based studies, which are limited by a lack of contextual information about the surrounding landscape, and landscape-scale studies, which are limited by a lack of detailed information about small areas. Therefore, although the landscape-scale assessments in this atlas are founded on the ecological principals of site-specific studies, the enclosed models may be limited by a lack of detailed information about small habitat areas. Thus, these models are intended as a preliminary screening tool for large areas that would otherwise be impractical to assess in the field. For best results, these GIS-based models should be used in combination with detailed field investigations.

Data Reporting and Statistics

The habitat *suitability* maps (Figure 11) depict the different habitat requirements for mallard ducks (Table 2a), black bears (Table 2b), least terns (Table 2c), and wetland plants (Table 2d). Habitat suitability maps are color-coded to best distinguish between habitat types and patches. Habitat *vulnerability* maps depict the relative risk of habitat loss or damage for each taxon or guild (i.e., wetland plants) as a result of patch size, patch shape, human-induced disturbance(s), or a combination of these parameters. Habitat vulnerability maps are color-coded from greatest vulnerability (red tones) to least vulnerability (blue tones), based on standard deviations from the mean of each vulnerability parameter (Figure 11).

In each water quality vulnerability map the data range in the legend shows the metric values within each of the 8-digit HUC subwatersheds, contained in each of five quintiles (Figure 11). A quintile contains one-fifth of the distribution of each watershed metric. Quintiles are formed after ranking watersheds for each metric. The map of the WRW is color-coded to show relative conditions among watersheds, ranging from red (i.e., greatest vulnerability) to green (i.e., least vulnerability), potentially indicating a relative range in terms of surface water quality impairment from nutrient or sediment loading.

Because one or both of the assumptions of parametric statistics tests (normality and equality of variance) are violated in all of the data, correlation analyses for all parameters were completed with Spearman Rank Correlation (Zar, 1984), $\alpha = 0.05$. All statistical analyses were computed with Statview software (SAS Institute, v.5.0.1, Cary, North Carolina). All GIS calculations, gradient analyses, and mappings were performed using ArcView GIS software (Environmental Systems Research Institute, v.3.2, Redlands, California) and ATtILA GIS software (U.S. EPA, v.2.999, Las Vegas, Nevada). To allow for visual comparison of relative habitat vulnerability across the study area landscapes, vulnerability each metric was displayed as a mean value and standard deviations from the mean (Figure 11).

CHAPTER 2. HABITAT ASSESSMENTS

Study Areas

The Lower White River Region (LWRR) study site is an 8,970 square km region in eastern Arkansas (Figure 2b). The LWRR study site was selected such that it encompassed the White River National Wildlife Refuge (NWR), Cache River NWR, Bald Knob NWR (Figure 9), and a full range of land cover observed throughout the region. The final decision about the extent of the LWRR study area was determined by the geographic availability of digital National Wetland Inventory data (Table 1a). All LWRR habitat maps are overlaid on a grayscale Landsat Enhanced Thematic Mapper (ETM+) satellite image (single near infra-red band, 30 m spatial resolution) displaying a minimum of an additional 1500 m region outside the study boundary. The satellite image, county boundaries, reference cities, and federal wildlife refuge boundaries may be used to identify specific locations on all LWRR maps, referencing Figure 2b.

The Mississippi Alluvial Valley Ecoregion (MAVE) study site is a 233,782 square km region in the Lower Mississippi River Valley, which primarily intersects Louisiana, Mississippi, Arkansas, and Missouri and small portions of Illinois and Kentucky (Figure 2). The MAVE delineates a regional area that contains similar land uses, soils, land surface forms, and potential natural vegetation types (Omernik, 1987). The MAVE contains the entire LWRR study area, and overlaps with a portion of the WRW (Figure 2a and Figure 2c). All MAVE habitat maps are overlaid on county and state boundaries, which may be used to identify specific locations throughout the MAVE, referencing Figure 2c.

How to Navigate and Interpret Habitat Assessment Maps

Figure 11 depicts the two types of habitat assessment maps that appear in this chapter along with a brief explanation of each map element. The habitat suitability maps depict the different parameters for each of the selected taxa, in accordance with available literature for mallard ducks (Table 2a), black bears (Table 2b), least terns (Table 2c), and wetland plants (Table 2d). Habitat *suitability* maps are color-coded to best distinguish between habitat types and patches, and are not intended to imply relative importance of habitat type(s) for any taxon. Habitat *vulnerability* maps are consistently color-coded from greatest vulnerability (red tones) to least vulnerability (blue tones), based on standard deviations from the mean of a particular vulnerability parameter, and are intended to imply the relative risk of loss or damage to each individual patch of habitat for the taxon or guild indicated on the map (Figure 11).

Specific locations on all maps may be examined in detail with the aid of the zoom and pan buttons in the icon bar if you are using the digital version of this atlas. For both the LWRR and MAVE study areas a very small percentage (less than 4 percent by area) of the wetland habitat assessed intersects with the study area boundary. These 'edge patches' have no effect on the habitat suitability maps. The habitat patches that intersect the study area boundary exert a minimal effect on the distribution of relative habitat vulnerability classes, which are based on a mean vulnerability parameter (Figure 11).

Habitat Suitability

The ecological bases of the habitat suitability models in this atlas are summarized below. The GIS-based habitat suitability models in this atlas use specific habitat requirements for mallard ducks, black bears, least terns, and wetland plants, to the extent that digital data is available to model their ecology in prior field research. The following ecological overview of organisms is condensed to include the information relevant to the GIS models contained within this atlas.

Mallard Duck Winter Habitat **(summarized from Appendix A)**

The Lower Mississippi Valley is the primary wintering habitat for mallard ducks in the Mississippi Flyway (Bellrose, 1976), resulting in a residence of an estimated 1.6 million ducks during the winter months (Bartonek et al., 1984). A wide variety of wetland hydrologic and vegetational conditions are required to meet different habitat requirements of various mallard sexes, ages, and behavioral segments of the mallard population. Generally, winter habitat conditions in the Lower Mississippi region influence all aspects of the socio-biology of mallards, which in turn affects the fecundity and survival of mallards. For example, mallard ducks in the Lower Mississippi region typically move 1.6 km to 8 km from roost sites to foraging areas. Flights of greater than 8 km are typically a response to changes in hydrology, temperature, depleted food resources, or other disturbances (Jorde et al., 1983).

Mallard ducks are omnivores that feed on available foods that include aquatic invertebrates; wetland plant seeds, fruits, rootlets, and tubers; mast from trees; agricultural grains; mollusks; insects; small fish; fish eggs; and amphibians (Heitmeyer, 1985; Allen, 1987; Appendix A). Consequently, wetlands and other open water areas are extremely important for mallard ducks because such areas are where most of the naturally occurring duck food occurs. The timing of flooding, flood depth, and the duration of wetland flooding is a critical factor in determining the diversity and availability of organisms upon which mallard ducks feed (Fredrickson, 1979; Heitmeyer and Fredrickson, 1981; Nichols et al., 1983; Heitmeyer, 1985; Allen, 1987), and much larger numbers of mallards have been observed in the Lower Mississippi Valley when these wetter conditions exist (Nichols et al., 1983), particularly in the forested wetlands (Heitmeyer, 1985). Mallards typically feed from the water's surface to a maximum of 50 cm (Heitmeyer and Fredrickson, 1981; Krapu, 1981; Batema et al., 1985; Allen, 1987). Thus, the depth of flooding, the duration of flooding, and the type of vegetation, as it relates to food resources, is cited as the primary determiner of mallard duck habitat suitability (Allen, 1987). Accordingly, these factors were used to establish suitable mallard habitat and to distinguish between mallard habitat patches of differing suitability characteristics (Table 2a). Although some of the agricultural land in the LWRR is managed to provide winter mallard forage, agricultural grains are not a complete substitute for natural foods (Frederickson and Taylor, 1982; Baldassarre et al., 1983; Jorde et al., 1984). Therefore, agricultural land was not considered to be suitable mallard habitat relative to non-agricultural wetland and was not used in the habitat vulnerability assessments in this atlas. A hierarchical schematic of the mallard duck habitat suitability model construction process is shown in Figure 12, depicting the links between the original digital data, the habitat suitability model, and the habitat vulnerability models. Black bear GIS models and wetland plant GIS models follow processes that are similar to the mallard duck GIS models, but use different GIS data layers.

Because all of the naturally occurring and diverse habitat requirements of mallard ducks occur in wetlands, mallards require access to a variety of wetland types, including emergent wetlands (Figure 13), scrub/shrub wetlands (Figure 14), forested wetlands (Figure 15), unconsolidated bottom wetlands (Figure 16), aquatic bed wetlands (Figure 17), and the open water areas of lakes, impoundments, or rivers (Figure 18). The wetland types described in this atlas are based on the wetland classes and hydrologic modifiers used in the National Wetland

Inventory (NWI; after Cowardin et al., 1979), as they apply to mallard duck habitat requirements (Figure 19). Specifically, mallard duck winter habitat suitability models in the LWRR and MAVE are based on optimal foraging-related habitat requirements of: (a) available wetland habitat; (b) the hydroperiod within a wetland (i.e., either temporarily-flooded/seasonally-flooded, permanently flooded, or dry); (c) the presence of woody vegetation; and (d) the presence of desirable mast producing oaks, specifically excluding overcup oak (*Quercus lyrata*) which produce acorns up to 2.5 cm long and are thus less suitable oak mast for forage (Allen, 1987; Table 2a). We chose mallard ducks as one of the modeled taxa for this atlas because they are abundant and ubiquitous, are dependent upon wetlands for most of the year, have well documented habitat requirements, require habitat that can be readily mapped using GIS data, and are a species that has recovered from previously lower numbers in the study area and throughout the Mississippi Flyway.

Black Bear Wetland Habitat **(summarized from Appendix B)**

Black bears are found throughout North America and, in the LWRR and MAVE, have a mean female home range from 9 km^2 to 12 km^2. Male home ranges have been reported as large as 116 km^2 to 148 km^2 (Pelton, 1982; Klepinger and Norton, 1983; Smith, 1985), while others have reported male home ranges from 13 km^2 to 24 km^2 (Rogers, 1992). The home ranges of male and female black bears are primarily dependent on the availability of resources (Jonkel and Cowan, 1971; Amstrup and Beecham, 1976; Garshelis and Pelton, 1980; LeCount, 1980; Reynolds and Beecham, 1980; McArthur, 1981; Elowe, 1984; Rogers, 1987), and are also influenced by population density, age of the individual, and seasonal conditions (Pelton, 1982). In 1997, one hundred eighty-seven black bears were legally killed in Arkansas using muzzleloader, modern gun, archery, and crossbow hunting techniques, solely in the mountainous regions. As a result of increasing numbers of black bears in the vicinity of the LWRR, hunting of black bears within selected areas to the west of the Mississippi River, using modern guns, became legal in 1999 excluding the White River National Wildlife Refuge (Arkansas Game and Fish Commission, 1998).

Black bears are omnivores that typically feed on easily digestible vegetative foods that are high in nutrients and low in cellulose (Rogers, 1976; Herrero, 1978; Herrero, 1979; Rogers, 1987). Thus, the typical black bear diet consists of fruits, nuts, acorns, insects, and earlysprouting green vegetation (Mealey, 1975; Herrero, 1979; Rogers, 1987). When naturally growing food items are scarce, black bears may alternatively feed on agricultural crops, such as orchard fruits or corn or at human-constructed food sources, such as centralized refuse disposal sites or at the residences of humans (Harger, 1967; Bray, 1974; Rogers, 1976; Rogers et al., 1976; Hugie, 1979; Landers et al., 1979; Beeman and Pelton, 1980; Rogers, 1987). Scarcity of naturally growing foods for black bears has been positively correlated with occurrences of bear cannibalism (Tietje et al., 1986) and the occurrences of bear-human interactions. Black bears in the LWRR and MAVE may remain active throughout the winter to feed on corn and other foods if other naturally growing foods are scarce (Carpenter, 1973; Matula, 1974; Lindzey et al., 1976; Rogers, 1976; Hamilton, 1978; Hamilton and Marchington, 1980; Elowe, 1984). Black bear predation on vertebrates is relatively rare but such captures in the LWRR and MAVE may include newborn deer, nestling birds, fish, or other animals whose escape is hampered (Rowan, 1928; Barmore and Stradley, 1971; Frame, 1974; Cardoza, 1976; Ozoga and Verme, 1984).

Wetlands and other open water areas are extremely important for black bears to survive because, aside from providing much of the food resources that they require, such areas are frequently the sole resource for drinking water and for providing water in which they can cool themselves. The home ranges of black bears are also closely tied to forested areas (Herrero, 1979; Hugie, 1979; Pelton, 1982), and are limited by the fact that much of the remaining forested areas in the LWRR and MAVE are fragmented and therefore relatively inaccessible (Cowan, 1972, Maehr and Brady, 1984; Twedt et al., 1999). Black bears in relatively fragmented landscapes, like the MAVE, are frequently observed in forest openings and clearings, which may provide a relatively higher degree of edge vegetation diversity than core forest areas (Herrero, 1979; Hugie, 1979). Wetlands, particularly in riparian areas, are used by black bears for seasonal foraging; denning; cover for escape; and as travel corridors. Thus, as a result of the diverse resource and travel corridor requirements, black bears require access to a variety of wetland types and resources, including emergent wetlands (Figure 13), scrub/shrub wetlands (Figure 14), forested wetlands (Figure 15), unconsolidated bottom wetlands (Figure 16), aquatic bed wetlands (Figure 17), and the open water areas of lakes, impoundments, or rivers (Figure 18). Specifically, the black bear habitat suitability models in the LWRR and MAVE are based on optimal habitat requirements of: (a) available wetland habitat; (b) the presence of woody vegetation; (c) the number of plant species within a patch, and (d) evidence of forest disturbance since the 1950s (Table 2b). We chose black bears as one of the modeled taxa for this atlas because they are a recovering species in the region, are dependent upon wetlands for most of the year, have well documented habitat requirements, and require habitat that can be readily mapped using GIS data.

Least Tern Breeding Habitat **(summarized from Appendix C)**

Least terns breed along marine and freshwater coastal areas of North, Central, and South America and the Caribbean Islands (American Ornithologists' Union, 1983). There are three subspecies of least terns in the United States, including the interior least tern (*Sterna antillarum athalassos*), which is modeled in this atlas. The interior least tern breeds along the major tributaries of the Mississippi River (Ducey, 1981; Cobb, 1992; U.S. ACOE, 1999) and within the Rio Grande River watersheds (Downing, 1980). The U.S. Fish and Wildlife Service lists the least tern (*Sterna antillarum*) as a federally endangered species (Endangered Species Act, 1973). The other two subspecies of least terns, not modeled in this atlas, are the eastern least tern (*S. a. antillarum*) that breeds along the Atlantic and Gulf of Mexico coasts (American Ornithologists' Union, 1983), and the California least tern (*S. a. browni*) that breeds from San Francisco Bay to southern Baja California, Mexico (California Least Tern Recovery Team, 1980).

Least tern breeding habitat is generally characterized as open sand, soil, or dried mud in the proximity of water (Hardy, 1957; Craig, 1971; Massey, 1971; Massey and Atwood, 1982; Appendix C). Foraging areas of interior least terns include rivers, lakes, ponds, sloughs, and borrow pits (Ganier, 1930). Foraging areas of least terns are usually close to breeding areas, with typical ranges of breeding individuals reported from 100 m to 1.6 km, and as far away as 6.4 km (Jernigan et al., 1978; Hays, 1980; Massey and Atwood, 1981; Atwood and Minsky, 1983; Faanes, 1983; Carreker, 1985). Least terns tend to inhabit ephemeral sandy shorelines year after year (Burger, 1984) even if reproduction has declined in prior years at these locations (Massey and Atwood, 1979). Site intolerance among least terns is related to vegetation encroachment (Burger, 1984); beach erosion (Downing, 1973); human-related disturbances that result from replacement of natural land cover with built structures (Chambers, 1908; Massey and Atwood, 1980; Ducey, 1981; Grochfeld, 1983); replacement of natural land cover with agricultural land (Schulenburg and Ptacek, 1984); and river channel deepening (Downing, 1980). Least terns are predominantly fish-eating birds, hovering and diving from 3 m to 10 m above the surface of the water (Hardy, 1957; Tomkins, 1959; Moseley, 1976). Least terns may also skim the surface of the water for prey (Bent, 1921; Oberholser, 1974) and occasionally feed on insects over land (Bent, 1921; McDaniel and McDaniel, 1963; Moseley, 1976; Schulenberg et al., 1980). In general, adult least terns consume fish in the 2.5 cm to 9 cm length range (Massey, 1974; Moseley, 1976; Massey and Atwood, 1980; Schulenberg et al., 1980). Accordingly, least tern habitat suitability models in the LWRR and MAVE are based on the optimal habitat requirements of available bare shoreline of lakes, impoundments, and rivers (Figure 20) during the nesting season from June through August (Table 2c). The relative rarity of bare shoreline compared to other land cover types in the LWRR and MAVE eliminated the necessity for further division of habitat characteristics in this atlas, such as the proximity of breeding areas to foraging habitat. We chose least terns as one of the modeled taxa for this atlas because they are an endangered species, dependent upon wetlands and aquatic ecosystems for most of the year, have well documented habitat requirements, and require habitat that can be readily mapped using GIS data.

Wetland Plant Habitat

Wetland plants are adapted to surviving in soils that are saturated with water (and consequently have a low oxygen content). Plants that flourish in wetlands are thus generally referred to as hydrophytes, but may also include plants that can survive with only brief periods of soil saturation, and the low-oxygen soil conditions that accompany soil saturation (Reed, 1988; Appendix D). Wetland plant species in the LWRR and the MAVE are numerous and provide cover and forage for other organisms in emergent wetlands (Figure 13), scrub/shrub wetlands (Figure 14), forested wetlands (Figure 15), aquatic bed wetlands (Figure 17), and in the littoral zones of some lakes, impoundments, and rivers (Figure 18). Accordingly, wetland plant habitat suitability models in the LWRR and MAVE are based on the optimal wetland plant habitat requirements of: (a) the presence of wetland conditions (particularly, the presence of wetland soil types; Mitsch and Gosselink, 1993) and (b) the hydroperiod within each wetland type (Table 2d). We chose the collective group (i.e., a guild) of regional wetland plant species for this study because they are strictly limited to the geographic extent of wetlands, are strictly dependent upon wetland hydrology, have well documented habitat requirements, have well understood physiological responses to hydrologic and other physical disturbances, and require habitat that can be readily mapped using GIS data.

Habitat Suitability Maps

Wetland and upland habitat suitability is mapped for mallard ducks (LWRR, Figure 21a; MAVE, Figure 24a), black bears (LWRR, Figure 21b; MAVE, Figure 24b), and least terns (LWRR, Figure 21c and Figure 21d; MAVE, Figure 24c and Figure 24d). Maps that solely include wetland habitat are displayed for mallard ducks (LWRR, Figure 21e; MAVE, Figure 24e), black bears (LWRR, Figure 21f; MAVE, Figure 24f), and wetland plants (LWRR, Figure 21g; MAVE, Figure 24g).

Wetland habitat patches less than or equal to 2 ha were mapped separately for mallard ducks (LWRR, Figure 21h; MAVE, Figure 24h), black bears (LWRR, Figure 21i; MAVE, Figure 24i), and wetland plants (LWRR, Figure 21j; MAVE, Figure 24j) because these smaller patches of wetland habitat account for 20,093 cumulative ha of wetlands in the LWRR and 196,360 cumulative ha of wetlands in the MAVE. These smaller wetlands are frequently overlooked, individually and collectively, in habitat assessments (Klett and Kirsch, 1976; Robinson, 1995; Naugle et al., 2002; Stevens et al., 2002). Thus, we included habitat suitability for patches less than or equal to 2 ha, but did not measure habitat patch vulnerability further in these smaller patches because of the accuracy limitations of the GIS data and the minimum mapping unit for each model (Table 1a and Table 1b). Suitable wetland habitat patches greater than 2 ha are mapped for mallard ducks (LWRR, Figure 21k; MAVE, Figure 24k), black bears (LWRR, Figure 21l; MAVE, Figure 24l), and wetland plants (LWRR, Figure 21m; MAVE, Figure 24m). The habitat suitability maps provide the bases for the habitat vulnerability models in the remainder of this atlas.

Habitat Vulnerability

Because the GIS models in this atlas are based on 30 m resolution data (e.g., AR-GAP in the LWRR; NLCD in the MAVE), caution should be exercised when using these results for fine scale interpretation (see Habitat Suitability section regarding habitat patches of 2 ha or less). The edge of each habitat patch was defined by a change in the wetland habitat suitability class for a particular taxa or guild (i.e., wetland plants). Thus, habitat vulnerability was determined for all suitable wetland habitat patches in the LWRR and MAVE for mallard duck, black bear, and wetland plants if a habitat patch was greater than 2 ha. All least tern habitat is extremely rare, and thus extremely vulnerable to loss or damage (LWRR, Figure 21c and Figure 21d; MAVE, Figure 24c and Figure 24d). Because of the relative rarity and minimal total area of least tern habitat, vulnerability measures were not calculated for their habitat patches.

Habitat vulnerability measures (Table 3a) within habitat patches for each taxa are based on patch size, patch shape, human-induced disturbances, and combinations of these metrics. All of the habitat vulnerability metrics within a habitat patch may affect the likelihood that a particular habitat patch will rebound after patch disturbance(s). That is, habitat vulnerability metrics are based on predicted habitat degradation as a result of patch destruction (i.e., total loss), patch fragmentation (i.e., partial loss), or patch degradation (i.e., stress) [after Odum, 1985).

Patch size metrics in this atlas (Table 3a) are based on previously observed ecosystem trends regarding the effects of patch size on habitat quality for specific taxa, in many different regions (e.g., MacArthur and Wilson, 1967; Simberloff and Wilson, 1970; Diamond, 1974; Forman et al., 1976; Pickett and Thompson, 1978; Soule et al., 1979; Hermy and Stieperaere, 1981; van der Valk, 1981; Simberloff and Abele, 1982; McDonnell and Stiles, 1983; Harris, 1984; McDonnell, 1984; Moller and Rordam, 1985; Brown and Dinsmore, 1986; Dzwonko, and Loster, 1988; Gutzwiller and Anderson, 1992; Opdam et al., 1993; Hamazaki, 1996; Kellman, 1996; Bastin and Thomas, 1999; McIntyre and Wiens, 1999a; McIntyre and Wiens, 1999b; Twedt and Loesch, 1999; Jones et al., 2000b; Lopez et al., 2002; Lopez and Fennessy, 2002). Accordingly, the ‘patch size’ habitat vulnerability models map the habitat patch area, habitat patch perimeter length, and habitat patch interior-to-edge ratio in the LWRR (Figure 22) and the MAVE (Figure 25). Smaller habitat patches (as measured by area, perimeter, or interior-to-edge ratio) are relatively less likely to rebound from disturbances (i.e., are more likely to be fragmented or destroyed after changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna) than larger habitat patches.

The ecological vulnerability metrics in this atlas regarding patch shape (Table 3a) are based on trends previously observed for specific taxa, in many different regions (e.g., MacArthur and Wilson, 1967; Gilpin, 1981; McDonnell and Stiles, 1983; Harris, 1984; McDonnell, 1984; Gutzwiller and Anderson, 1992; Hamazaki, 1996; Kellman, 1996; Bastin and Thomas, 1999;

Jones et al., 2000b; Lopez et al., 2002; Lopez and Fennessy, 2002), and include patch 'sinuosity' (after Bosch, 1978; Davis, 1986) in the LWRR (Figure 22) and the MAVE (Figure 25). Patches with a smaller sinuosity index are less winding or convoluted in shape, thus are relatively less likely to rebound from disturbances than patches with a greater sinuosity index. That is, smaller index values indicate that a habitat patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. Another metric of patch shape is patch 'circularity' (after Stoddart, 1965; Unwin, 1981) in the LWRR (Figure 22) and the MAVE (Figure 25). Habitat patches with a smaller circularity index are more circular in shape, thus are relatively less likely to rebound from disturbances than patches with a larger circularity index. That is, smaller index values indicate that a habitat patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The unified patch index (Table 3a) multiplicatively combines the patch interior-to-edge metric, the patch sinuosity index, and the patch circularity index into a single metric that depicts patch area, patch perimeter, and patch shape simultaneously as a measure of habitat patch vulnerability in the LWRR (Figure 22) and the MAVE (Figure 25).

Human-induced disturbance factors within habitat patches in the LWRR and MAVE (Table 3a) are based on previously observed positive correlations between ecosystem degradation and amount of land cover conversion during road construction, road maintenance, and other human-activities (e.g., Connell and Slatyer, 1977; van der Valk, 1981; Ehrenfeld, 1983; Johnston, 1989; Scott et al., 1993; Johnston, 1994; Poiani and Dixon, 1995; Strittholt and Boerner, 1995; Jenning, 1995; Wilcox, 1995; Ogutu, 1996; Stiling, 1996; Heggem et al., 2000; Lopez et al., 2002; Lopez and Fennessy, 2002). Thus, the directly measurable human-induced disturbance metrics within habitat patches are road length and road density in the LWRR (Figure 23) and the MAVE (Figure 26). Patches with greater total road length or road density (or their combined index value; Table 3a) are relatively less likely to rebound from disturbances than patches with a lesser road presence. That is, greater road length, road density, or road index values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of roads within a patch may also bring about a decrease in patch size or shape metrics. The road index additively combines road length and road density metrics to depict the combined potential habitat degradation effects of road construction and maintenance on habitat patches in the LWRR (Figure 23) and the MAVE (Figure 26).

The indirect metrics of human-induced disturbance within habitat patches are human population density in 1990, estimated human population density in 2011 (i.e., future human population density), and estimated human population density change from 1990 to 2011 for the LWRR (Figure 23) and the MAVE (Figure 26). The human population density change metric was normalized to a positive number by adding 50 to the calculation for the LWRR, and by adding 8000 to the calculation for the MAVE models (Table 3a). Habitat patches that exist within in census block groups (Table 1a and Table 1b) with a greater population density now, or in the future are relatively less likely to rebound from disturbances than patches that exist in areas of lesser population density, now or in the future. That is, greater human population density values indicate that a habitat patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of humans near habitat patches may also bring about a decrease in patch size metrics, patch shape metrics, an increase in road length, or an increase in road density. The unified human index additively combines road length, road density, and human population density change (from 1990 to 2011) to depict the combined effects of direct and indirect human-induced disturbance in the LWRR (Figure 23) and the MAVE (Figure 26). The unified vulnerability index (Table 3a) additively combines the unified patch index, direct human-induced disturbance metrics, and indirect human-induced disturbance metrics, so that the combined effects of patch size, patch shape, road metrics, and human population density metrics can be depicted simultaneously in the LWRR (Figure 23) and the MAVE (Figure 26). Applications of the habitat vulnerability metrics to wildlife refuges and for landscape simulations are described in Chapter 4.

CHAPTER 3. WATER QUALITY VULNERABILITY ASSESSMENTS

Study Area

The White River Watershed (WRW) study site is a 101,533 square km region in Arkansas and southern Missouri (Figure 2a and Figure 2c). The study site was selected such that it encompassed the twenty-five 8-digit HUC subwatersheds (Figure 27) comprising the entire catchment area of the White River, and contained a full range of the land cover types in the region (Figure 3). Thirty-eight National Water Quality Assessment (NAWQA) surface water sampling locations are located within the WRW (Figure 27). Field-based water quality data at the thirty-eight NAWQA locations were used to validate some of the metrics described in this chapter, and were sampled from 1992 through 2000 in the Spring and Summer months (U.S. GS, 2001). All land cover metric maps in this atlas are overlaid on 8-digit HUC subwatershed reference boundaries (Figure 27) so that they may be referenced in relationship to the locations of counties in the WRW (Figure 2c). Additional information about a specific watershed may be accessed at the following URL: http://www.epa.gov/surf/.

How to Navigate and Interpret Water Quality Vulnerability Maps

Figure 11 illustrates the types of watershed-based land cover maps that appear in this chapter. Using the land cover types provided in the National Land Cover Dataset (NLCD; Table 4), several land cover metrics were developed to assess the vulnerability of surface water to pollution from various land cover types and configurations (Table 3b), including the proximity of land cover to surface water. Measurements of land cover in proximity to surface water were calculated by intersecting a 'buffer zone' around each surface water body (Figure 10) with each land cover metric (Table 3b). These measurements were then used to create a watershed map that depicts the percent of a selected land cover metric at the bank, and within cumulative 30 m buffer zone intervals (Figure 11) from all water bodies. For each map, the data range in the legend shows the metric values within each of the 8-digit HUC subwatersheds, contained in each of five quintiles. A quintile contains one-fifth of the distribution of each watershed metric. Quintiles are formed after ranking watersheds for each metric. The map of the WRW is color-coded to show relative conditions among watersheds, ranging from red (i.e., greatest vulnerability) to green (i.e., least vulnerability), potentially indicating a relative range in terms of surface water quality impairment from nutrient or sediment loading.

Water Quality Vulnerability

Land-cover gradients within the White River Watershed were used to develop landscape indicators of surface water quality at a broad scale. The theoretical relationships between watershed land cover and the surface water chemistry within the WRW are based on previously published field results. For example, there is a strong negative correlation between the presence of 'natural vegetation' (i.e., trees, grassland, and wetland vegetation) and the amount of nutrients (e.g., nitrogen and phosphorus) and sediment in downstream surface water (Gregory et al., 1991; Valett et al., 2002). Peterjohn and Correll (1984) demonstrated that the negative correlation between the presence of natural vegetation in riparian zones and nutrient loading from agricultural land to streams is primarily a result of nutrient uptake in the root zone, and assimilation of these nutrients into vegetative plant parts. Other research strongly suggests that the high degree of clay and organic components in wetland soils, anoxic soil conditions, and low through-flow in wetlands (in combination with natural vegetation) are responsible for the strong negative correlations observed between the presence of 'natural areas' and the concentrations of nutrients, sediment, or trace metals in connected surface water bodies (e.g., Hey et al., 1989; Johnston, 1989; Gregory et al., 1991; Poiani et al., 1996; Fennessy and Cronk, 1997; Crumpton and Baker; 1998l Giese et al., 2000). Historically, the loss of forests and other natural vegetation in the MAVE is a result of the expansion of agricultural land development (see Chapter 1) and there is a strong positive correlation between the presence of agricultural land cover and the amount of nutrients and sediment in downstream surface water bodies (e.g., Johnston et al., 1965; Triplett et al., 1969; Romkens et al., 1973; Hergert et al., 1981; Robinson and Sharpley, 1995). Therefore, we selected road, agriculture, and natural vegetation metrics (NLCD codes 31, 41, 42, 43, 51, 71, 91, 92 in Table 4) as potential landscape indicators of surface water quality, and mapped these metrics among HUC subwatersheds in the WRW (Figure 27).

Roads and Agriculture

There are 132,042 kilometers of streams and 130,165 kilometers of roads in the WRW. Information about the location of surface water in the WRW, including the location of streams, rivers, lakes, impoundments, and ditches (Figure 28) was used in combination with information about the location of roads (Figure 29) to determine the number of streams within thirty meters of roads within the WRW (Figure 30). The placement of roads in close proximity to streams is a surface water quality impairment risk because runoff from paved surfaces flows relatively quickly to low areas (e.g., streams or lakes) and carries with it any substances that spill onto roads. These substances can include hydrocarbons, metals, or other chemicals that are toxic to plants or animals (Warren, 1981; Carter, 1982; Merian, 1990; Ehrenfeld and Schneider, 1991).

Information about the location of current land cover in the WRW from the NLCD (Figure 3; Table 4) was used to determine the percent of all agriculture (Figure 31; NLCD codes 81, 82, 83, and 85 in Table 4), percent crop agriculture (Figure 32; NLCD codes 82, 83, and 85 in Table 4), and percent agricultural pasture (Figure 33; NLCD code 81 in Table 4) within each HUC subwatershed (Figure 27). Greater amounts of agricultural activities within a HUC subwatershed increase the risks of surface water quality impairment because of the greater potential for soil loss from tilled land, runoff of agricultural fertilizers and pesticides, or the runoff of livestock byproducts. Modifying tilling practices may mitigate soil loss and runoff from crop-agricultural land, because less soil is disturbed during plowing.

Information about the slope of the terrain within the WRW (Figure 34) was used in combination with the land cover information from the NLCD to determine the percent of area within each HUC subwatershed that contains agriculture on slopes greater than three percent (Figure 35). Agricultural activities on steep slopes are a surface water quality impairment risk because of the increased likelihood of soil erosion and loss to downhill areas and streams. Soil loss and runoff on steep slopes may be mitigated by soil conservation practices such as terracing pastures and fields parallel to the elevational contours of the land.

We selected 'percent total agriculture' for validity testing, using the 1990s NAWQA field data, because it is an easily measurable variable that is relatively unchanging throughout the WRW, thus repeatable with other available data sets. Significant positive correlations between percent total agriculture and surface water concentrations of dissolved organic carbon (DOC), amino and organic nitrogen (OrgN), total phosphorus (P), and suspended sediment (Sed) [Table 5] suggest that 'percent total agriculture' is an appropriate landscape indicator of actual increases in nutrient and sediment concentrations in surface water of the WRW. The same significant positive correlation trend exists for 'percent total agriculture' within the riparian zone, up through 300 m from shorelines (Figure 31). The significant positive correlations between surface water chemistry measurements and streamside percent total agriculture ($P < 0.0001$) suggests that a GIS data set containing solely the agricultural land cover data along streams is sufficient to initially detect risk of surface water impairment from nutrient and sediment loading as a result of agriculture in the WRW. These initial water quality vulnerability results, in combination with a map analysis of percent total agriculture, among HUCs (Figure 36), suggest that HUC 8020204 and HUC 8020201 are extremely vulnerable to water quality impairment as a result of agricultural activities in proximity to surface water, particularly within 120 m of shorelines (Figure 27).

Natural Vegetation

Information about the location of current land cover in the WRW from the NLCD was used to create six landscape forest metrics (Figure 37), measuring 'largest 'forest patch proportion of HUC', 'mean forest patch area', 'largest forest patch proportion of HUC', 'forest patch density', 'forest patch number', and 'percent forest' (areal measurement) within a HUC. The 'percent forest' metric (NLCD codes 41, 42, and 43 in Table 4) was compared among HUCs and within cumulative 30 m riparian zones (Figure 38). Replacement of forests with other land cover types is a surface water quality impairment risk because the root systems of trees and forest understory vegetation tend to absorb substances that are plant nutrients (e.g., nitrogen) and accumulate these substances in vegetation. Riparian forests also decrease the rate of overland flow, and intercept a substantial amount of nutrients (e.g., phosphorus) and sediment, incorporating these substances into wetland soils for long periods of time. Thus, 'percent wetland' (including forested and emergent wetland vegetation; NLCD codes 91 and 92 in Table 4) was compared among HUCs and within cumulative 30 m riparian zones (Figure 39). All natural land cover types in the NLCD (i.e., NLCD codes 31, 41, 42, 43, 51, 71, 91, and 92 in Table 4) were combined to measure the percent of natural land cover in the landscape, and were compared among HUCs and within cumulative 30 m riparian zones (Figure 40).

Although many of the theoretical 'natural vegetation loss' risks of surface water quality impairment are important, we selected 'mean forest patch area', 'largest forest patch proportion of HUC', and 'percent forest' for validity testing, using the 1990s NAWQA field data, because these metrics are easily measurable using existing GIS data sets. Significant positive correlations between the selected landscape forest metrics and the surface water concentrations of DOC, OrgN, P, and Sed (Table 6) suggest that 'mean forest patch area', 'largest forest patch proportion of HUC', and 'percent forest' are appropriate landscape indicators of actual increases in nutrient and sediment concentrations in surface water of the WRW. The same significant positive correlation trend exists for 'percent forest' within riparian zone distances, up through 300 m from shorelines (Figure 38). The significant positive correlations between surface water chemistry measurements, 'mean forest patch area', 'largest forest patch proportion of HUC', and either HUC or streamside percent forest ($P < 0.0001$) suggests that a GIS data set containing solely forest cover data is sufficient to detect risk of surface water impairment from nutrient or sediment loading in the WRW. These initial water quality vulnerability results, in combination with a map analysis of percent forest among HUCs, suggest that six HUCs are extremely vulnerable to water quality impairment as a result of forest loss in proximity to streams, with HUC 11010014 as the subwatershed with the greatest loss of forest on land that is directly adjacent to streams (Figure 41).

Chapter 4. Assessment of Habitat Vulnerability in Wildlife Refuges

National Wildlife Refuges in the Lower White River Region

Mallard duck winter habitat vulnerability models were used to assess the 895 square kilometers of federal refuge lands within the 8,921 square kilometer Lower White River Region (LWRR). LWRR mallard duck winter habitat (Table 7) is contained within thirteen Arkansas counties (Figure 2b), of which a portion intersects the seventy-two separate parcels of land that comprise the White River National Wildlife Refuge (NWR), Cache River NWR, and Bald Knob NWR (Figure 9 and Figure 42). The U.S. Fish and Wildlife Service (DeWitt, Arkansas, 2001) supplied the boundary of each National Wildlife Refuge Zone (RZ, hereafter) as ArcView shape files (Environmental Systems Research Institute, v.3.2, Redlands, California).

Results

The 89,529 ha of federal refuge land in the LWRR ranges in size from 7.6 ha (RZ 12) to 64,552 ha (RZ 72), with a mean RZ area of 2,558 ha (S.D. = 10,838 ha; Table 8). Refuge perimeter length ranges from 1,182 m (RZ 12) to 335 km (RZ 72), with a mean RZ perimeter length of 25 km (S.D. = 55 km). RZ area is strongly negatively correlated with mean percent contribution of habitat patches within the RZ ($\rho = -0.723$, $P = <0.0001$) and weakly positively correlated with mean area of habitat patches within the RZ ($\rho = 0.127$, $P = <0.0001$). To examine the influence of the four largest RZs (contributing 83% of the area to all RZs in the LWRR) we excluded them (i.e., RZs 72, 67, 62, and 8) from the analyses (Table 9) but correlations between habitat area and refuge area did not substantially change (Table 9). The rank order of RZs with regard to RZ area, RZ perimeter, area of habitat patches within RZ, and mean percent contribution of habitat patches within a RZ suggests that larger RZs tend to capture larger wetland habitat patches, but this relationship is nonlinear, and the relationship is most clearly demonstrated among either relatively larger RZs or relatively smaller RZs (Table 10). Eight specific RZs demonstrate how a larger refuge does not necessarily result in larger mallard habitat within the refuge. RZ 29 is relatively large with very small intersecting habitat patches; and RZs 48, 44, 40, 32, 18, 13, and 11 are relatively small with large intersecting habitat patches.

Table 9 summarizes the general trend that RZ area is weakly negatively correlated with (a) original area of habitat patches inside and outside of the RZ (ρ = - 0.141, P = <0.0001); (b) habitat patch perimeter within a RZ (ρ = - 0.095, P = <0.0001); (c) habitat patch interior-to-edge ratio within a RZ (ρ = - 0.188, P = <0.0001); (d) population density in the year 1990 (ρ = - 0.214, P = <0.0001); (e) estimated population density in the year 2011 (ρ = - 0.233, P = <0.0001); and (f) estimated population density change from 1990 to 2011 in a RZ (ρ = - 0.039, P = <0.031). To hold aside the influence of the four largest RZs we excluded them from the metric comparisons, resulting in trends similar to the full group of seventy-two RZs (Table 9). Rankings of mallard duck wetland habitat patch metrics and indexes (Table 11) indicate that (a) RZs 72, 67, 62, and 8 are relatively more vulnerable to disturbance as a result of a smaller habitat patch interior-to-edge ratio; (b) RZs 72, 67, and 8 are relatively more vulnerable to disturbance as a result of a smaller habitat patch area; (c) RZs 72 and 8 are relatively more vulnerable to disturbance as a result of a smaller habitat patch perimeter, sinuosity index, and circularity index; and (d) RZ 8 is relatively more vulnerable to disturbance as a result of a smaller habitat patch unified patch index (Table 11).

Table 12 describes the seventy-two RZs, ranked by 'human-induced disturbance' metrics and indexes, with the median indicated for each value range. The ranks of RZs indicate that (a) RZs 72, 67, 62, and 8 are relatively more vulnerable to disturbance as a result of a greater habitat patch road density, road length, road index, and unified human index; (b) RZs 67, 62, and 8 are relatively more vulnerable to disturbance as a result of a greater habitat patch population density in 1990 and expected population density in 2011; (c) RZ 8 is relatively more vulnerable to disturbance as a result of a greater habitat patch population density change expected in the year 2011; and (d) RZs 72, 67, 62, and 8 are relatively less vulnerable to disturbance as indicated by the relatively larger unified vulnerability index (Table 12).

For wetland habitat patches less than or equal to 2 ha there is a greater percent contribution of the original habitat patch area in smaller RZs (by area, ρ = -0.897, P < 0.0001; by perimeter, ρ = -0.868, P < 0.0001) than in larger RZs. The ranks of RZs with regard to wetland habitat patches less than or equal to 2 ha within them indicate that all RZs have patches that are less than or equal to 2 ha, with the exception of RZs 31, 28, 22 and 2 (Table 13; Figure 42; Figure 9). For wetland habitat patches less than or equal to 2 ha the mean original habitat patch area is weakly positively correlated with the area of RZ (ρ = 0.285, P = 0.0197) and the perimeter of the RZ ($\rho = 0.310$, $P = 0.0112$). For wetland habitat patches less than or equal to 2 ha, the strongest positive correlation exists between total habitat patch count and the area of RZ ($\rho = 0.909$, $P < 0.0001$) and the perimeter of the RZ ($\rho = 0.905$, $P < 0.0001$). Because wetlands that are 2 ha or smaller are too small to reliably monitor with currently available satellite remote-sensing-derived land cover products, routine broad-scale monitoring of such small wetland areas may be difficult.

Discussion

RZ gradient analyses in the LWRR suggest that larger habitat patches are relatively more likely to rebound (i.e., are less likely to be fragmented or destroyed) than smaller habitat patches after disturbances, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. However, large size alone may not be sufficient to ensure that a patch is capable of existing and flourishing in a disturbed setting; other contributing disturbance factors such as patch perimeter length, interior-to-edge ratio, sinuosity, and circularity may also be relevant (see Chapter 2). Additionally, human-induced disturbances, such as runoff, agriculture, and land conversion may function as drivers of habitat degradation, fragmentation, and loss. Thus, those areas with increased human-induced disturbance (as evidenced by present and future population density, population density change, and road development) in the LWRR may bring about future net wetland degradation or loss in the LWRR.

The positive correlation between wetland habitat area or the percent contribution of habitat area, with area of RZ indicates that larger refuges contain more wetland habitat than smaller refuges. However, the percent contribution of wetland habitat to a refuge is inversely correlated with the area of the refuge. The weakness of the correlation between RZ area and mean area of habitat patches within a RZ, and outside a RZ, (Table 9) indicates that the presence of a relatively large refuge is not necessarily a predictor of large habitat area within the refuge. The weak negative correlation between RZ area, and the *original area* of the habitat patches inside and outside the RZ; the habitat patch perimeter within a RZ; and the habitat patch interior-to-edge ratio within a RZ (Table 11) also indicates that relatively large available and suitable mallard duck winter habitat patches in the LWRR are not encompassed within current federal refuge boundaries.

The weak negative correlations between RZ area and human population density metrics in the LWRR indicate that larger RZs tend to exist in areas of lower human population densities, and smaller RZs tend to exist in areas of higher human population densities. Results of estimated future human population density change in the RZs (from 1990 to 2011) are inconclusive, but could be expected to follow the same trend as the population density metrics because large RZs in rural areas would likely lessen the effects of increased population density change.

Recommendations and Conclusion

The ranks of the four largest RZs (i.e., RZ 72, 67, 62, and 8) indicate that RZs are vulnerable to degradation as a result of smaller habitat patch size, less complex habitat patch shape, and human-induced disturbances within a habitat patch. All four of the largest RZs have a substantial proportion of very small wetland habitat patches within them (i.e., habitat ≤ 2 ha). Because of the high likelihood that these very small wetland habitat patches may be lost in the future (by definition), and because of the intrinsic difficulty in monitoring their loss, we recommend that relatively small patches of wetland habitat in the LWRR be a high priority for future remote-sensing and field-based monitoring and conservation efforts.

Based on the number of human-induced disturbance and patch metric vulnerabilities among the four largest RZs, wetland habitat in RZ 8 is likely to experience the highest levels of disturbance and patch fragmentation and/or loss in the future because its vulnerability to *all factors* except the unified vulnerability index is greater than the median. The next most vulnerable RZ among the four largest RZs are: RZ 72 because it has greater than the median vulnerability to all factors except the unified patch index, population density factors, and the unified vulnerability index, and RZ 67 because it has greater than the median vulnerability to all factors except the patch perimeter metric, sinuosity index, circularity index, unified patch index, and population density factors. The least vulnerable among the four largest RZs is RZ 62 because it has greater than the median vulnerability to all factors except the patch area metric, patch perimeter metric, sinuosity index, circularity index, unified patch index, unified vulnerability index, and population density factors. Considering the relative total area of the four largest RZs (Table 8), the number of small habitat patches (i.e., ≤ 2 ha) in RZs 72, 67, and 62 is approximately proportional to each refuge’s area, leaving RZ 8 with approximately half the expected number of small habitat patches. RZ 8 (Figure 42; Figure 9) is a unit of the Bald Knob National Wildlife Refuge, a relatively recent wildlife refuge land acquisition, and is currently predominated by agricultural land (Figure 9). Thus, RZ 8 is the largest federally owned parcel in the LWRR to have been recently (and almost completely) impacted by wetland fragmentation, loss, and human-induced disturbances (Figure 9). Therefore, we recommend that the Bald Knob National Wildlife Refuge be the highest priority for wetland habitat restoration and protection among the four largest RZs in the LWRR.

Because indexes are (by definition) derived from other more directly measured metrics they may be less sensitive to the relative differences among patches than the metrics themselves (Yoder, 1991; Karr and Chu, 1997). We found that the indexes that included ‘patch characteristics’ (i.e., the unified patch index and the unified vulnerability index) tended to rank the four largest RZs as less vulnerable than their component metrics. That is, the ‘patch characteristic’ vulnerability *indexes* used in this atlas tend to indicate that habitat is less vulnerable than the *component metrics* of that index. The purely ‘human-induced disturbance’ indexes (i.e., the road index and the unified human index) tended to rank the four largest RZs consistently with their component metrics, with regard to the median parameter value. Thus, the results of the unified patch index and unified vulnerability index for RZ 72 (indicating that RZ 72 is relatively less vulnerable than other RZs) may be misleading because of this ‘dilution effect’ of combining the sub-component metrics (Table 3a). Accordingly, if index results are held aside, wetland vulnerability to landscape-ecological degradation factors in RZ 72 and 8 is similar. Consequently, we recommend that RZ 72, the largest RZ, be given the second highest priority for wetland restoration and protection among the four largest RZs in the LWRR.

Results of the habitat vulnerability assessment of RZ 67 suggest that it is predominantly vulnerable to the influence of road construction and the presence of relatively smaller wetland habitat patches. Human-induced disturbance factors related to the presence of roads in RZ 67 may be partially mitigated by the robustness of patch characteristics within this RZ, with the exception of patch area. Therefore, we recommend that RZ 67 be given the third highest priority for continued wetland restoration and protection among the four largest RZs in the LWRR.

Results of habitat vulnerability assessments for RZ 62 suggest that it is primarily vulnerable to the influence of roads. The human-induced disturbance factors related to the presence of roads in RZ 62 may be partially mitigated by the robustness of patch characteristics within this RZ, because all of the habitat size and shape metrics for RZ 62 are relatively high. Thus, we recommend that RZ 62 be given the lowest priority for continued wetland restoration and protection among the four largest RZs in the LWRR.

Simulating Landscape Change in the White River National Wildlife Refuge

Because the unified vulnerability index (UVI) integrates habitat patch size, habitat patch shape, and human-induced disturbance metrics into a single index value it is the most conservative (i.e., describes the 'least potential impact' scenario) of the measures used to model habitat vulnerability. That is, a high UVI indicates component metrics that may range from low vulnerability to extreme vulnerability, but it encompasses all of the subcomponent metrics (see Table 11 and Table 12; see discussion of using indexes versus component metrics in previous section). Thus, the UVI was selected to model potential future land cover change in riparian wetland mallard duck winter habitat, in a portion of RZ 72 (LWRR), given a hypothetical decrease in the extent and duration of riparian wetland flooding. The hypothetical decrease in the extent and duration of flooding was assumed to involve a change from "permanently flooded" or "semi-permanently flooded" wetland conditions to "intermittently flooded" or "rarely flooded" wetland conditions (after Cowardin et al., 1979; see Table 2a for mallard duck habitat hydrologic parameters). One hundred-thirteen kilometers of river channel and the surrounding landscape in the vicinity of the South Unit of the White River National Wildlife Refuge (Figure 43) was used to simulate these potential future hydrologic changes.

Results of the simulation from an arbitrary upstream point (UTM 15 = 663318E, 3814972N) to an arbitrary downstream terminus (UTM 15 = 674296E, 3769144N) indicate current wetland habitat vulnerability along the adjacent 226 km of riparian habitat (Figure 44A), per the UVI. The UVI in patches of mallard duck winter habitat grossly determines the potential affects of the hypothesized future hydrologic changes (Figure 44B), within wetlands adjacent to a 30 m region on the riverbank. Mallard duck winter habitat under the simulated future hydrologic conditions indicates a decrease in the periodicity and duration of flooding along the 226 km of river-adjacent riparian wetlands, which could result in a conversion of twenty-one percent (2,822 ha) of the 13,514 ha of riparian wetland along the 113 km of White River system tested (Figure 44B and Figure 44C). Accordingly, seventy-nine percent of the tested wetlands are relatively less vulnerable to conversion from such decreases in periodicity and duration of flooding in the future.

The results of this simulation are substantially simplified because they describe solely the conversion of wetlands from relatively ‘wetter conditions’ to relatively ‘drier conditions’. Actual wetland change in riparian areas is more complex, involving many biophysical constraints (Vannote et al., 1980; Gregory et al., 1991; Middleton, 1999). Additionally, because the UVI is a conservative model, hydrologic changes in this region of the LWRR may result in substantially greater biological affects, such that facultative-wetland or obligate-wetland plants (Reed, 1988) might be less able to flourish, resulting in facultative or facultative-upland (Reed, 1988) plant influx and establishment. Thus, future changes in the hydrology of the White River could result in the loss of plant species that are important resources for wetland organisms (e.g., *Potamogeton* spp. or *Polygonum* spp. for waterfowl forage). Improved hydrologic models for the White River could be used to improve upon the assumptions made in this simple example. Such improvements would help to determine the important linkages between hydrology and the vulnerability of biological resources for wetland organisms in the Lower White River Region.

Acronyms and Abbreviations Used

AR-GAP = Arkansas GAP Program
DEM = Digital Elevation Model
EPA = Environmental Protection Agency
ETM+ = Enhanced Thematic Mapper
GAP = GAP Program
GIS = Geographic Information System
HUC = Hydrologic Unit Code
LWRR = Lower White River Region study area
MAVE = Mississippi Alluvial Valley Ecoregion study area
MAVA-LULC = Mississippi Alluvial Valley of Arkansas Landuse/Landcover Project
NAWQA = National Water Quality Assessment Program
NED = National Elevation Dataset
NHD = National Hydrography Dataset
NLCD = National Land Cover Dataset
NWR = National Wildlife Refuge
ORD = Office of Research and Development
PCI = Habitat patch circularity index
PIER = Habitat patch interior to edge ratio
Popdenchg = Habitat patch human population density change from 1990 to 2011
Popdens 1990 = Habitat patch human population density in 1990
Popdens 2011 = Habitat patch human population density in 2011
PRI = Habitat patch road index
PSI = Habitat patch sinuosity index
RARE = Regional Applied Research Effort
Rddens = Habitat patch road density
Rdlen = Habitat patch road length
RZ = Refuge Zone
URL = Universal Reference Locator
USACOE = United States Army Corps of Engineers
U.S. EPA = United States Environmental Protection Agency
U.S. GS = United States Geological Survey
UTM 15 = Universal Transverse Mercator, Zone 15
UVI = Habitat patch unified vulnerability index
WRW = White River Watershed study area

APPENDICES
(CLICK ON LINK)

Appendix A. U.S. Fish and Wildlife Service Publication: Habitat Suitability Index Models: Mallard (Winter Habitat, Lower Mississippi Valley)

Appendix B. U.S. Fish and Wildlife Service Publication: Habitat Suitability Index Models: Black Bear, Upper Great Lakes Region

Appendix C. U.S. Fish and Wildlife Service Publication: Habitat Suitability Index Models: Least Tern

Appendix D. U.S. Fish and Wildlife Service Publication: Classification of Wetlands and Deepwater Habitats of the United States [Available online at URL: http://wetlands.fws.gov/Pubs_Reports/Class_Manual/class_titlepg.htm]

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Tables

Table 1a. GIS data sets used to derive mallard duck, black bear, least tern, and wetland plant habitat suitability and habitat vulnerability in the Lower White River Region.

Data Used	Derived Land Cover or Land Use	Reference or Source	Relevant Internet URL
Mississippi Alluvial Valley of Arkansas Landuse/Landcover (MAVA-LULC)	Agriculture Crop Cover	Gorham, 1999	http://www.cast.uark.edu/local/lulc/
National Hydrographic Dataset (NHD) v.1	Surface Water Location	USGS and USEPA , 1999	http://nhd.usgs.gov/
National Wetland Inventory (NWI)	Wetland Cover and Hydrology Type	U.S. FWS, Various	http://www.nwi.fws.gov/
Arkansas GAP Program (AR-GAP)	Vegetation Community Cover, Vegetation Taxa Cover, Surface Water Location, Agriculture Cover, Urban Cover	Smith et al., 1998	http://web.cast.uark.edu/gap/
Historical Forest Cover	1950s Forest Cover	Llewellyn et al., 1996	
U.S. Census Bureau Statistics	Current and Future Estimates of Human Population	Applied Geographic Solutions, 2001	http://www.appliedgeographic.com/datadescripts.htm#censussf1
Wessex Streets v.7.0	Road Length and Density	Geographic Data Technology, 1999	

Table 1b. GIS data sets used to derive mallard ducks, black bears, least terns, and wetland plant habitat suitability and habitat vulnerability in the Mississippi Alluvial Valley Ecoregion.

Data Used	Derived Land Cover or Land Use	Reference or Source	Relevant Internet URL
National Land Cover Dataset (NLCD)	Open Water, Residential/Commercial/Industrial, Barren, Agriculture, Forest, Shrubland, Grassland/Herbaceous, Woody Wetland, and Emergent Herbaceous Wetland Cover	Vogelmann et al., 2001	http://landcover.usgs.gov/natllandcover.html
National Hydrographic Dataset (NHD) v.1	Surface Water Location	U.S. GS and U.S. EPA , 1999	http://nhd.usgs.gov/
U.S. Census Bureau Statistics	Current and Future Estimates of Human Population	Applied Geographic Solutions, 2001	http://www.appliedgeographic.com/datadescripts.htm#censussf1
Wessex Streets v.7.0	Road Length and Density	Geographic Data Technology, 1999	http://www.geographic.com/home/index.cfm

Table 1c. GIS data sets used to derive water quality vulnerability models in the White River Watershed.

Data Used	Derived Land Cover or Land Use	Reference or Source	Relevant Internet URL
National Land Cover Dataset (NLCD)	Open Water, Residential/Commercial/Industrial, Barren, Agriculture, Forest, Shrubland, Grassland/Herbaceous, Woody Wetland, and Emergent Herbaceous Wetland Cover	Vogelmann et al., 2001	http://landcover.usgs.gov/natllandcover.html
National Hydrographic Dataset (NHD) v.1	Surface Water Location	U.S. GS and U.S. EPA , 1999	http://nhd.usgs.gov/
Wessex Streets v.7.0	Road Length and Density	Geographic Data Technology, 1999	http://www.geographic.com/home/index.cfm
National Elevation Dataset (NED)	Topographic slope	Gesch et al., 2002	http://gisdata.usgs.net/NED/default.asp

Table 2a. Data classes used to produce habitat suitability GIS models for mallard ducks in the Lower White River Region and the Mississippi Alluvial Valley Ecoregion. Hydroperiodicity per Cowardin et al. (1979).

Habitat Suitability Class in GIS Models	Lower White River Region Models	Mississippi Alluvial Valley Ecoregion Models
Wetland with fluctuating hyrdoperiod; trees/shrubs present; oak included; overcup oak excluded	√	
Wetland with fluctuating hyrdoperiod; trees/shrubs present; oak included; overcup oak included	√	
Wetland with fluctuating hyrdoperiod; trees/shrubs present; oak excluded	√	
Wetland with fluctuating hydroperiod; solely herbaceous plants present	√	
Wetland with fluctuating hydroperiod; no plants present	√	
Wetland with infrequent flooding or a lake, impoundment, river, or stream; trees/shrubs present; oak included; overcup oak excluded	√	
Wetland with infrequent flooding or a lake, impoundment, river, or stream; trees/shrubs present; oak included; overcup oak included	√	
Wetland with infrequent flooding or a lake, impoundment, river, or stream; trees/shrubs present; oak excluded	√	
Wetland with infrequent flooding or a lake, impoundment, river, or stream; solely herbaceous plants present	√	
Wetland with infrequent flooding or a lake, impoundment, river, or stream; no plants present	√	
Upland; Agriculture	√	√
Upland; Non-agriculture	√	√
Wetland; not open water; solely herbaceous plants present		√
Wetland; not open water; woody plants present		√
Open water		√

Table 2b. Data classes used to produce habitat suitability GIS models for black bears in the Lower White River Region and the Mississippi Alluvial Valley Ecoregion.

Habitat Suitability Classes used in GIS Models	White River Region	Valley Ecoregion Models
Wetland; woody plants present; 4 tree species present; forest present in the 1950s	√	
Wetland; woody plants present; 3 tree species present; forest present in the 1950s	√	
Wetland; woody plants present; 2 tree species present; forest present in the 1950s	√	
Wetland; woody plants present; 1 tree species present; forest present in the 1950s	√	
Wetland; woody plants present; 4 tree species present; forest present solely after 1950s	√	
Wetland; woody plants present; 3 tree speciespresent; forest present solely after 1950s	√	
Wetland; woody plants present; 2 tree speciespresent; forest present solely after 1950s	√	
Wetland; woody plants present; 1 tree species present; forest present solely after 1950s	√	
Non-woody wetland; 4 herbaceous plant species present; forest absent in 1950s	√	
Non-woody wetland; 3 herbaceous plant species present; forest absent in 1950s	√	
Non-woody wetland; 2 herbaceous plant species present; forest absent in 1950s	√	
Non-woody wetland; 1 herbaceous plant species present; forest absent in 1950s	√	
Non-woody wetland; no herbaceous plant species present; forest absent in 1950s	√	
Non-woody wetland; 4 herbaceous plant species present; forest present in 1950s	√	
Non-woody wetland; 3 herbaceous plant species present; forest present in 1950s	√	
Non-woody wetland; 2 herbaceous plant species present; forest present in 1950s	√	
Non-woody wetland; 1 herbaceous plant species present; forest present in 1950s	√	
Non-woody wetland; no herbaceous plant species present; forest present in 1950s	√	
Open water	√	√
Wetland; trees present, > 250 meters from trees		√
Wetland; non-agriculture herbaceous plants present; < 250 meters from trees		√
Wetland; non-agriculture herbaceous plants present; > 250 meters from trees		√
Upland; trees present; < 250 meters from trees		√
Upland; non-agriculture herbaceous plants present; < 250 meters from trees		√
Upland; non-agriculture herbaceous plants present; > 250 meters from trees		√
Upland, agriculture, urban, or non-vegetated; < 250 meters from trees		√
Upland, agriculture, urban, or non-vegetated; > 250 meters from trees		√

Table 2c. Data classes used to produce habitat suitability GIS models for least terns in the Lower White River Region and the Mississippi Alluvial Valley Ecoregion.

Habitat Suitability Classes used in GIS Models	Lower White River Region Models	Mississippi Alluvial Valley Ecoregion Models
Sandy shore present during June-August time period; lotic or lentic ecosystem within 30 meters	√	
Sandy shore present during June-August time period		√

Table 2d. Data classes used to produce habitat suitability GIS models for wetland plants in the Lower White River Region and the Mississippi Alluvial Valley Ecoregion.

Habitat Suitability Classes used in GIS Models	Lower White River Region Models
Wetland; lacustrine; littoral; rooted vascular plants present; semipermanently flooded	√
Wetland; lacustrine; littoral; rooted vascular plants present; permanently flooded	√
Wetland; lacustrine; littoral; unconsolidated bottom; permanently flooded	√
Wetland; palustrine; aquatic bed; rooted vascular plants present; permanently flooded	√
Wetland; palustrine; persistent emergent plants present; temporarily flooded	√
Wetland; palustrine; persistent emergent plants present; seasonally flooded	√
Wetland; palustrine; persistent emergent plants present; semipermanently flooded	√
Wetland; palustrine; broad-leaved deciduous forest present; seasonally flooded	√
Wetland; palustrine; broad-leaved deciduous forest present; temporarily flooded	√
Wetland; palustrine; broad-leaved deciduous forest present; semipermanently flooded	√
Wetland; palustrine; deciduous forest present; temporarily flooded	√
Wetland; palustrine; deciduous forest present; seasonally flooded	√
Wetland; palustrine; needle-leaved deciduous forest present; seasonally flooded	√
Wetland; palustrine; needle-leaved deciduous forest present; semipermanently flooded	√
Wetland; palustrine; broad-leaved deciduous shrubs present; seasonally flooded	√
Wetland; palustrine; broad-leaved deciduous shrubs present; temporarily flooded	√
Wetland; palustrine; broad-leaved deciduous shrubs present; semipermanently flooded	√
Wetland; palustrine; unconsolidated bottom	√
Wetland; palustrine; unconsolidated shore; seasonally flooded	√
Wetland; riverine; lower perennial; unconsolidated bottom; permanently flooded	√
Wetland; riverine; lower perennial; unconsolidated bottom; temporarily flooded	√
Wetland; riverine; lower perennial; unconsolidated bottom; seasonally flooded	√
Upland	√
Wetland; woody plants present	
Wetland; soley herbaceous plants present	
Open water	

Table 3a. Data classes used to produce habitat vulnerability GIS models for mallard ducks, black bears, least terns, and wetland plants in the Lower White River Region and the Mississippi Alluvial Valley Ecoregion.

Habitat Vulnerability Parameter	Interpretation and calculation
Wetland habitat patch total area for patches greater than 2 ha	Smaller patches are relatively less likely to rebound from disturbances (i.e., are more likely to be fragmented or destroyed after changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna) than larger patches.
Wetland habitat patch total perimeter length for patches greater than 2 ha	Patches with shorter perimeters are relatively less likely to rebound from disturbances than patches with longer perimeters. That is, shorter perimeter length values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna.
Wetland habitat patch interior to edge ratio for patches greater than 2 ha	Patches with a smaller interior to edge ratio are relatively less likely to rebound from disturbances than patches with a larger interior to edge ratio. That is, smaller ratio values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. Calculation: [Area] / [Perimeter], where Perimeter = the patch perimeter and Area = the patch area.
Wetland habitat patch sinuosity index for patches greater than 2 ha	Patches with a smaller sinuosity index are less winding or convoluted in shape, thus are relatively less likely to rebound from disturbances than patches with a larger sinuosity index. That is, smaller index values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetatior or the establishment of opportunistic flora and fauna. Calculation: $[Perimeter] / \{2 * \pi * [\sqrt{(Area / \pi)}]\}$, where Perimeter = the patch perimeter and Area = the patch area (after Bosch, 1978 and Davis, 1986).
Wetland habitat patch circularity index for patches greater than 2 ha	Patches with a smaller circularity index are more circle-like in shape, thus are relatively less likely to rebound from disturbances than patches with a larger circularity index. That is, smaller index values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetatior or the establishment of opportunistic flora and fauna. Calculation: $\{\pi * [Perimeter / (2 * \pi)]^2\} / [Area]$, where Perimeter = the patch perimeter and Area = the patch area (after Stoddart, 1965 and Unwin, 1981).
Wetland habitat unified patch index for patches greater than 2 ha	Patches with a smaller unified patch index are relatively less likely to rebound from disturbances than patches with a larger Unified Patch Index. That is, smaller index values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. Calculation: Pier * CIRC_ind * SIN_ind, where Pier = the patch interior to edge ratio, CIRC_ind = the patch Circularity Index, and SIN_ind = the patch Sinuosity Index.

Habitat Vulnerability Parameter	Interpretation and calculation
Wetland habitat patch total road length for patches greater than 2 ha	Patches with greater total road length are relatively less likely to rebound from disturbances than patches with a lesser total road length. That is, greater length values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of roads may also bring about the aforementioned disturbances.
Wetland habitat patch total road density for patches greater than 2 ha	Patches with greater total road density are relatively less likely to rebound from disturbances than patches with a lesser total road density. That is, greater density values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of roads may also bring about the aforementioned disturbances.
Wetland habitat patch road index for patches greater than 2 ha	Patches with a greater road index are relatively less likely to rebound from disturbances than patches with a lesser Road Index. That is, greater index values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of roads may also bring about the aforementioned disturbances. Calculation: Rddens + Rdlen, where Rddens = the number of roads per patch area and Rdlen is the total length of road per patch area.
Wetland habitat patch human population density in 1990 for patches greater than 2 ha	Patches that reside in census block groups with a greater population density are relatively less likely to rebound from disturbances than patches that reside in areas of lesser population density. That is, greater density values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of residents near patches may also bring about the aforementioned disturbances.
Wetland habitat patch human population density in 2011 for patches greater than 2 ha	Patches that reside in census block groups with a greater population density in the future are relatively less likely to rebound from disturbances than patches that reside in areas of lesser population density in the future. That is, greater density values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of residents near patches may also bring about the aforementioned disturbances.
Wetland habitat patch human population density change from 1990 to 2011 for patches greater than 2 ha	Patches that reside in census tracts with a greater increase in population density are relatively less likely to rebound from disturbances than patches that reside in areas of lesser population density change. That is, greater (predicted) increases in human population density indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased density of human population near patches may also bring about the aforementioned disturbances. Calculation: popden2-popden1, where popden2 = 2011 population density and popden1 = population density in 1990.
Wetland habitat patch unified human index for patches greater than 2 ha	Patches with a greater unified human index are relatively less likely to rebound from disturbances than patches with a smaller unified human index. That is, greater index values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. The increased presence of roads and growth of residential areas near patches may also bring about the aforementioned disturbances. Calculation: $[(popdenchg90\_11) + C] + [\sqrt{(rdden+len)}]$, where popdenchg90_11 = the population density change between 1990 and 2011, C = a normalization quantity to ensure that the net change value is positive, and rdden+len = the Road Index.
Wetland habitat patch unified vulnerability index for patches greater than 2 ha	Patches with a smaller unified vulnerability index are less likely to rebound from disturbances than patches with a larger unified vulnerability index. That is, smaller index values indicate that a patch has a greater likelihood of fragmentation or loss as a result of environmental change, such as changes in hydrology, destruction of vegetation, or the establishment of opportunistic flora and fauna. Calculation: $[1 / (\sqrt{UPI})] + (\sqrt{UHI})$, where UPI = the patch Unified Patch Index and UHI = the patch Unified Human Index.

Table 3a (continued)

Table 3b. Metrics used to produce water quality vulnerability GIS models in the Lower White River Region, measured among 8-digit Hydrologic Unit Codes (HUCs). "Natural land cover" is a combination of National Land Cover Dataset codes 31, 41, 42, 43, 51, 71, 91, and 92 in Table 4).

Water Quality Vulnerability Metric (compared among HUCs)
Largest forest patch proportion of HUC
Mean forest patch area
Largest forest patch area
Forest patch number
Forest patch density
Percent streams within 30 meters of roads
Percent total agriculture on slopes greater than 3%
Percent total agriculture within entire HUC
Percent crop agriculture within entire HUC
Percent pasture within entire HUC
Percent forest within entire HUC
Percent wetland within entire HUC
Percent natural land cover within entire HUC
Percent total agriculture within a 300 meter riparian zones at 30 meter increments
Percent crop agriculture within a 300 meter riparian zones at 30 meter increments
Percent pasture within a 300 meter riparian zones at 30 meter increments
Percent forest within a 300 meter riparian zones at 30 meter increments
Percent wetland within a 300 meter riparian zones at 30 meter increments
Percent natural land cover within a 300 meter riparian zones at 30 meter increments

Table 4. National Land Cover Dataset (NLCD) categories. NLCD codes were used to develop land cover metrics in this atlas. See Table 1c for more information about this data set.

Land Cover Category	NLCD Land Cover Code
Open Water	11
Perennial Ice/Snow	12
Low Intensity Residential	21
High Intensity Residential	22
Commercial/Industrial/Transportation	23
Bare Rock/Sand/Clay	31
Quarries/Strip Mines/Gravel Pits	32
Transitional	33
Deciduous Forest	41
Evergreen Forest	42
Mixed Forest	43
Deciduous Shrubland	51
Evergreen Shrubland	52
Mixed Shrubland	53
Orchards/Vineyards/Other	61
Grasslands/Herbaceous	71
Pasture/Hay	81
Row Crops	82
Small Grains	83
Fallow	84
Urban/Recreational Grasses	85
Woody Wetlands	91
Emergent Herbaceous Wetlands	92

Table 5. Spearman Rank Correlation of surface water parameters and percent agriculture land cover within 8-digit HUC subwatersheds in the White River Watershed. Correlation (Rho) values shown, P < 0.0001

Water Quality Parameter	N	Watershed Percent Total Agriculture	Streamside Percent Total Agriculture
Dissolved organic carbon	344	0.697	0.651
Amino and organic nitrogen	188	0.510	0.532
Total phosphorus	367	0.707	0.682
Suspended sediment	424	0.692	0.643

Table 6. Spearman Rank Correlation of surface water parameters and forest land cover metrics within 8-digit HUC subwatersheds in the White River Watershed. Correlation (Rho) values shown, P < 0.0001

Water Quality Parameter	N	Forest Metric				
		Largest forest patch proportion of HUC	Mean forest patch area	Largest forest patch area	Watershed Percent Forest	Streamside Percent Forest
Dissolved organic carbon	344	-0.548	-0.716	-0.722	-0.693	-0.693
Amino and organic nitrogen	188	-0.202	-0.507	-0.480	-0.570	-0.569
Total phosphorus	367	-0.495	-0.706	-0.624	-0.709	-0.706
Suspended sediment	424	-0.496	-0.713	-0.687	-0.692	-0.692

Table 7. Area of potential mallard duck winter habitat in the Lower White River Region.

Mallard Duck Winter Habitat Suitability Class	Habitat Area (ha)
Wetland with fluctuating hyrdoperiod; trees/shrubs present; oak included; overcup oak excluded	82,164
Wetland with fluctuating hyrdoperiod; trees/shrubs present; oak included; overcup oak included	21,173
Wetland with fluctuating hyrdoperiod; trees/shrubs present; oak excluded	77,036
Wetland with fluctuating hydroperiod; solely herbaceous plants present	8,564
Wetland with fluctuating hydroperiod; no plants present	5,730
Wetland with infrequent flooding or a lake, impoundment, river, or stream; trees/shrubs present; oak included; overcup oak excluded	1,924
Wetland with infrequent flooding or a lake, impoundment, river, or stream; trees/shrubs present; oak included; overcup oak included	486
Wetland with infrequent flooding or a lake, impoundment, river, or stream; trees/shrubs present; oak excluded	7,344
Wetland with infrequent flooding or a lake, impoundment, river, or stream; solely herbaceous plants present	2,772
Wetland with infrequent flooding or a lake, impoundment, river, or stream; no plants present	19,875
Upland; Agriculture	423,763
Upland; Non-agriculture	241,246
Total	892,077

Table 8. Area and perimeter of each of the 72 federal refuge zones in the Lower White River Region, in ascending order of refuge zone area. Note: four largest (area) federal refuge zones (8, 62, 67, and 72) are listed in red type.

Federal Refuge Zone ID	Area (Ha)	Perimeter (m)
12	7.6	1182
64	7.7	1237
2	8.0	1208
22	8.4	1211
53	8.4	1204
9	15.0	1548
59	15.1	2427
26	15.9	1596
25	16.0	1600
41	16.2	2025
31	16.3	1617
28	16.9	1646
24	17.7	1684
47	19.6	2112
51	22.3	1895
55	22.8	1899
57	28.1	2702
52	31.3	2353
14	33.7	2485
13	34.0	2475
19	35.3	2514
33	39.9	3799
17	40.0	2808
35	40.1	3823
54	40.3	2970
3	56.3	3132
16	65.0	4024
50	65.6	3773
37	66.5	3263
34	67.7	5196
21	78.5	4815
1	79.4	7156
11	80.8	3847
38	81.3	4032
42	89.4	5606
45	92.3	5224
40	95.1	4971
44	96.4	4822
63	99.5	5824
66	106.4	4380
32	114.2	4459
27	124.4	8113
65	128.7	4811
60	131.4	6252
68	161.1	7609
36	167.3	9596
39	174.3	10229
71	205.2	8099
10	212.4	7158
18	213.5	8143
30	230.7	10935
5	250.9	14060
46	251.4	9844
61	287.3	10260
69	295.1	11304
6	372.8	13889
23	401.8	10756
49	407.6	9278
48	441.6	9046
70	510.3	13622
7	738.1	25561
20	740.6	18248
4	757.3	25088
58	767.9	19509
43	1094.4	30733
15	1261.4	30217
29	1629.0	31502
56	1756.1	32308
67	2622.5	42974
62	2899.8	44889
8	5325.8	52555
72	64552.1	335315
Sum	89529.1	891387
Mean	2558.0	25468
1 S.D.	10838.3	55365

Table 9. Summary table of Spearman Rank Correlation between federal refuge zone area and: (a) area of habitat patches, (b) percent contribution of habitat patches, (c) the original area of the habitat patches (inside and outside of the zone), (d) habitat patch perimeter, (e) habitat patch interior:edge ratio, (f) habitat patch sinuosity index, (g) habitat patch circularity index, (h) unified patch index, (i) habitat patch road density, (j) habitat patch road length, (k) habitat patch road index, (l) population density in the year 1990, (m) estimated population density in the year 2011, (n) estimated population density change from 1990 to 2001, (o) unified human index, and (p) unified vulnerability index within a zone. Correlation (Rho) values and significance are shown for all refuge zones (N = 72), and for all refuge zones except the four largest (N = 68, i.e., excluding refuge zones 8, 62, and 67, and 72); ns = not significant, * = 0.05, ** = 0.01, *** = 0.001, **** = 0.0001. All calculations are based upon habitat patches > 2 ha.

Habitat Patch Metric or Index Name	Area of All Federal Refuge Zones	Area of All Federal Refuge Zones Except Four Largest Refuge Zones
Area of habitat patches within a refuge zone	0.127 ****	0.116 **
Percent contribution of habitat patches within a refuge zone	-0.723 ****	-0.503 ****
Original (i.e., inside and outside) area of the habitat patches for a refuge zone	-0.141 ****	-0.149 ****
Habitat patch perimeter within a refuge zone	-0.095 ****	-0.125 ***
Habitat patch interior:edge ratio within a refuge zone	-0.188 ****	-0.148 ****
Habitat patch sinuosity index within a refuge zone	ns	ns
Habitat patch circularity index within a refuge zone	ns	ns
Unified patch index within a refuge zone	ns	ns
Habitat patch road density within a refuge zone	0.032 ****	-0.026 ****
Habitat patch road length within a refuge zone	ns	ns
Habitat patch road index within a refuge zone	ns	ns
Population density in the year 1990 within a refuge zone	-0.214 ****	-0.113 **
Estimated population density in the year 2011 within a refuge zone	-0.233 ****	-0.114 **
Estimated population density change from 1990 to 2001 within a refuge zone	-0.039 *	ns
Unified human index within a refuge zone	ns	ns
Unified vulnerability index within a refuge zone	ns	ns

Table 10. Rank of each of the 72 federal refuge zones in the Lower White River Region by (a) zone area, (b) zone perimeter, (c) mean area of habitat patches within a zone, and (d) mean percent contribution of habitat patches within a zone. Federal refuge zone ranks are in ascending order for each parameter. All calculations are based upon habitat patches > 2 ha.
Note: four largest (area) federal refuge zones (8, 62, 67, and 72) are listed in red type.

Rank of Federal Wildlife Refuge Zone Metric (Zones 1-72)				
Federal Refuge Zone Area (ha)	Federal Refuge Zone Perimeter (km)	Mean Original Habitat Patch Area Within Federal Refuge Zone	Mean Percent Contribution of Each Habitat Patch to Federal Refuge Zone	Relative Metric Value Guide
12	12	12	**72**	**Low**
64	53	24	29	
2	2	25	**8**	
22	22	2	**67**	
53	64	53	15	
9	9	44	**62**	
59	26	29	4	
26	25	64	56	
25	31	40	48	
41	28	22	7	
31	24	50	43	
28	51	17	58	
24	55	9	44	
47	41	59	6	
51	47	19	18	
55	52	42	40	
57	59	33	20	
52	13	26	24	
14	14	34	61	
13	19	14	30	
19	57	18	12	
33	17	16	23	
17	54	28	69	
35	3	47	5	
54	37	48	71	
3	50	60	42	
16	33	51	50	
50	35	3	60	
37	11	54	46	
34	16	55	39	
21	38	30	10	
1	66	31	34	
11	32	71	25	
38	65	**8**	17	
42	21	6	70	
45	44	61	27	
40	40	39	16	
44	34	4	65	
63	45	35	36	
66	42	45	33	
32	63	5	45	
27	60	7	19	
65	1	21	68	
60	10	27	3	
68	68	15	66	
36	71	41	21	
39	27	13	49	
71	18	69	14	
10	48	10	1	
18	49	1	54	
30	36	46	63	
5	46	65	37	
46	39	37	2	
61	61	66	9	
69	23	58	53	
6	30	23	35	
23	69	36	59	
49	70	63	26	
48	6	68	51	
70	5	43	47	
7	20	**67**	38	
20	58	57	32	
4	4	20	64	
58	7	56	22	
43	15	38	55	
15	43	52	13	
29	29	11	11	
56	56	**72**	28	
67	**67**	**62**	31	
62	**62**	32	41	
8	**8**	70	57	
72	**72**	49	52	**High**

Table 11. Rank of each of the 72 federal refuge zones in the Lower White River Region by mallard duck winter habitat patch characteristics: (a) habitat patch area, habitat patch perimeter, [c] habitat patch interior:edge ratio within a zone (PIER), [d] habitat patch sinuosity index within a zone (PSI), [e] habitat patch circularity index within a zone (PCI), and [f] unified patch index within a zone (UPI). The gradients of parameter values and vulnerability among the 72 federal refuge zones are indicated from 'High' to 'Low'. A double line indicates median. All calculations are based upon habitat patches > 2 hectares. Note: four largest (area) federal refuge zones (8, 62, 67, and 72) are listed in red type.

Rank of Federal Wildlife Refuge Zone Metric or Index (Zones 1-72)							
Patch Area (ha)	Patch Perimeter (km)	PIER	PSI	PCI	UPI	Relative Metric or Index Value Guide	Relative Vulnerability to Disturbance Guide
24	24	50	54	54	24	**Low**	**High**
50	40	24	40	52	40		
40	59	44	52	40	54		
59	60	59	24	24	60		
53	53	62	60	53	59		
60	50	47	53	60	53		
18	54	72	2	2	37		
51	37	8	59	59	50		
54	51	71	18	9	51		
8	18	20	9	18	9		
47	9	46	5	3	18		
44	8	53	3	42	2		
9	65	6	42	5	65		
6	6	67	1	51	3		
37	30	48	4	30	8		
30	47	40	30	33	47		
65	2	15	10	4	52		
4	4	26	6	10	6		
17	5	60	51	6	5		
15	3	4	33	1	30		
19	15	30	43	65	42		
26	44	69	15	37	34		
34	48	7	14	15	33		
3	7	17	65	8	48		
7	19	58	8	57	4		
71	34	45	7	7	7		
5	17	19	37	43	15		
2	33	43	36	14	19		
16	42	65	19	34	17		
1	1	18	23	19	44		
48	10	34	72	31	57		
10	72	1	57	48	10		
42	43	39	17	17	26		
67	58	36	34	23	1		
72	26	35	58	47	16		
14	71	10	48	72	43		
23	52	37	56	56	14		
43	14	9	62	36	58		
57	67	51	39	44	31		
58	23	5	31	50	23		
36	57	56	44	58	38		
33	16	21	67	39	71		
62	62	23	47	38	55		
39	36	61	20	62	39		
68	39	68	50	67	36		
55	55	70	38	16	67		
38	56	16	29	20	21		
46	38	66	69	55	72		
21	31	14	55	26	56		
45	21	3	16	29	62		
69	69	64	71	21	22		
22	68	22	26	71	69		
61	46	33	46	69	29		
31	22	11	21	11	11		
52	29	25	68	22	68		
56	20	54	11	68	13		
11	11	63	61	46	46		
70	61	42	22	12	12		
66	45	38	45	13	20		
29	70	2	49	27	70		
35	13	28	27	61	28		
13	12	55	12	25	45		
63	27	27	70	70	27		
28	28	57	13	49	61		
32	66	49	25	45	25		
12	25	29	66	28	41		
64	63	13	63	41	66		
27	35	32	28	66	63		
25	32	41	32	63	32		
20	41	31	41	32	35		
41	64	12	64	35	49		
49	49	52	35	64	64	**High**	**Low**

Table 12. Rank of each of the 72 federal refuge zones in the Lower White River Region by mallard duck winter habitat patch human-induced disturbance characteristics: [a] habitat patch road density within a zone (Rddens), [b] habitat patch road length within a zone (Rdlen), [c] habitat patch road index within a zone (PRI), [d] population density in the year 1990 within a zone (Popdens1990), [e] estimated population density in the year 2011 within a zone (Popdens2011), [f] estimated population density change from 1990 to 2001 in a zone (Pdenchg 1990-2011), [g] unified human index within a zone (UHI), and [h] unified vulnerability index within a zone (UVI). The gradients of parameter values and vulnerability among the 72 federal refuge zones are indicated from 'High' to 'Low'. A double line indicates median. All calculations are based upon habitat patches > 2 ha. Note: four largest (area) federal refuge zones (8, 62, 67, and 72) are listed in red type.

Rank of Federal Wildlife Refuge Zone Metric or Index (Zones 1-72)									
Rddens	Rdlen	PRI	Popdens1990	Popdens2011	Pdenchg 1990-2011	UHI	UVI	Relative Metric or Index Value Guide	Relative Vulnerability to Disturbance Guide
37	49	49	66	66	1	49	12	**High**	**High**
65	20	20	12	1	2	12	41		
56	12	12	63	2	66	13	57		
3	56	56	**8**	**8**	**8**	1	28		
19	13	13	64	12	20	64	52		
31	31	31	61	64	57	37	50		
69	37	37	13	61	64	31	49		
13	64	64	41	57	35	2	20		
72	58	58	43	41	45	41	56		
62	3	3	42	13	55	20	31		
49	70	70	57	63	32	3	63		
12	41	41	40	43	56	66	66		
10	11	11	31	42	61	56	1		
40	63	63	38	20	46	11	58		
8	1	1	49	45	41	**8**	64		
71	**72**	**72**	45	38	11	70	70		
34	69	69	44	**62**	10	19	37		
64	10	10	**62**	49	71	58	11		
58	19	19	2	47	14	25	**8**		
30	**67**	**67**	47	31	65	69	**72**		
39	**62**	**62**	70	40	17	21	69		
15	21	21	52	70	48	10	3		
48	66	66	1	52	7	71	10		
67	34	34	3	71	18	45	40		
1	71	71	71	44	28	57	**67**		
11	**8**	**8**	27	55	68	63	**62**		
41	27	27	58	58	16	**72**	21		
63	14	14	**67**	3	52	27	19		
18	45	45	46	**67**	47	14	27		
70	25	25	20	46	9	**62**	71		
46	61	61	5	35	51	39	14		
23	39	65	39	68	50	**67**	45		
17	65	39	30	32	53	65	61		
43	30	30	68	60	59	34	25		
21	23	23	60	28	60	61	65		
29	40	40	28	51	54	23	34		
20	15	15	55	39	24	29	2		
14	46	46	51	56	58	15	39		
4	17	17	36	65	69	46	30		
27	29	29	32	16	15	17	43		
66	43	43	56	5	70	18	46		
45	7	48	65	69	21	48	15		
6	48	7	34	27	**62**	35	23		
61	18	18	4	33	33	30	17		
7	6	6	26	**72**	25	55	29		
25	4	4	16	30	**67**	7	4		
32	32	35	69	34	39	32	13		
35	35	32	35	6	22	6	48		
28	28	28	33	36	19	28	7		
22	22	68	**72**	11	**72**	68	26		
68	68	22	6	17	6	16	18		
38	38	36	29	29	13	52	44		
55	55	55	37	25	29	47	6		
36	36	38	23	4	23	9	5		
16	16	16	25	37	49	51	36		
57	57	26	11	10	37	50	55		
52	52	57	17	7	42	53	38		
26	26	44	22	23	5	59	35		
42	42	33	10	15	12	60	42		
33	33	42	7	22	38	54	22		
44	44	5	15	48	34	24	32		
5	5	52	19	14	3	33	33		
2	2	47	21	21	36	40	68		
47	47	2	48	26	4	22	16		
9	9	9	14	19	43	43	47		
51	51	51	18	18	30	42	9		
54	54	50	9	9	44	5	51		
50	50	53	54	54	27	4	53		
53	53	59	50	50	26	38	59		
60	60	60	53	53	31	36	60		
59	59	54	59	59	40	44	54		
24	24	24	24	24	63	26	24	**Low**	**Low**

Table 13. Assessment of the presence of wetlands less than or equal to 2 ha within each of 68 federal refuge zones in the Lower White River Region. Four federal refuge zones (2, 22, 28, and 31) did not contain habitat patches less than 2 ha. Federal refuge zones are ranked by ascending areal contribution of wetlands less than 2 ha within the zone, and include (a) areal percent contribution, (b) mean patch area (+/- S.D.), and (c) total number of habitat patches less than 2 ha in federal refuge zone. All calculations are based upon habitat patches less than 2 ha. Note: four largest (area) federal refuge zones (8, 62, 67, and 72) are listed in red type.

Federal Refuge Zone ID	Mean Percent Contribution to Federal Zone Area (ha)	Mean Habitat Patch Area (ha)	Std. Dev. (ha)	Total Habitat Patch Count
72	0.000004	2814	3550	11391
8	0.000058	3110	3944	510
62	0.000081	2356	3157	460
67	0.000098	2563	3291	631
56	0.000120	2107	2741	552
29	0.000144	2343	2915	199
20	0.000168	1244	1816	184
15	0.000235	2961	3773	281
43	0.000258	2825	3306	182
23	0.000349	1400	1600	21
7	0.000380	2801	3502	237
58	0.000411	3157	4212	151
48	0.000423	1869	2661	76
4	0.000435	3293	4089	156
54	0.001000	508	795	18
37	0.001000	817	306	4
45	0.001000	931	1299	17
11	0.001000	1080	380	10
32	0.001000	1261	2154	33
60	0.001000	1415	2109	72
63	0.001000	1450	1755	36
68	0.001000	1462	1915	63
71	0.001000	1509	2152	154
46	0.001000	1747	1554	99
61	0.001000	1845	2513	75
18	0.001000	1880	2460	52
36	0.001000	2082	2777	33
69	0.001000	2139	2544	127
10	0.001000	2400	2578	64
30	0.001000	2600	2926	111
70	0.001000	2941	3859	36
6	0.001000	2950	3511	153
5	0.001000	3279	3627	86
49	0.001000	3460	4664	29
40	0.002000	1664	2289	27
66	0.002000	2163	2965	18
39	0.002000	2769	4365	37
27	0.002000	2931	4334	20
55	0.003000	640	247	5
19	0.003000	900	-	1
35	0.003000	1259	1848	28
16	0.003000	2006	1815	7
42	0.003000	2319	1765	4
44	0.003000	2696	3853	39
65	0.003000	3707	3967	48
14	0.004000	1319	-	1
50	0.004000	2482	3597	11
38	0.004000	2879	5049	23
34	0.004000	2893	3636	7
24	0.005000	805	862	3
59	0.005000	808	986	13
13	0.005000	1572	1958	8
17	0.006000	2399	2640	8
21	0.006000	4487	5975	7
1	0.006000	4519	5104	12
57	0.007000	1842	2133	12
33	0.007000	2645	3572	26
64	0.008000	649	823	4
47	0.009000	1684	1108	2
51	0.011000	2537	2922	3
12	0.012000	900	0	2
52	0.015000	4656	5776	4
3	0.015000	8593	-	1
41	0.016000	2590	2986	3
26	0.018000	2885	2594	3
25	0.019000	3022	2329	5
53	0.021000	1801	-	1
9	0.023000	3459	2695	5
Sum	0.282164	157082	174630	16701
Mean	0.004149	2310	2729	246
1 S.D.	0.005525	1228	1323	1378

Figures

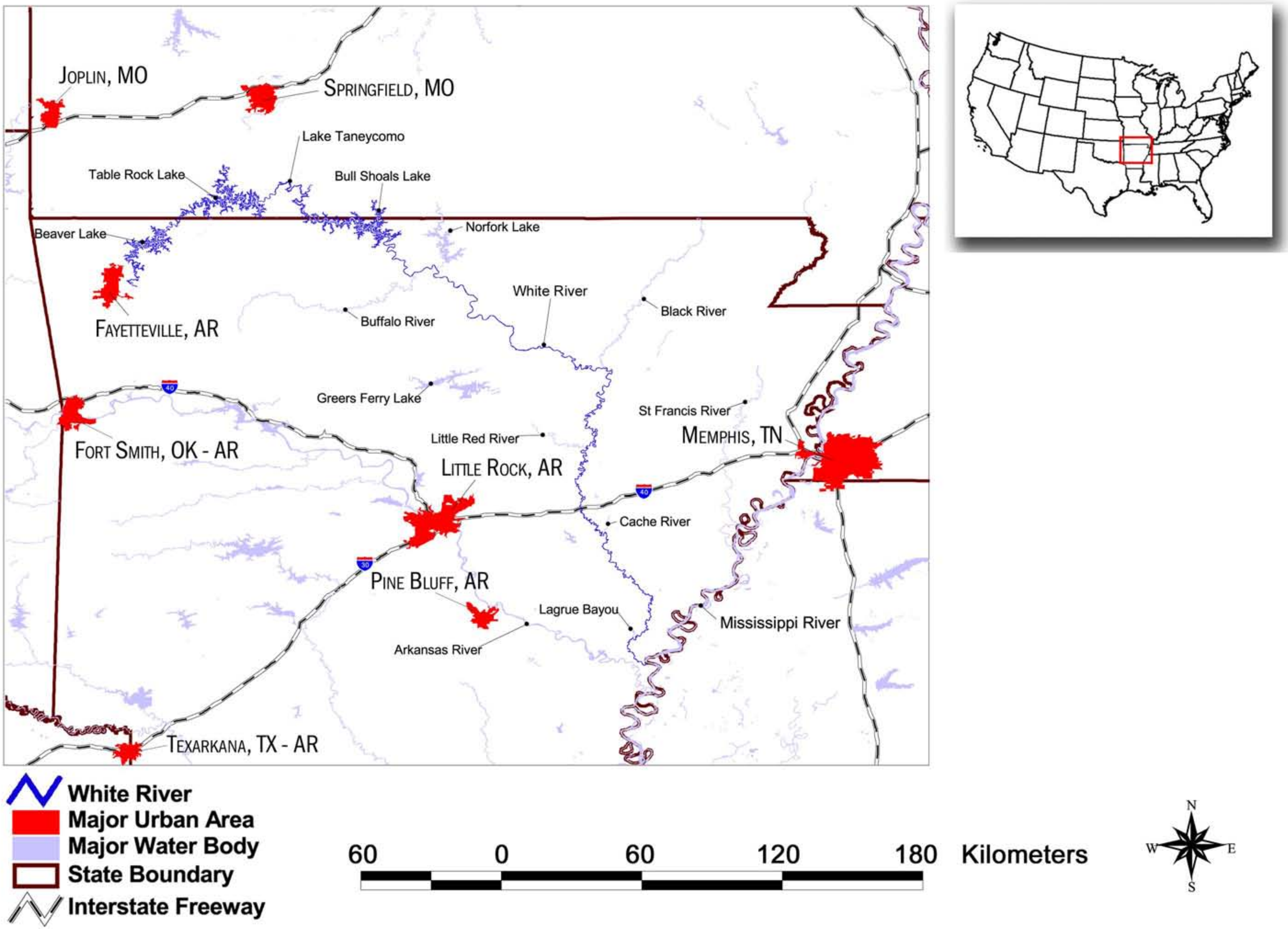


Figure 1. Geographic overview of the Lower White River Region (LWRR) and White River Watershed (WRW) study areas.

Study Site Orientation Maps

Figure 2a. Orientation map of Lower White River Region (LWRR), Mississippi Alluvial Valley Ecoregion (MAVE), and White River Watershed (WRW). Inset shows the states that intersect the MAVE study area.

Figure 2b. Orientation map of Lower White River Region (LWRR), including the 13 counties that intersect the LWRR study area.

Figure 2c. County map of all study areas including 170 counties in Arkansas, Missouri, Louisiana, Tennessee, Illinois, and Kentucky that intersect the Lower White River Region (LWRR), Mississippi Alluvial Valley Ecoregion (MAVE), and the White River Watershed (WRW).

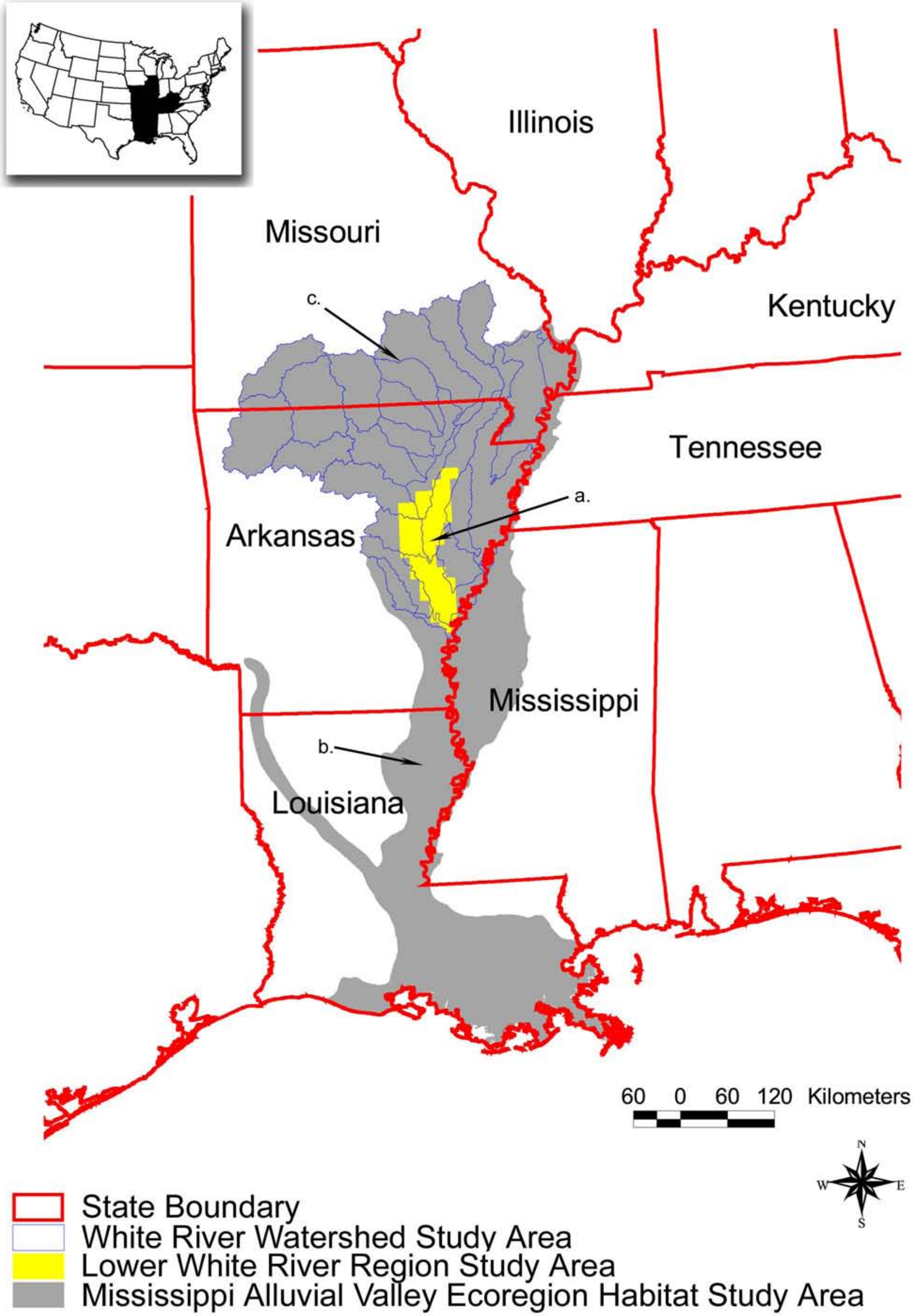

Illinois
Missouri
Kentucky
Tennessee
Arkansas
Mississippi
Louisiana
a.
b.
c.
60 0 60 120 Kilometers
N
W
E
S
State Boundary
White River Watershed Study Area
Lower White River Region Study Area
Mississippi Alluvial Valley Ecoregion Habitat Study Area

Figure 2a.

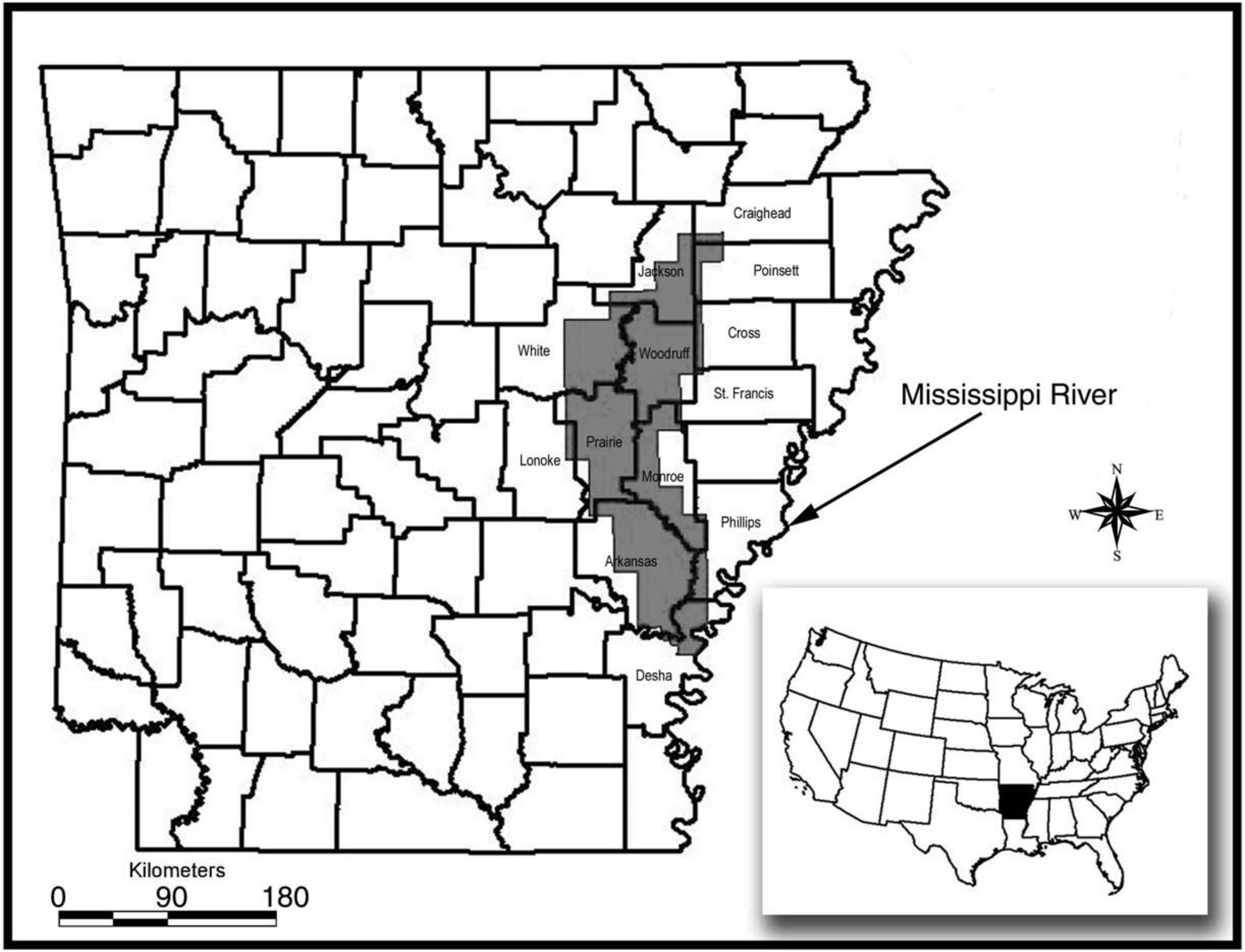

Craighead
Jackson
Poinsett
Cross
White
Woodruff
St. Francis
Mississippi River
Prairie
Lonoke
Monroe
N
W
E
S
Phillips
Arkansas
Desha
Kilometers
0
90
180

Figure 2b.

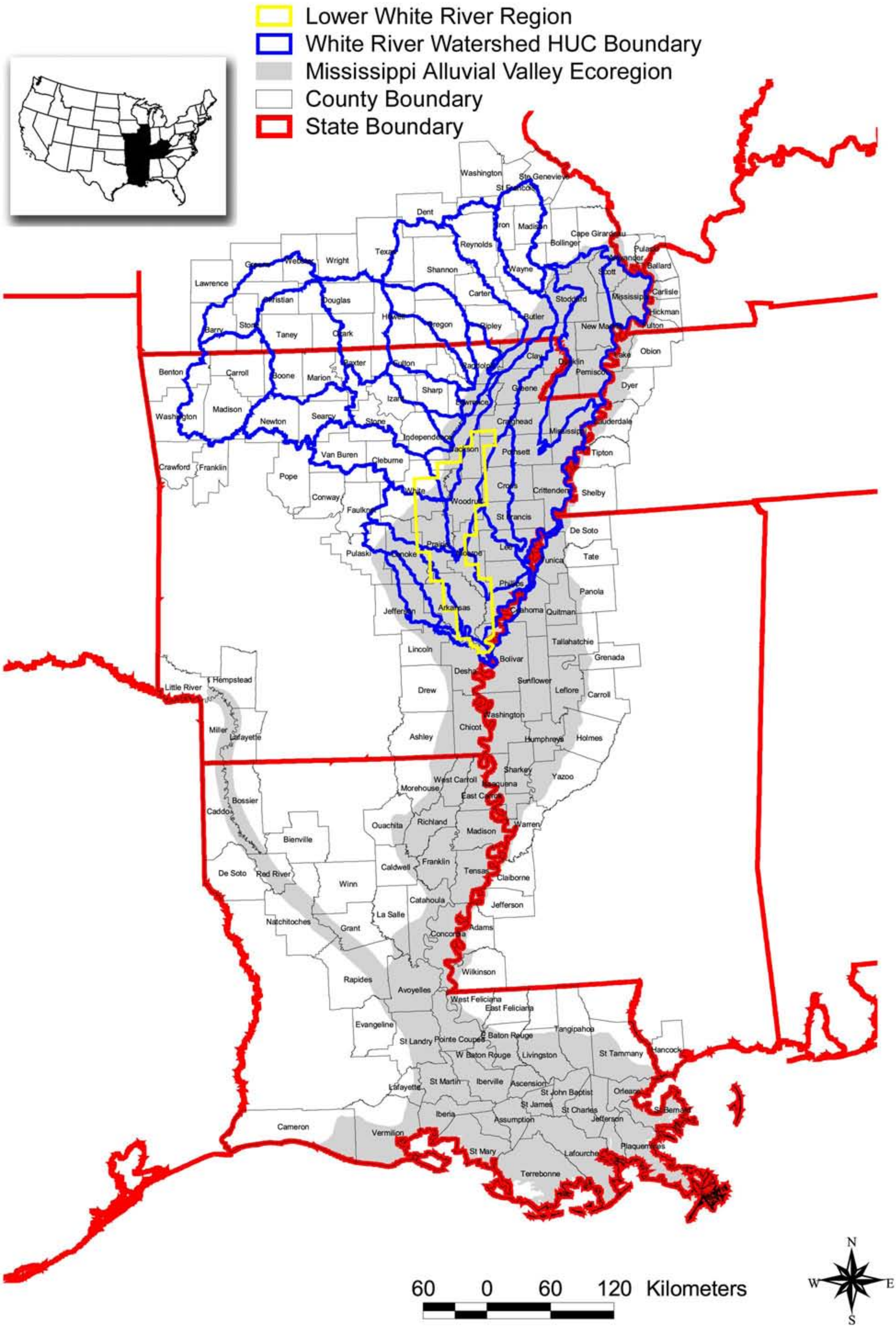

Lower White River Region
White River Watershed HUC Boundary
Mississippi Alluvial Valley Ecoregion
County Boundary
State Boundary
60 0 60 120 Kilometers
N
W
E
S

Figure 2c.

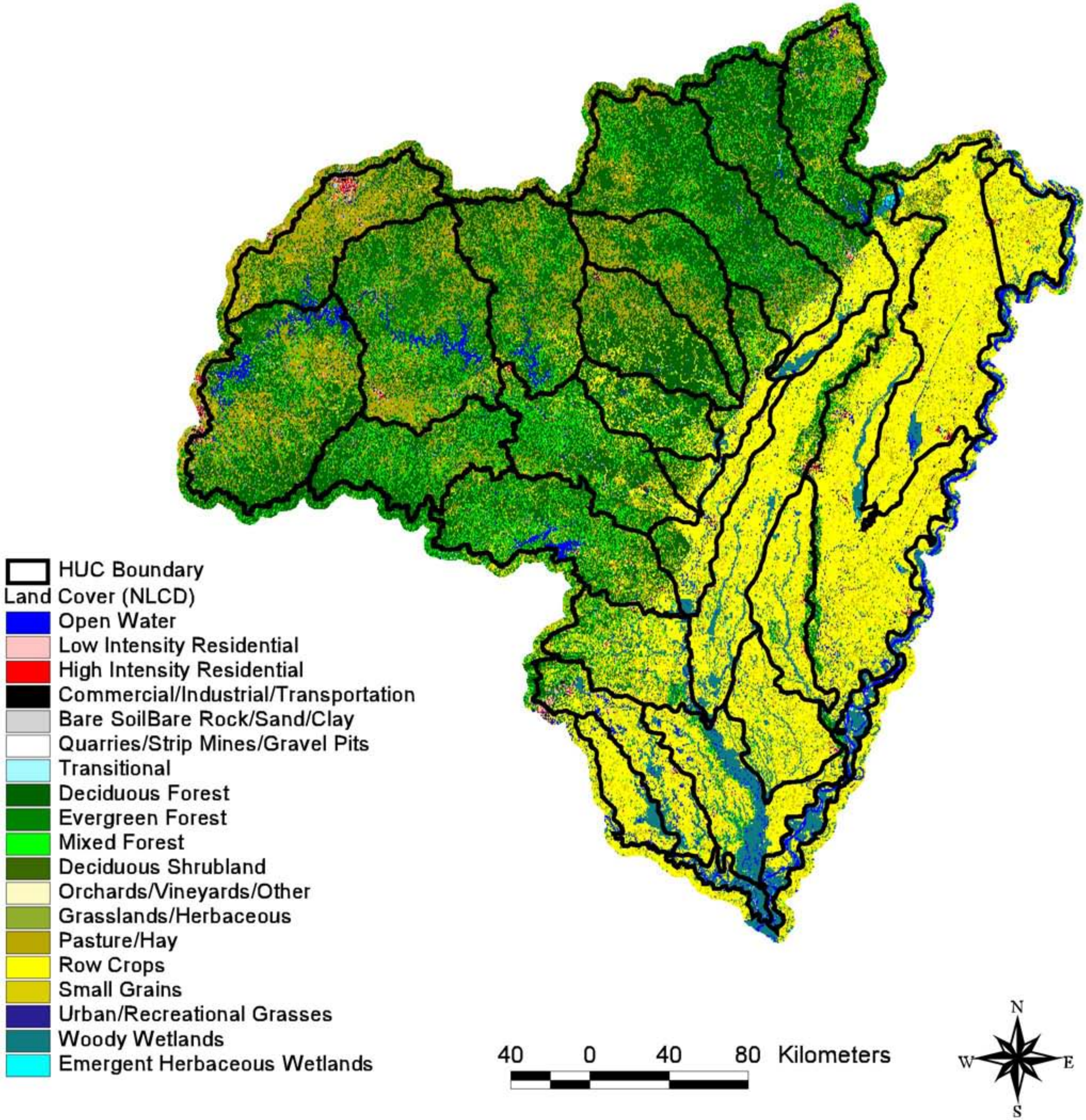


Figure 3. Land cover (National Land Cover Dataset; NLCD) in the White River Watershed, showing subwatershed boundaries (per USGS 8-digit Hydrologic Unit Code).

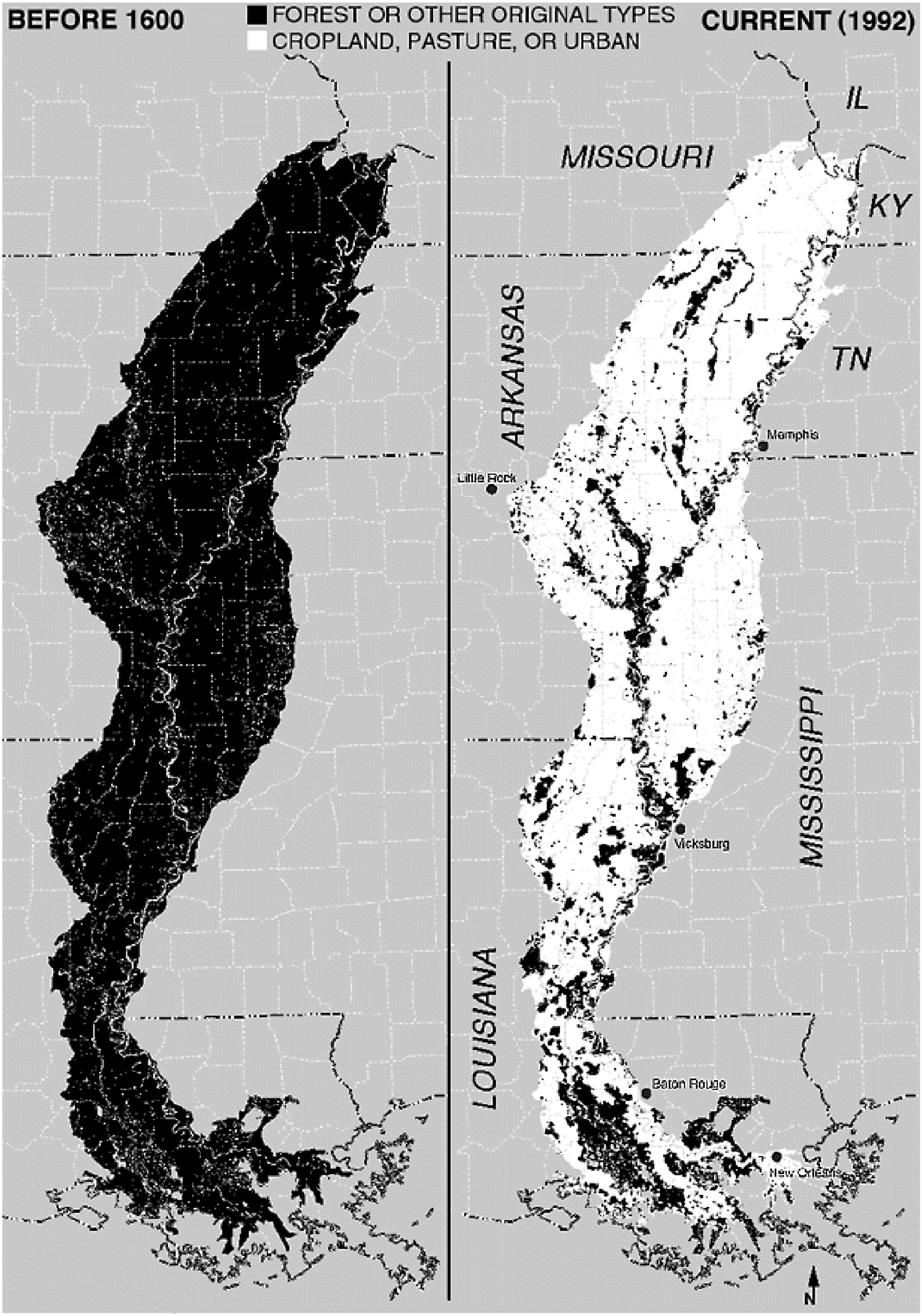


Figure 4. Wetland conversion to crop agriculture, pasture, or urban land cover (pre-1600 to 1992) in the Lower Mississippi River Basin (The Nature Conservancy, 1998).

Figure 5. "Loading logs on a lumber company railroad in early 1900" in an Arkansas bottomland hardwood swamp (Photo: Arkansas Historic Commission). Deforestation and draining of swamps allowed land to be farmed or developed for other uses..

Figure 6. Diesel generator pumping groundwater for the irrigation of row crops in Arkansas County, Arkansas (Photo: Ricardo D. Lopez, 2001).

Figure 7. The Beouf-Tensas Project, Arkansas-Louisiana (Photo: U.S. Army Corps of Engineers, date unknown), an example of riparian vegetation destruction and wetland hydrologic alteration in the Mississippi Alluvial Valley Ecoregion.

Figure 8. The McClellan-Kerr Navigation Channel on the Arkansas-Louisiana border (Photo: Ricardo D. Lopez, 2001), an example of riparian vegetation destruction and wetland hydrologic alteration in the Lower White River Region (LWRR).

Lower White River Region Landsat Images (November, 1999)

Figure 9a. Lower White River Region reference image with selected towns indicated with blue arrows; Landsat ETM+ single near-infrared band; 30 meter spatial resolution; November, 1999. Red rectangle indicates habitat vulnerability focus area in the South Unit of the White River National Wildlife Refuge.

Figure 9b. Lower White River Region reference image with selected towns indicated with blue arrows; Landsat ETM+ 3 band false-color infra-red composite; 30 meter spatial resolution; November, 1999. Red tones indicate photosynthetic vegetation. Red rectangle indicates habitat vulnerability focus area in the South Unit of the White River National Wildlife Refuge.

Figure 9c. Lower White River Region reference image with selected towns indicated with blue arrows; Landsat ETM+ 3 band false-color 'enhanced vegetation' infra-red composite; 30 meter spatial resolution; November, 1999. Green tones indicate photosynthetic vegetation. Red rectangle indicates habitat vulnerability focus area in the South Unit of the White River National Wildlife Refuge.

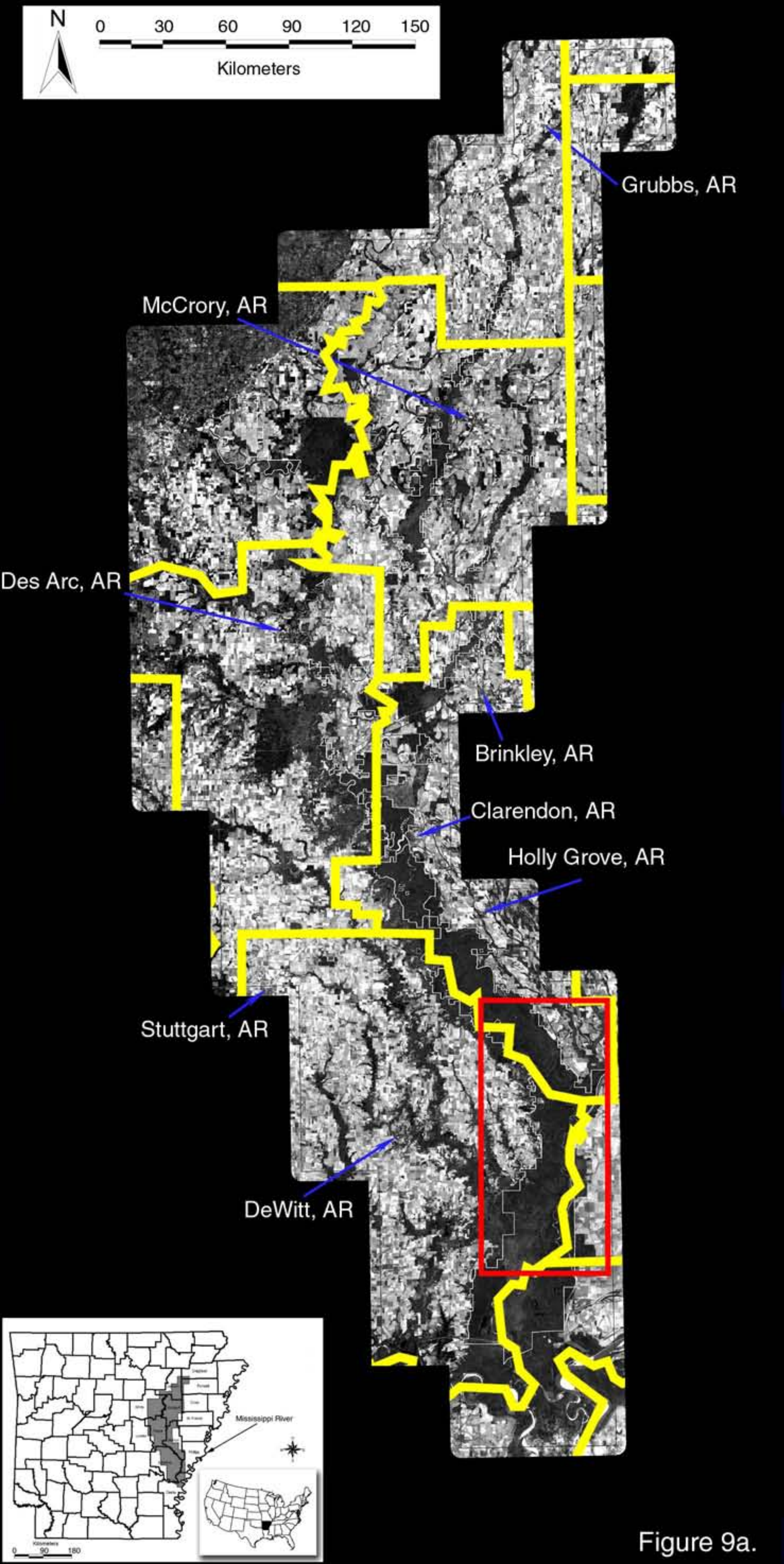

N
0 30 60 90 120 150
Kilometers
Grubbs, AR
McCrory, AR
Des Arc, AR
Brinkley, AR
Clarendon, AR
Holly Grove, AR
Stuttgart, AR
DeWitt, AR
Mississippi River

Figure 9a.

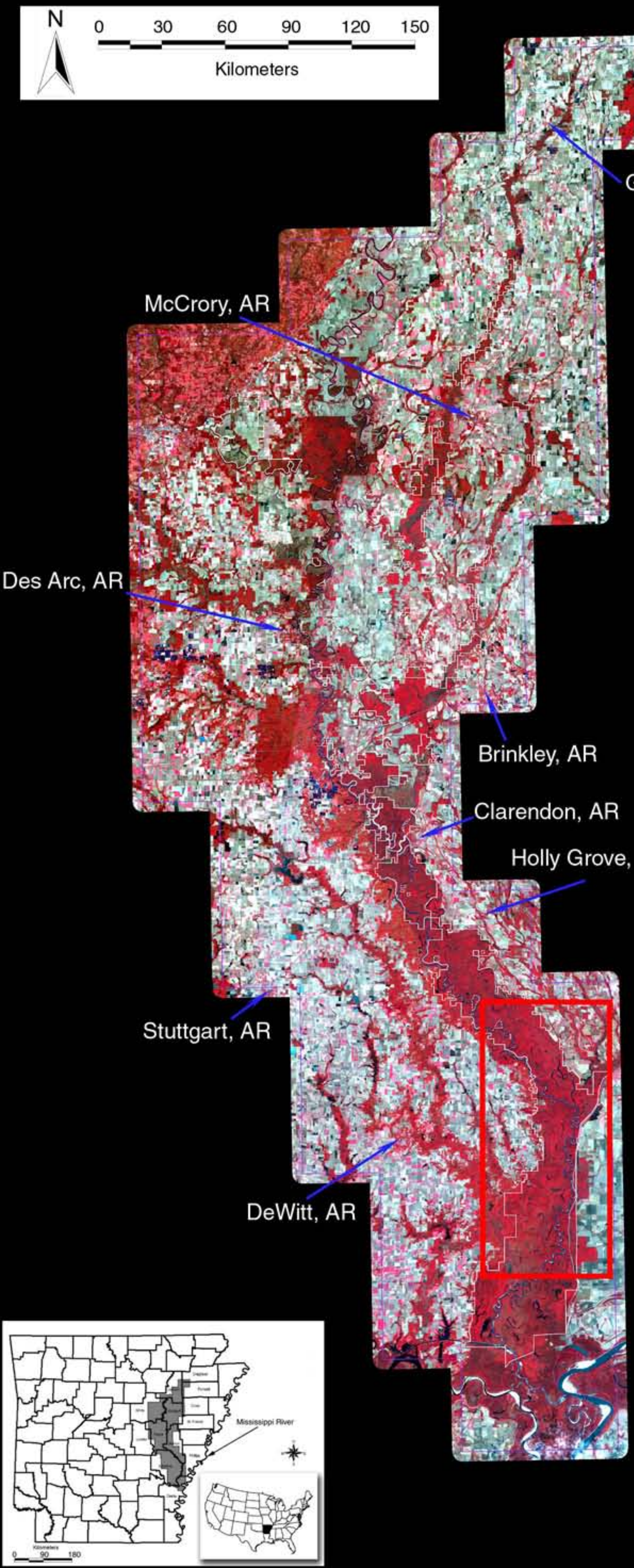

N
0
30
60
90
120
150
Kilometers
Grubbs, AR
McCrory, AR
Des Arc, AR
Brinkley, AR
Clarendon, AR
Holly Grove, AR
Stuttgart, AR
DeWitt, AR
Mississippi River
Kilometers
0
90
180

Figure 9b.

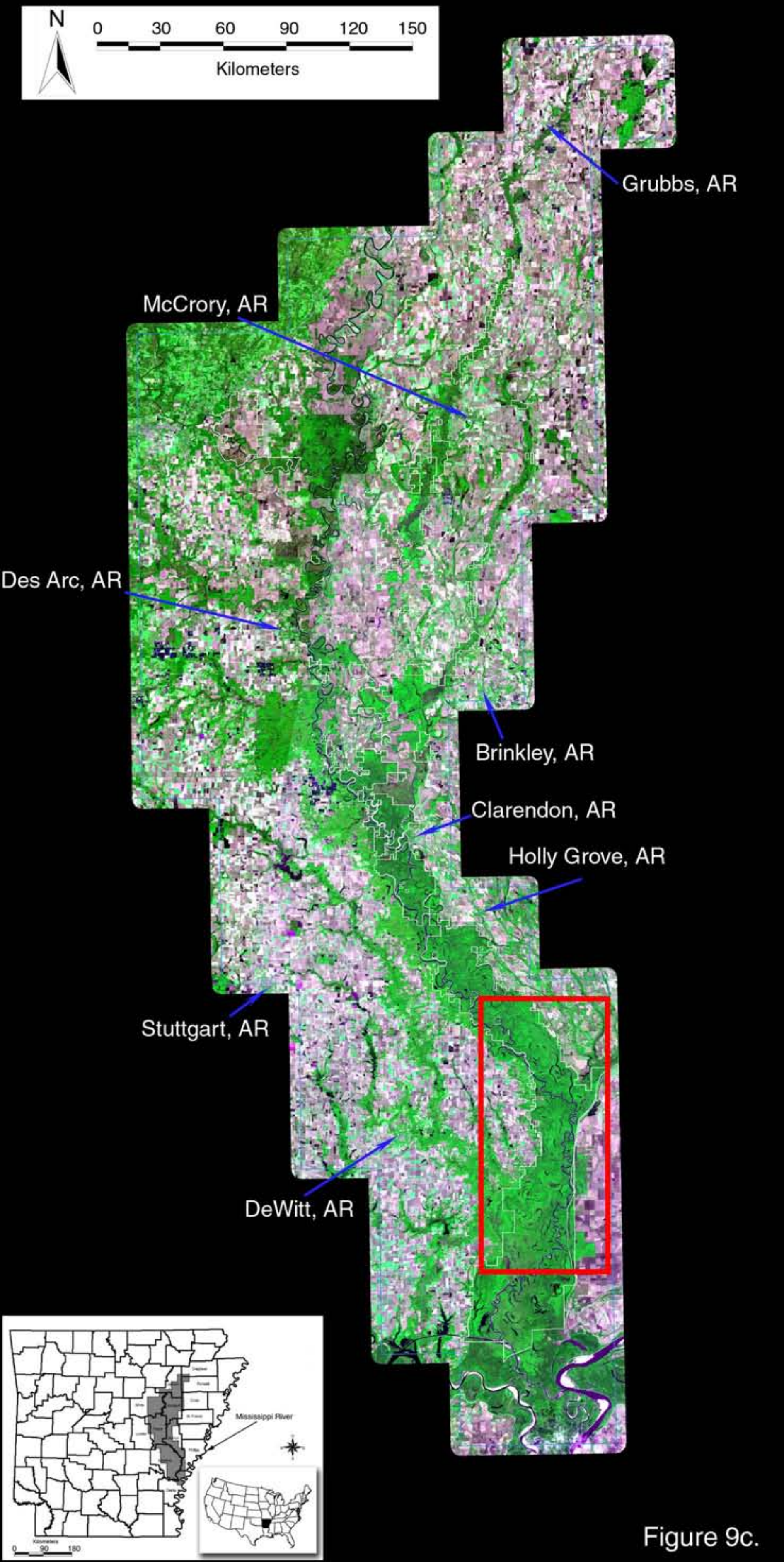

N
0 30 60 90 120 150
Kilometers
Grubbs, AR
McCrory, AR
Des Arc, AR
Brinkley, AR
Clarendon, AR
Holly Grove, AR
Stuttgart, AR
DeWitt, AR
Mississippi River
Kilometers
0 90 180

Figure 9c.

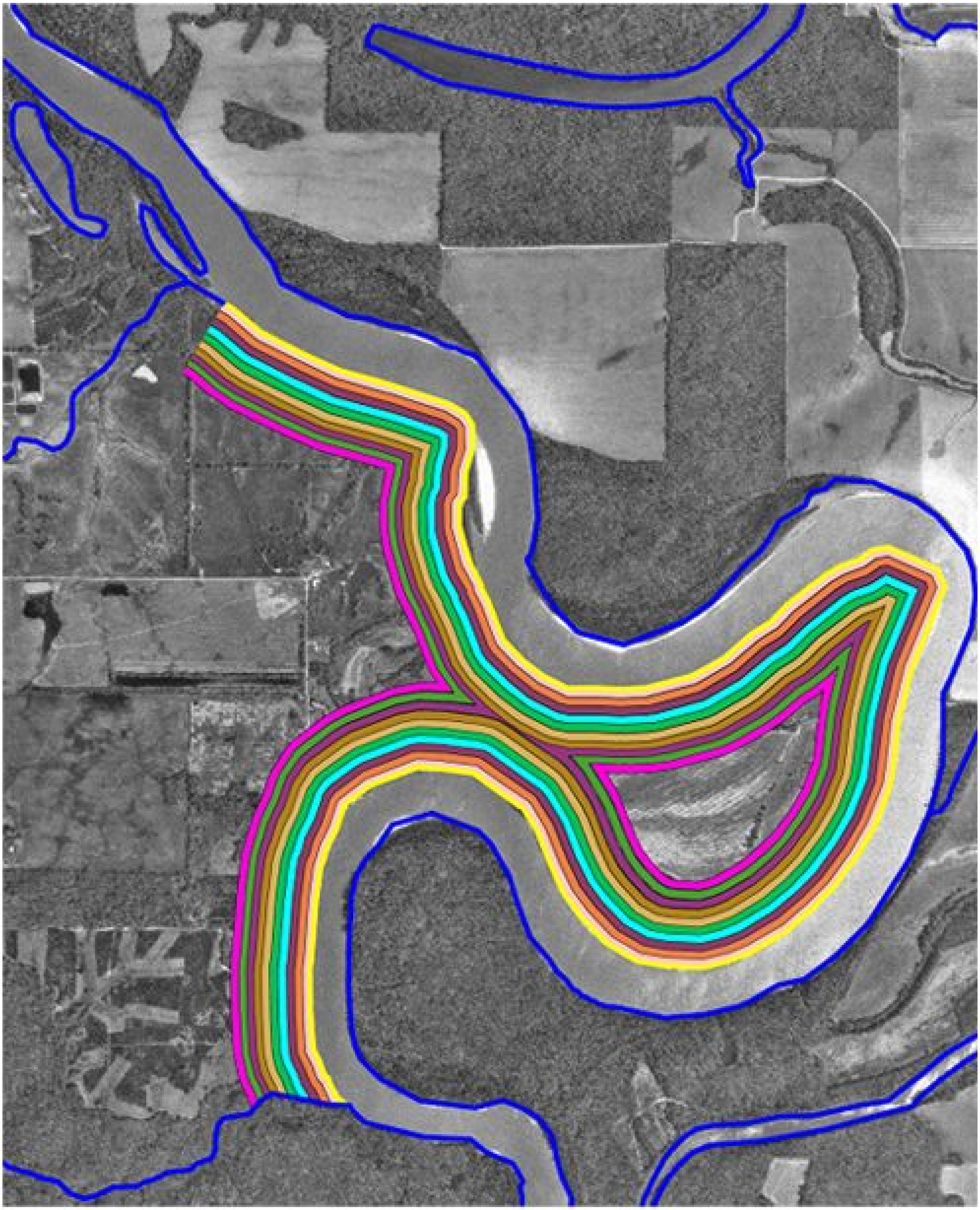


Figure 10. Land cover in the White River Watershed study area was measured adjacent to surface water bodies and within each cumulative 30 m riparian zone. Single blue line indicates edge of water. Each colored band represents a selected length of riparian zone from the shoreline to a maximum of 300 m.

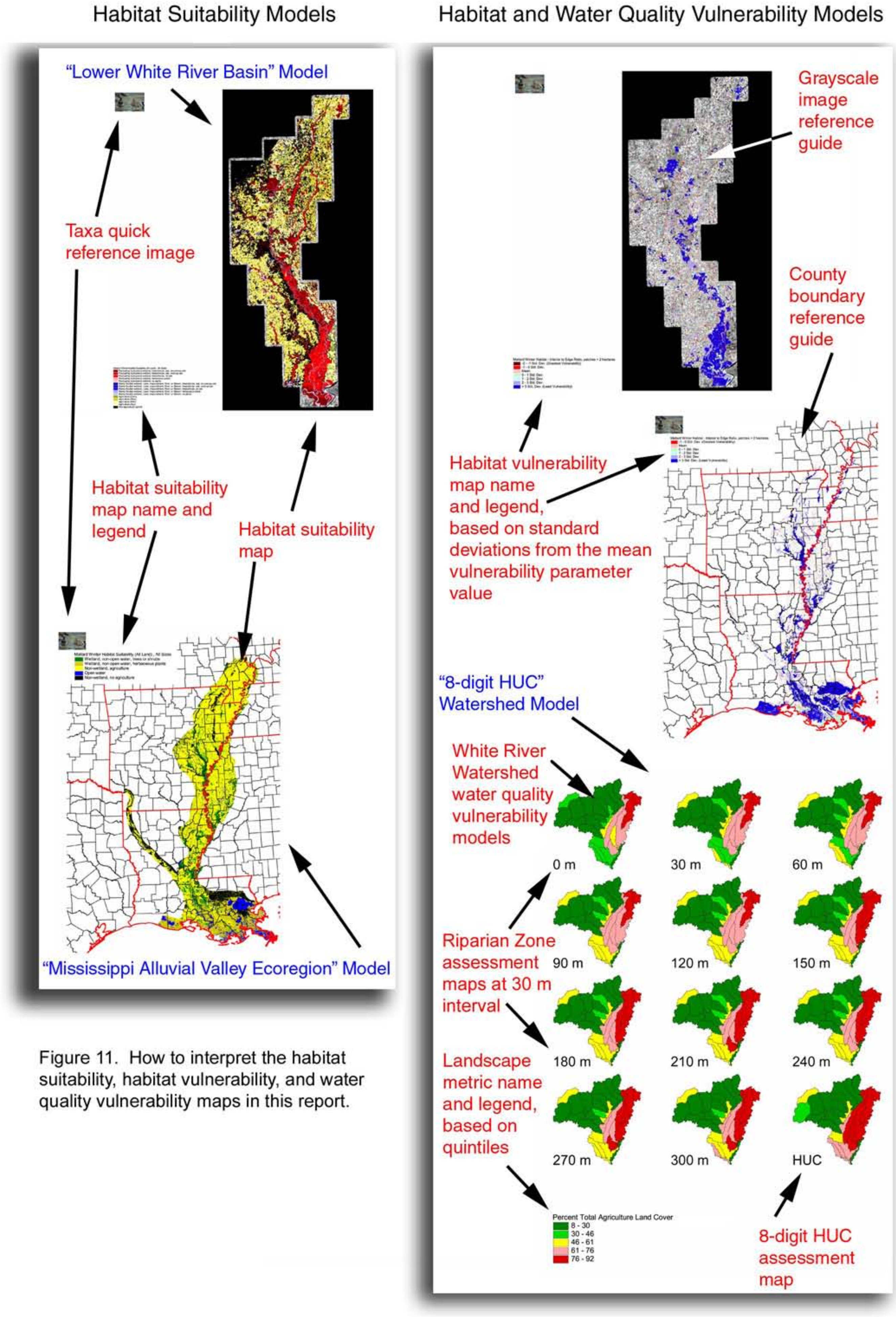


Figure 11. How to interpret the habitat suitability, habitat vulnerability, and water quality vulnerability maps in this report.

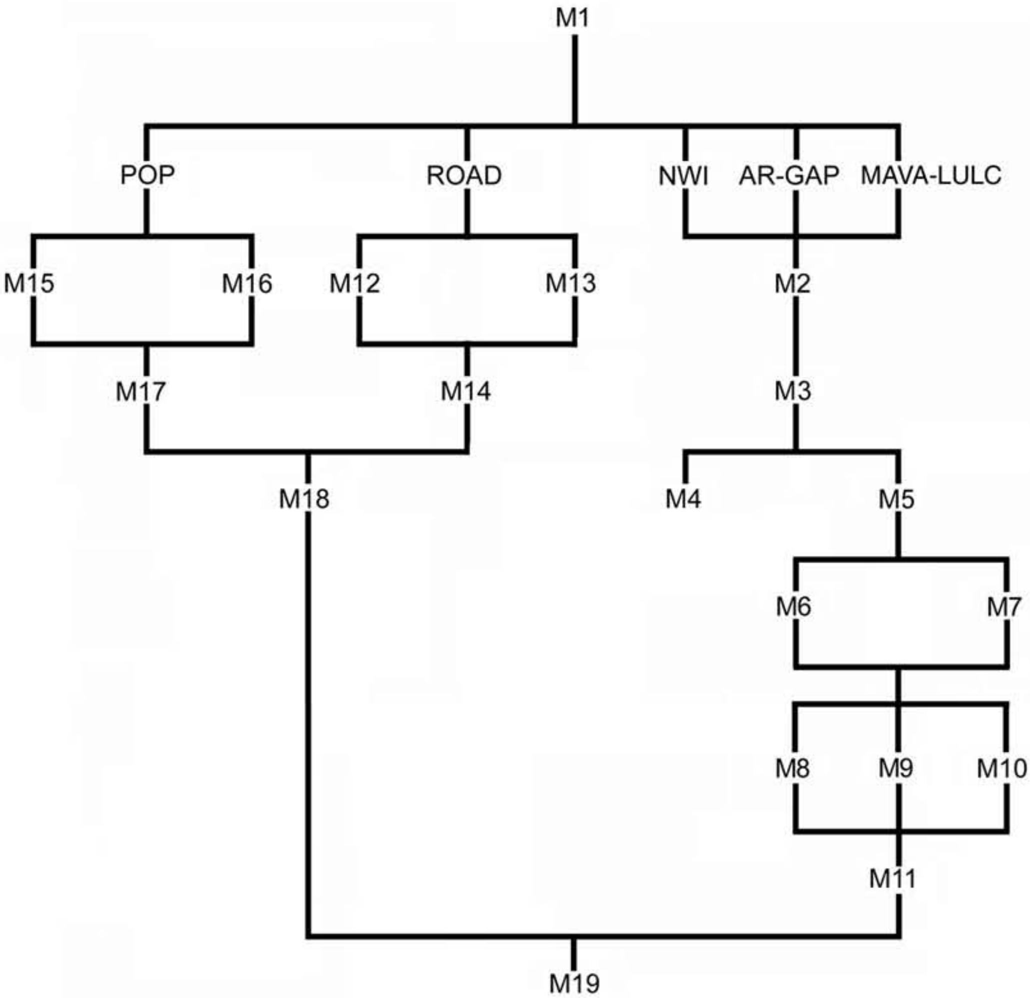


Figure 12. Hierarchical schematic of the mallard duck (M) winter habitat modeling process for the Lower White River Region (LWRR). See Table 1a for information about data components, Table 2a for habitat suitability model parameters, and Table 3a for habitat vulnerability parameters. M1 = Study site boundaries; POP = Population Block Group Data; ROAD = Wessex Road Data; NWI = National Wetland Inventory Data; AR-GAP = Arkansas GAP Data; MAVA-LULC = Mississippi Alluvial Valley of Arkansas Landuse/Landcover; M2 = 15 class mallard duck winter habitat suitability under current conditions (all land, all sizes included); M3 = 10 class mallard duck winter habitat suitability under current conditions (wetland habitat only), patches of all sizes; M4 = 10 class mallard duck winter habitat suitability under current conditions (wetland habitat only), patches less than 2 ha; M5 = 10 class mallard duck winter habitat suitability under current conditions (wetland habitat only), patches > 2 ha; M6 = Wetland habitat patch total area, patches > 2 ha; M7 = Wetland habitat patch total perimeter length, patches > 2 ha; M8 = Wetland habitat patch interior-to-edge ratio, patches > 2 ha; M9 = Wetland habitat patch sinuosity index, patches > 2 ha; M10 = Wetland habitat patch circularity index, patches > 2 ha; M11 = Wetland habitat unified patch index, patches > 2 ha; M12 = Wetland habitat patch road density, patches > 2 ha; M13 = Wetland habitat patch total road length, patches > 2 ha; M14 = Wetland habitat patch road index, patches > 2 ha; M15 = Wetland habitat patch human population density in 1990, patches > 2 ha; M16 = Wetland habitat patch human population density in 2011, patches > 2 ha; M17 = Wetland habitat patch human population density change from 1990 to 2011, patches > 2 ha; M18 = Wetland habitat patch unified human index, patches > 2 ha; M19 = Wetland habitat patch unified vulnerability index, patches > 2 ha.

Figure 13. An “emergent wetland” (per Cowardin et al., 1979) in the Lower White River Region (Photo: Ricardo D. Lopez, 2001).

Figure 14. A "scrub/shrub wetland" (per Cowardin et al., 1979), across a pool with duckweed (*Lemna* sp.) and watermeal (*Wolffia* sp.) on the surface; Lower White River Region (Photo: Ricardo D. Lopez, 2001).

Figure 15. A “forested wetland” (per Cowardin et al., 1979), in the Lower White River Region (Photo: Ricardo D. Lopez, 2001).

Figure 16. (a) An “unconsolidated bottom wetland” (per Cowardin et al., 1979), across an open field and (b) in an “oxbow wetland”, which is an isolated pond that is formed from an abandoned meander of a river (Photo: Ricardo D. Lopez, 2001).

Figure 17. An “aquatic bed” (per Cowardin et al., 1979) with submersed vegetation present in the foreground. Emergent vegetation and forest present across an area of open water (Photo: Ricardo D. Lopez, 2002).

Figure 18. A portion of the White River in the Lower White River Region study area (Photo: Ricardo D. Lopez, 2001). Rivers provide areas for animals to feed, drink, and rest.

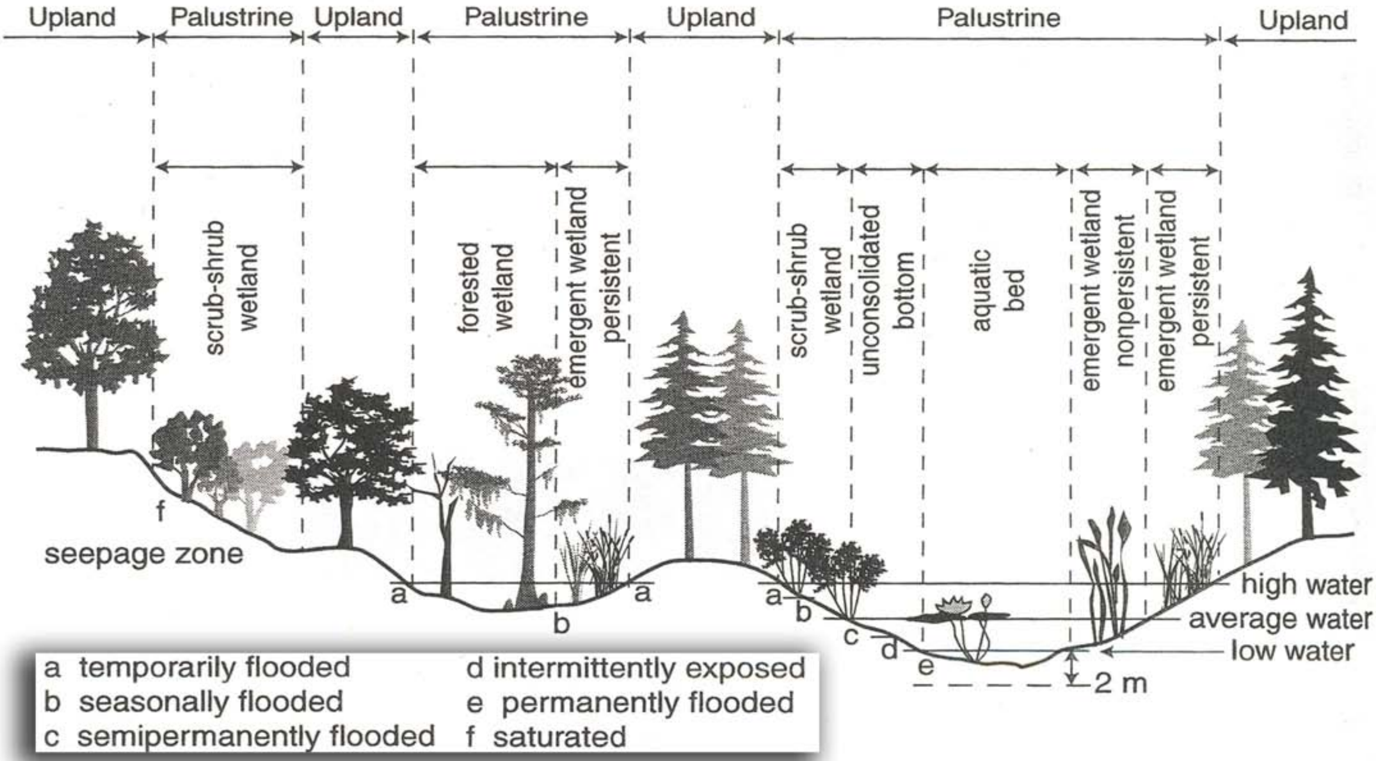


Figure 19. Features and examples of classes and hydrologic modifiers in cross-sectional view of palustrine wetlands (from Cowardin et al., 1979)

Figure 20. Narrow sandy shores on the banks of the White River in the Lower White River Region study area (Photo: Ricardo D. Lopez, 2001).

Lower White River Region Habitat Suitability Models

Figure 21a. Lower White River Region (LWRR) mallard duck winter habitat suitability (All Land), All Sizes.
Figure 21b. Lower White River Region (LWRR) black bear habitat suitability (All Land), All Sizes.
Figure 21c. Lower White River Region (LWRR) least tern habitat suitability reference aid (All Land), All Sizes.
Figure 21d. Lower White River Region (LWRR) least tern habitat image overlay (All Land), All Sizes.

Figure 21e. Lower White River Region (LWRR) mallard duck winter habitat suitability (Wetlands Only), All Sizes.
Figure 21f. Lower White River Region (LWRR) black bear habitat suitability (Wetlands Only), All Sizes.
Figure 21g. Lower White River Region (LWRR) wetland plant habitat suitability (Wetlands Only), All Sizes. Classes and hydrologic modifiers per Cowardin et al. (1979).

Figure 21h. Lower White River Region (LWRR) mallard duck winter habitat suitability (Wetlands Only), ≤ 2 ha.
Figure 21i. Lower White River Region (LWRR) black bear habitat suitability (Wetlands Only), ≤ 2 ha.
Figure 21j. Lower White River Region (LWRR) wetland plant habitat suitability (Wetlands Only), ≤ 2 ha. Classes and hydrologic modifiers per Cowardin et al. (1979).

Figure 21k. Lower White River Region (LWRR) mallard duck winter habitat suitability (Wetlands Only), > 2 ha.
Figure 21l. Lower White River Region (LWRR) black bear habitat suitability (Wetlands Only), > 2 ha.
Figure 21m. Lower White River Region (LWRR) wetland plant habitat suitability (Wetlands Only), > 2 ha. Classes and hydrologic modifiers per Cowardin et al. (1979).

Lower White River Region Habitat Suitability Models (All Land, All Sizes)

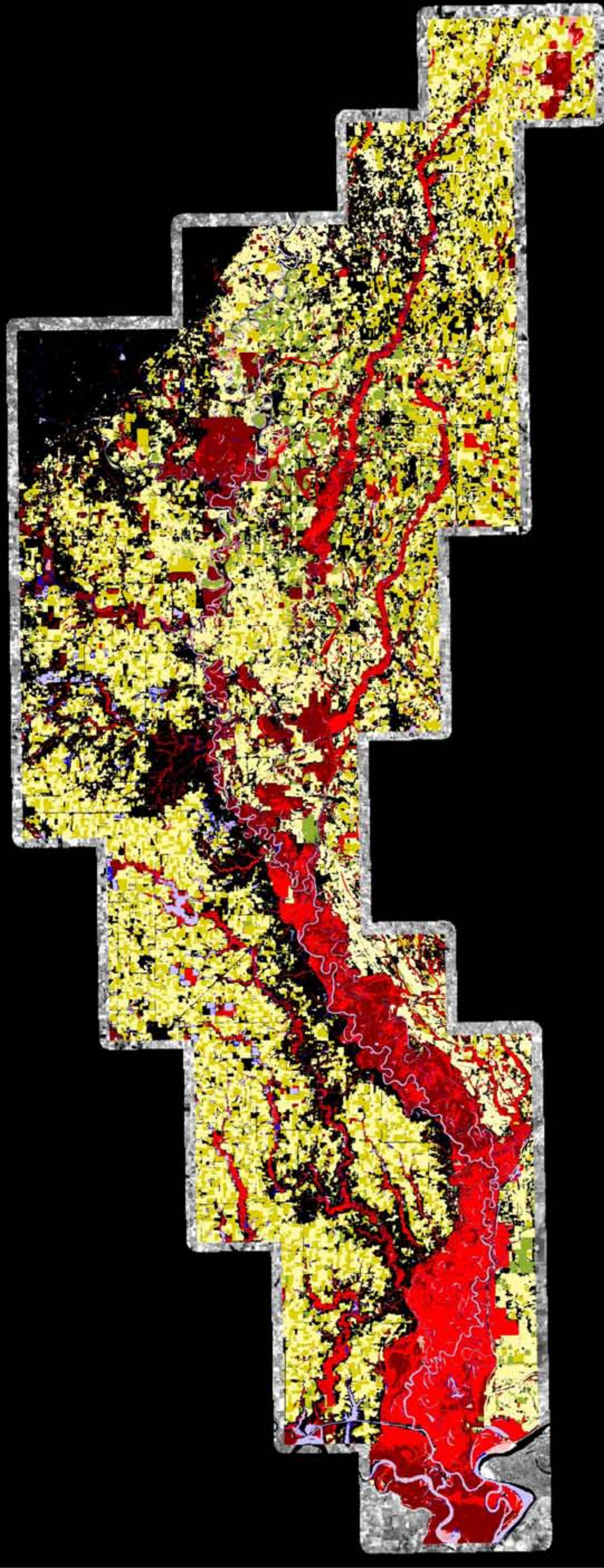


Figure 21a.

Mallard Winter Habitat Suitability (All Land) , All Sizes

- Fluctuating hydroperiod wetland, trees/shrubs, oak, no overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, oak, overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, no oak
- Fluctuating hydroperiod wetland, herbaceous plants
- Fluctuating hydroperiod wetland, no plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, no overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, no oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, herbaceous plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, no plants
- Agriculture (Corn)
- Agriculture (Rice)
- Agriculture (Milo)
- Agriculture (Soy)
- Non-agricultural upland

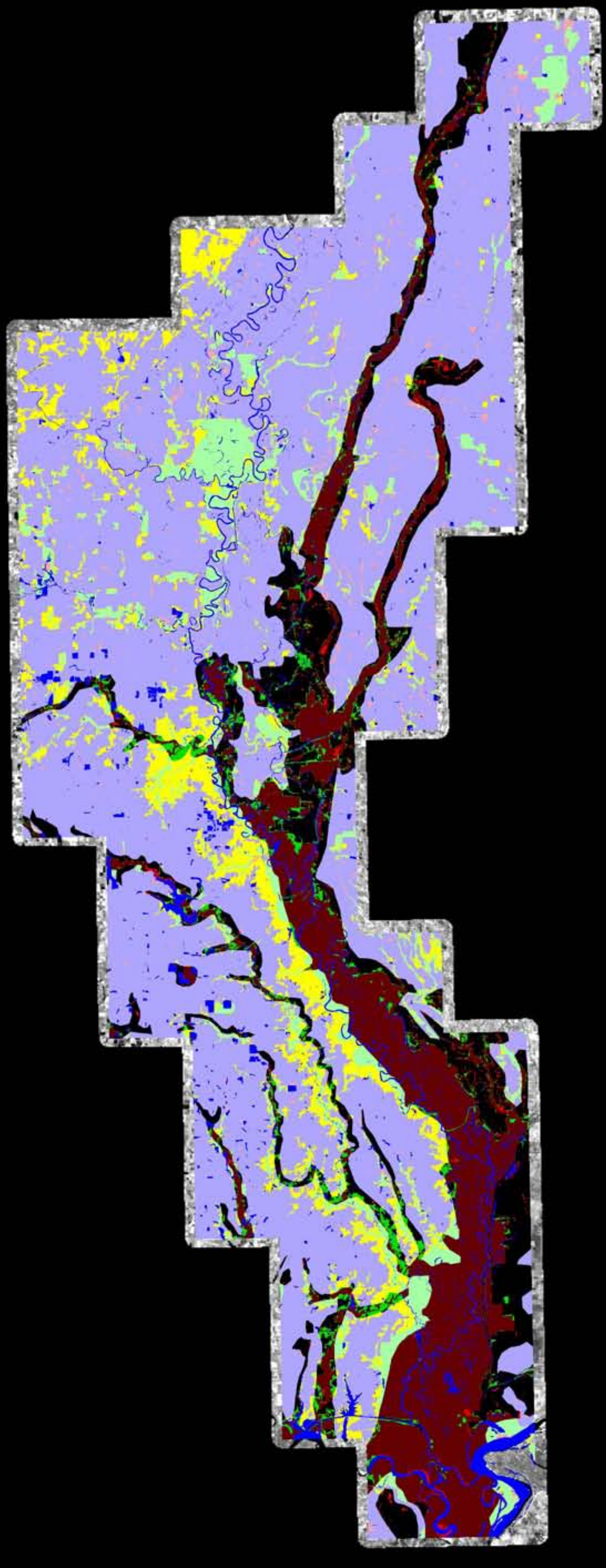


Figure 21b.

Black Bear Habitat Suitability - All Land, All Sizes

- Woody wetland with 4 tree species present prior to 1950's
- Woody wetland with 3 tree species present prior to 1950's
- Woody wetland with 2 tree species present prior to 1950's
- Woody wetland with 1 tree species present prior to 1950's
- Woody upland with 4 tree species present prior to 1950's
- Woody upland with 3 tree species present prior to 1950's
- Woody upland with 2 tree species present prior to 1950's
- Woody upland with 1 tree species present prior to 1950's
- Woody wetland with 4 tree species present after 1950's
- Woody wetland with 3 tree species present after 1950's
- Woody wetland with 2 tree species present after 1950's
- Woody wetland with 1 tree species present after 1950's
- Woody upland with 4 tree species present after 1950's
- Woody upland with 3 tree species present after 1950's
- Woody upland with 2 tree species present after 1950's
- Woody upland with 1 tree species present after 1950's
- Non-woody wetland with 4 plant species present, non-forested in the 1950's
- Non-woody wetland with 3 plant species present, non-forested in the 1950's
- Non-woody wetland with 2 plant species present, non-forested in the 1950's
- Non-woody wetland with 1 plant species present, non-forested in the 1950's
- Non-woody wetland with 0 plant species present, non-forested in the 1950's
- Non-woody upland with 4 plant species present, non-forested in the 1950's
- Non-woody upland with 3 plant species present, non-forested in the 1950's
- Non-woody upland with 2 plant species present, non-forested in the 1950's
- Non-woody upland with 1 plant species present, non-forested in the 1950's
- Non-woody upland with 0 plant species present, non-forested in the 1950's
- Non-woody wetland with 4 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 3 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 2 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 1 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 0 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody upland with 4 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody upland with 3 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody upland with 2 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody upland with 1 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody upland with 0 plant species present, forested in the 1950's (i.e., disturbed)
- Open Water

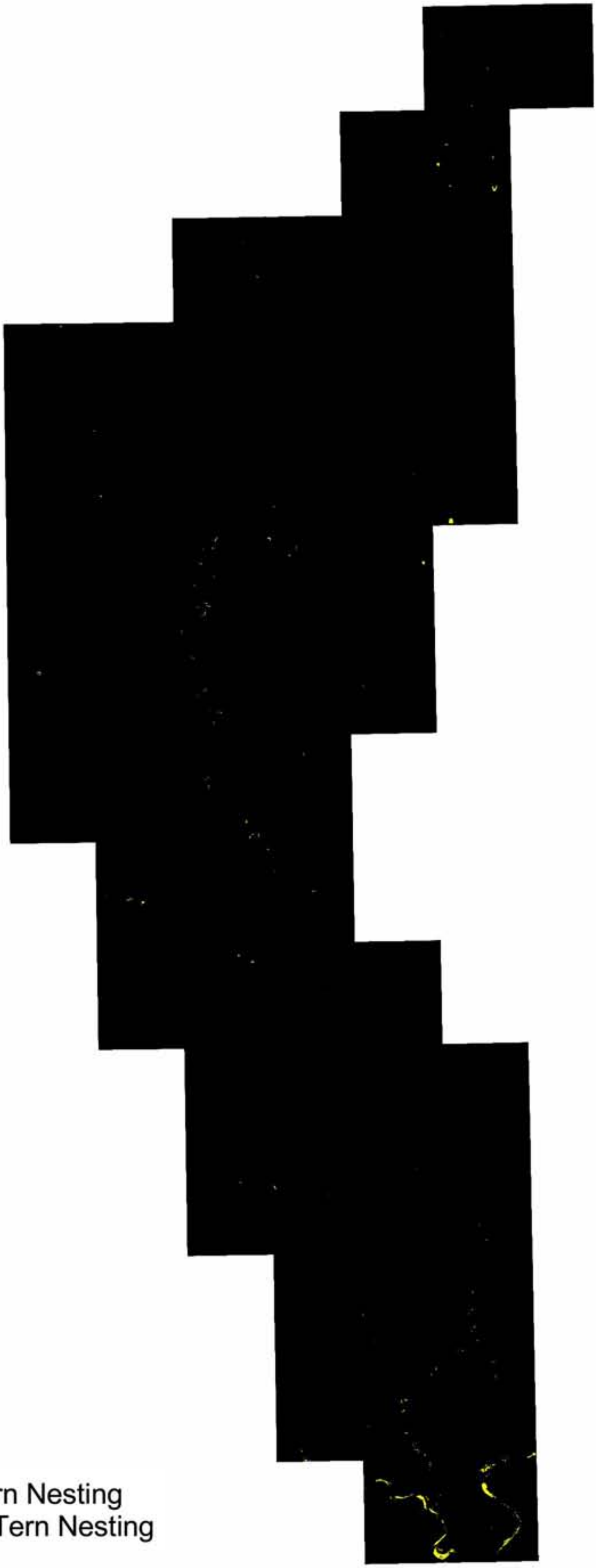


Figure 21c.

Suitable For Tern Nesting
Unsuitable For Tern Nesting

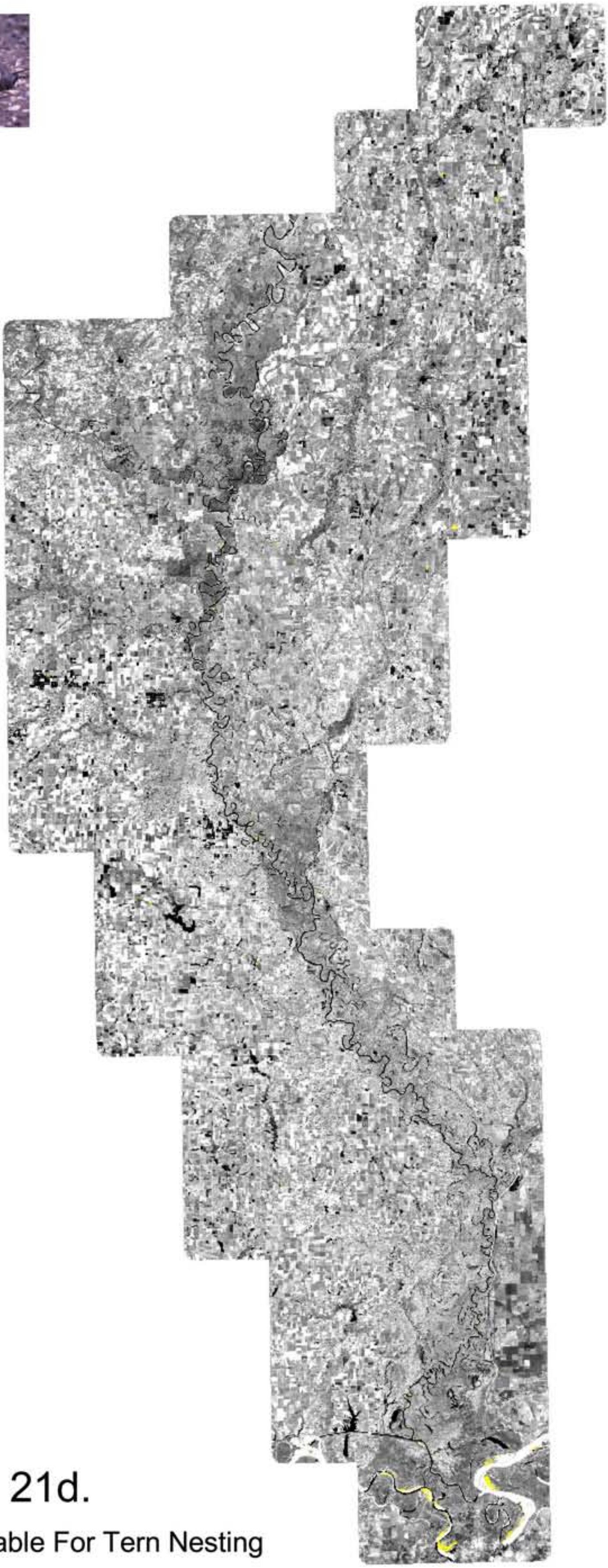


Figure 21d.

Suitable For Tern Nesting

Lower White River Region Wetland Habitat Suitability Models (All Sizes)

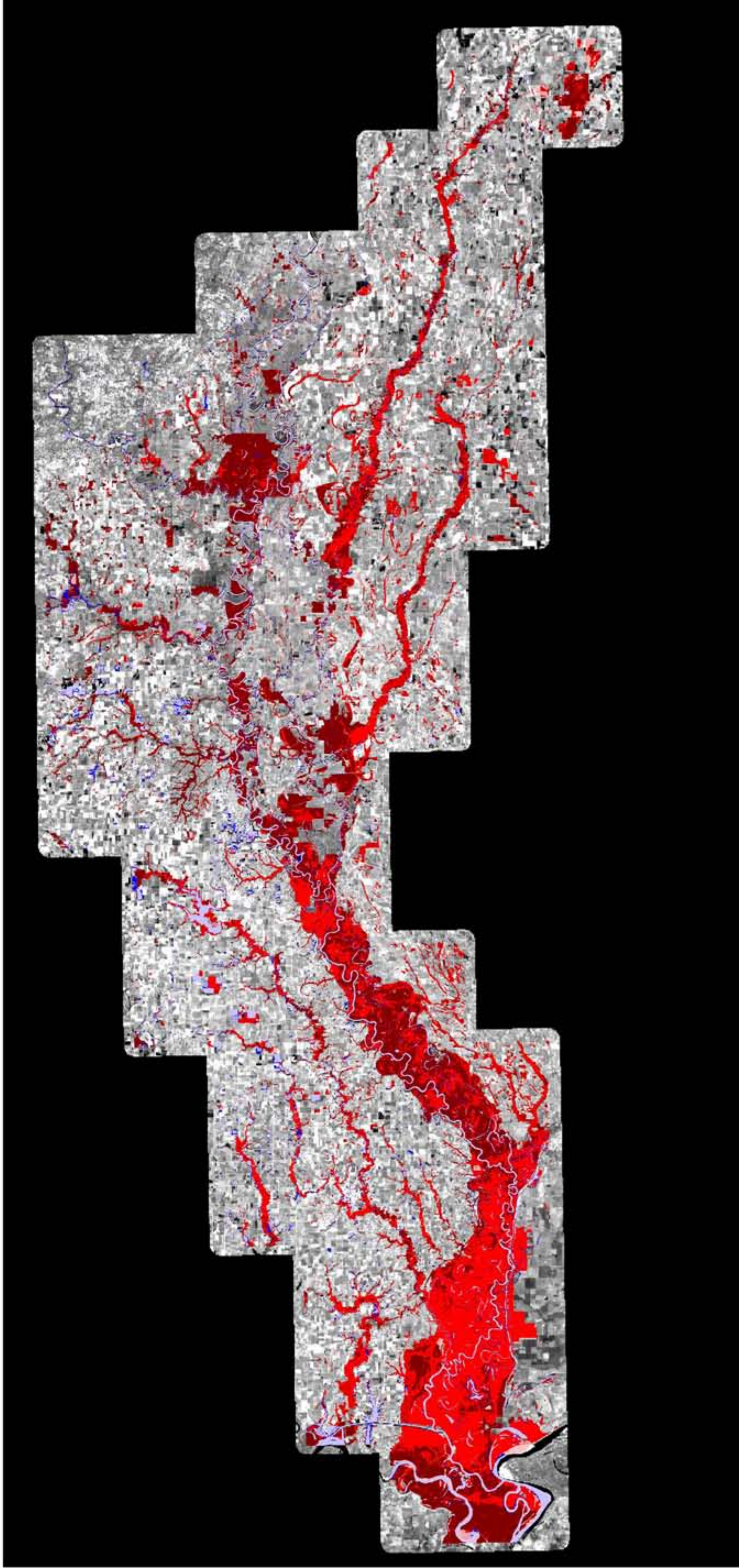


Figure 21e.

Mallard Winter Habitat Suitability (Wetlands Only) , All Sizes

- Fluctuating hydroperiod wetland, trees/shrubs, oak, no overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, oak, overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, no oak
- Fluctuating hydroperiod wetland, herbaceous plants
- Fluctuating hydroperiod wetland, no plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, no overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, no oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, herbaceous plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, no plants

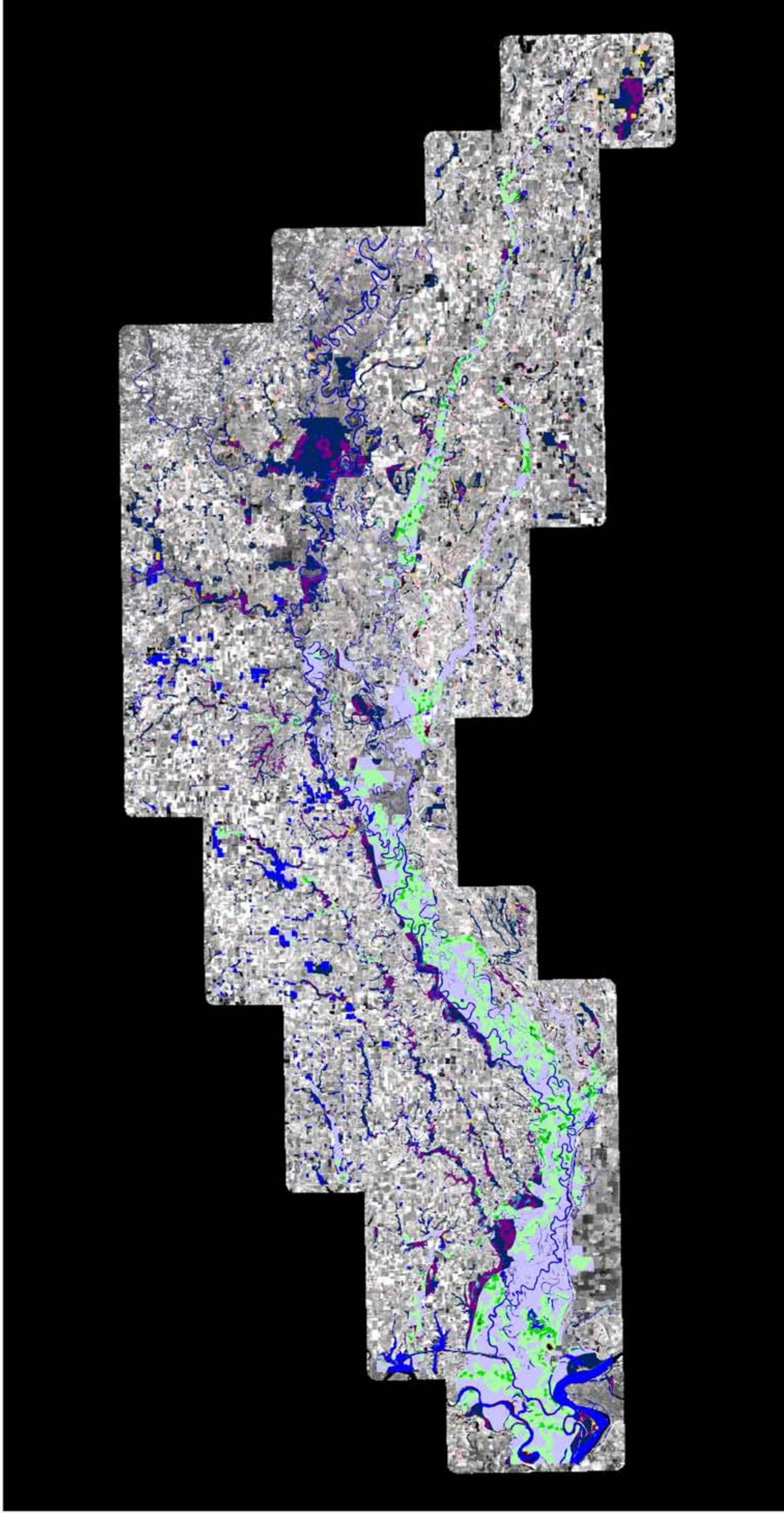


Figure 21f.

Black Bear Wetland Habitat Suitability - (Wetlands Only), All Sizes

- Woody wetland with 4 tree species present prior to 1950's
- Woody wetland with 3 tree species present prior to 1950's
- Woody wetland with 2 tree species present prior to 1950's
- Woody wetland with 1 tree species present prior to 1950's
- Woody wetland with 4 tree species present after 1950's
- Woody wetland with 3 tree species present after 1950's
- Woody wetland with 2 tree species present after 1950's
- Woody wetland with 1 tree species present after 1950's
- Non-woody wetland with 4 plant species present, non-forested in the 1950's
- Non-woody wetland with 3 plant species present, non-forested in the 1950's
- Non-woody wetland with 2 plant species present, non-forested in the 1950's
- Non-woody wetland with 1 plant species present, non-forested in the 1950's
- Non-woody wetland with 0 plant species present, non-forested in the 1950's
- Non-woody wetland with 4 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 3 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 2 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 1 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 0 plant species present, forested in the 1950's (i.e., disturbed)
- Open Water

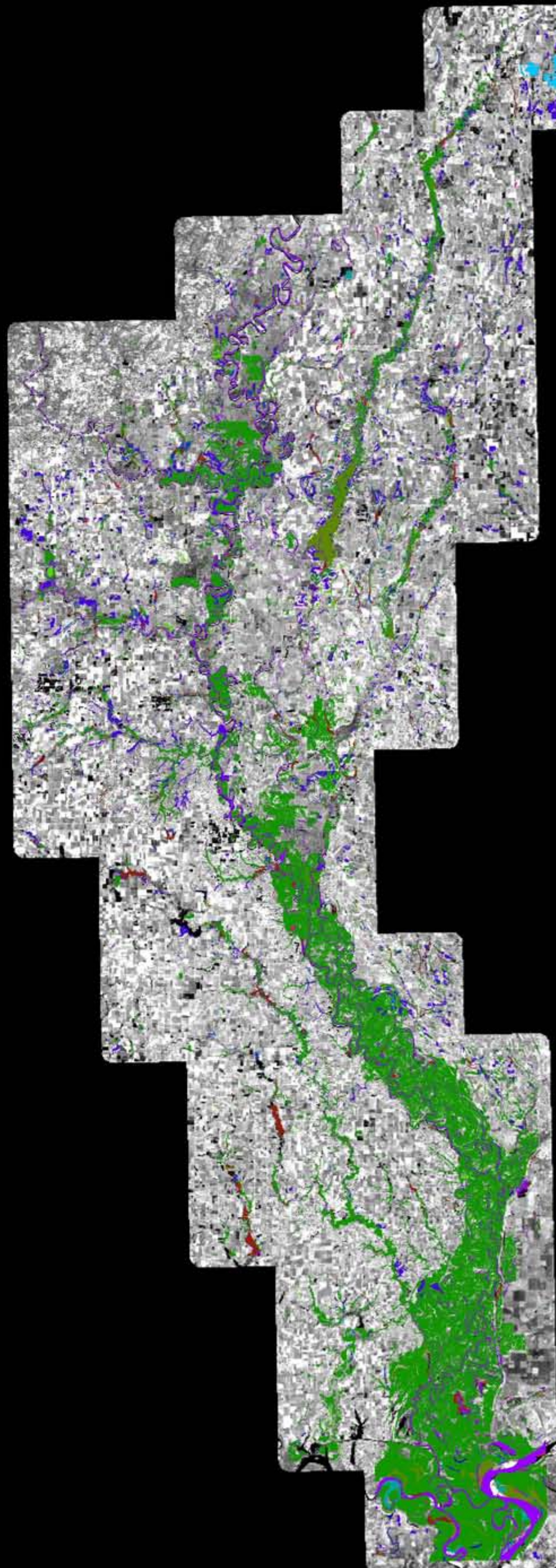


Figure 21g.

Wetland Plant Habitat Suitability (Wetlands Only), All Sizes

- [L] Lacustrine, [2] Littoral, [AB] Aquatic Bed, [3] Rooted Vascular, [F] Semipermanently Flooded
- [L] Lacustrine, [2] Littoral, [AB] Aquatic Bed, [3] Rooted Vascular, [H] Permanently Flooded
- [L] Lacustrine, [2] Littoral, [UB] Unconsolidated Bottom, [H] Permanently Flooded
- [P] Palustrine, [AB] Aquatic Bed, [3] Rooted Vascular, [H] Permanently Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [A] Temporarily Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [C] Seasonally Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [2] Needle-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [FO] Forested, [2] Needle-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [6] Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [FO] Forested, [6] Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [UB] Unconsolidated Bottom
- [P] Palustrine, [US] Unconsolidated Shore, [C] Seasonally Flooded
- [R] Riverine, [2] Lower Perennial, [UB] Unconsolidated Bottom, [H] Permanently Flooded
- [R] Riverine, [2] Lower Perennial, [US] Unconsolidated Shore, [A] Temporarily Flooded
- [R] Riverine, [2] Lower Perennial, [US] Unconsolidated Shore, [C] Seasonally Flooded

Lower White River Region Wetland Habitat Suitability Models ($\leq$ 2 ha)

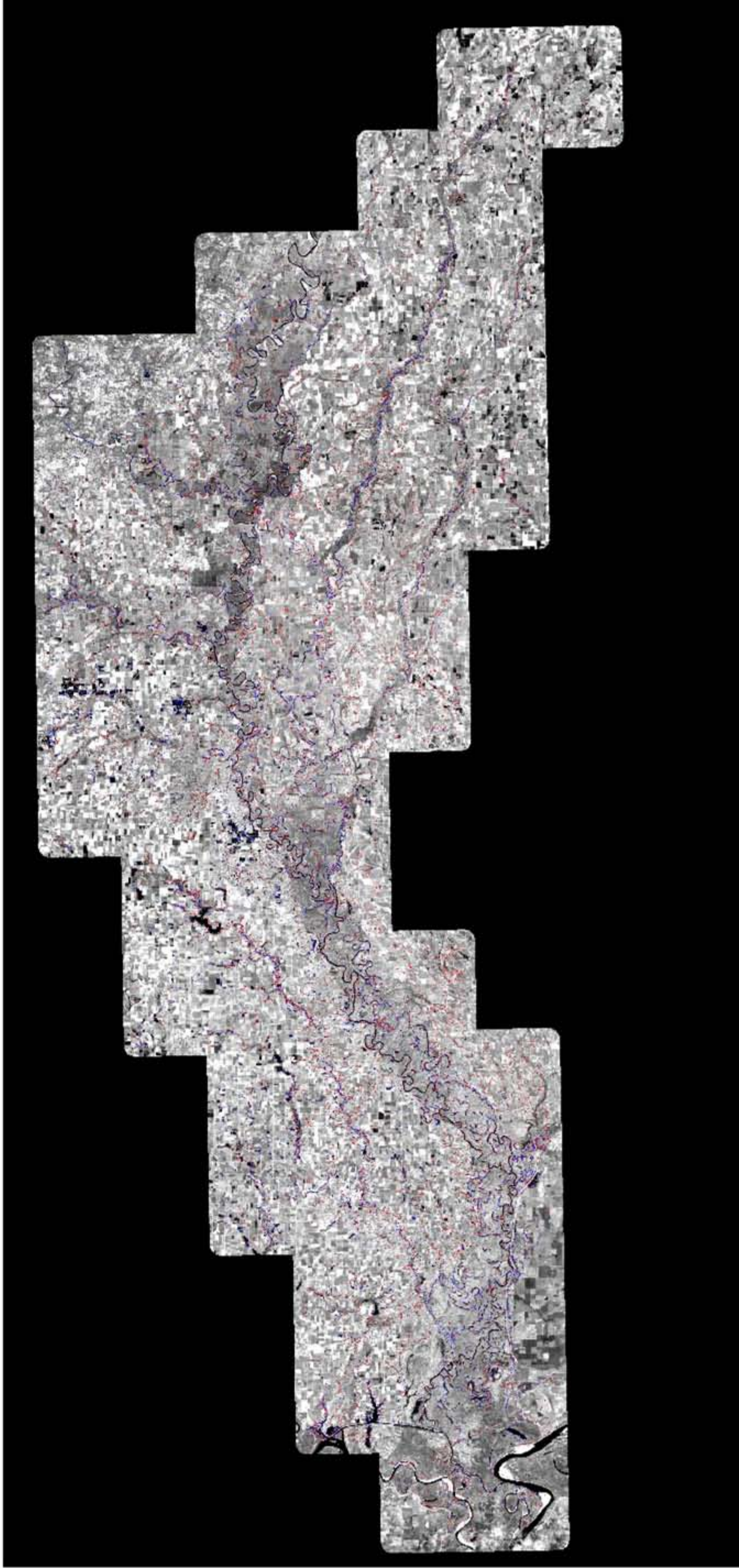


Figure 21h.

Mallard Winter Habitat Suitability (Wetlands Only) , less than or equal to 2 hectares

- Fluctuating hydroperiod wetland, trees/shrubs, oak, no overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, oak, overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, no oak
- Fluctuating hydroperiod wetland, herbaceous plants
- Fluctuating hydroperiod wetland, no plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, no overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, no oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, herbaceous plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, no plants

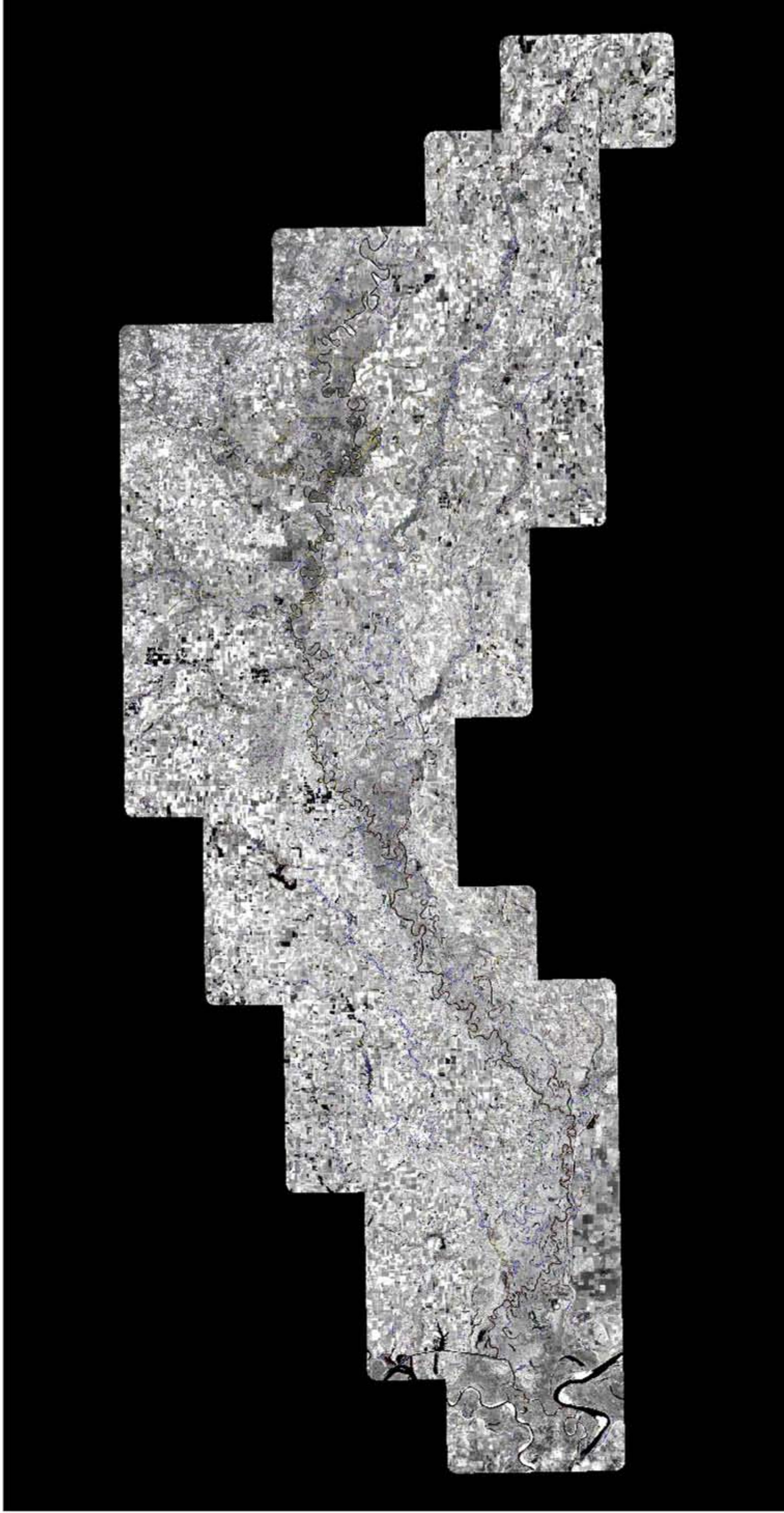


Figure 21i.

Black Bear Wetland Habitat Suitability - Wetlands less than or equal to 2 hectares

- Woody wetland with 4 tree species present prior to 1950's
- Woody wetland with 3 tree species present prior to 1950's
- Woody wetland with 2 tree species present prior to 1950's
- Woody wetland with 1 tree species present prior to 1950's
- Woody wetland with 4 tree species present after 1950's
- Woody wetland with 3 tree species present after 1950's
- Woody wetland with 2 tree species present after 1950's
- Woody wetland with 1 tree species present after 1950's
- Non-woody wetland with 4 plant species present, non-forested in the 1950's
- Non-woody wetland with 3 plant species present, non-forested in the 1950's
- Non-woody wetland with 2 plant species present, non-forested in the 1950's
- Non-woody wetland with 1 plant species present, non-forested in the 1950's
- Non-woody wetland with 0 plant species present, non-forested in the 1950's
- Non-woody wetland with 4 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 3 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 2 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 1 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 0 plant species present, forested in the 1950's (i.e., disturbed)
- Open Water

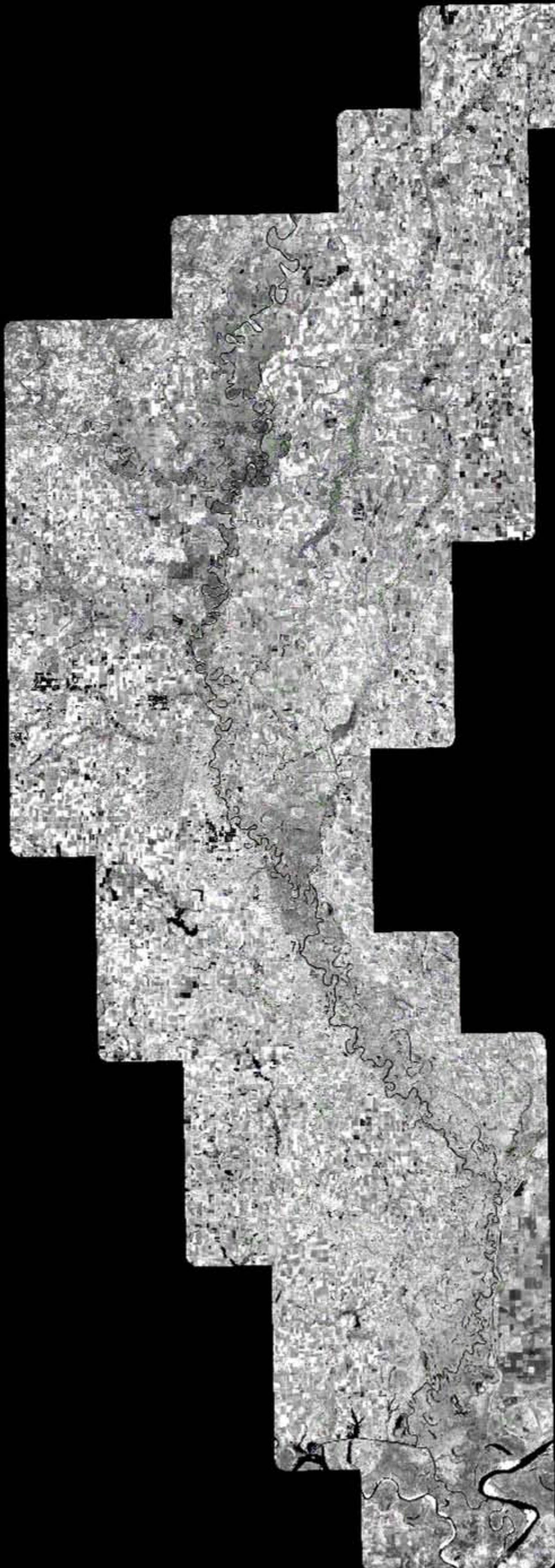


Figure 21j.

Wetland Plant Habitat Suitability (Wetlands Only), less than or equal to 2 hectares

- [L] Lacustrine, [2] Littoral, [AB] Aquatic Bed, [3] Rooted Vascular, [F] Semipermanently Flooded
- [L] Lacustrine, [2] Littoral, [AB] Aquatic Bed, [3] Rooted Vascular, [H] Permanently Flooded
- [L] Lacustrine, [2] Littoral, [UB] Unconsolidated Bottom, [H] Permanently Flooded
- [P] Palustrine, [AB] Aquatic Bed, [3] Rooted Vascular, [H] Permanently Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [A] Temporarily Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [C] Seasonally Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [2] Needle-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [FO] Forested, [2] Needle-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [6] Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [FO] Forested, [6] Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [UB] Unconsolidated Bottom
- [P] Palustrine, [US] Unconsolidated Shore, [C] Seasonally Flooded
- [R] Riverine, [2] Lower Perennial, [UB] Unconsolidated Bottom, [H] Permanently Flooded
- [R] Riverine, [2] Lower Perennial, [US] Unconsolidated Shore, [A] Temporarily Flooded
- [R] Riverine, [2] Lower Perennial, [US] Unconsolidated Shore, [C] Seasonally Flooded

Lower White River Region Wetland Habitat Suitability Models (> 2 ha)

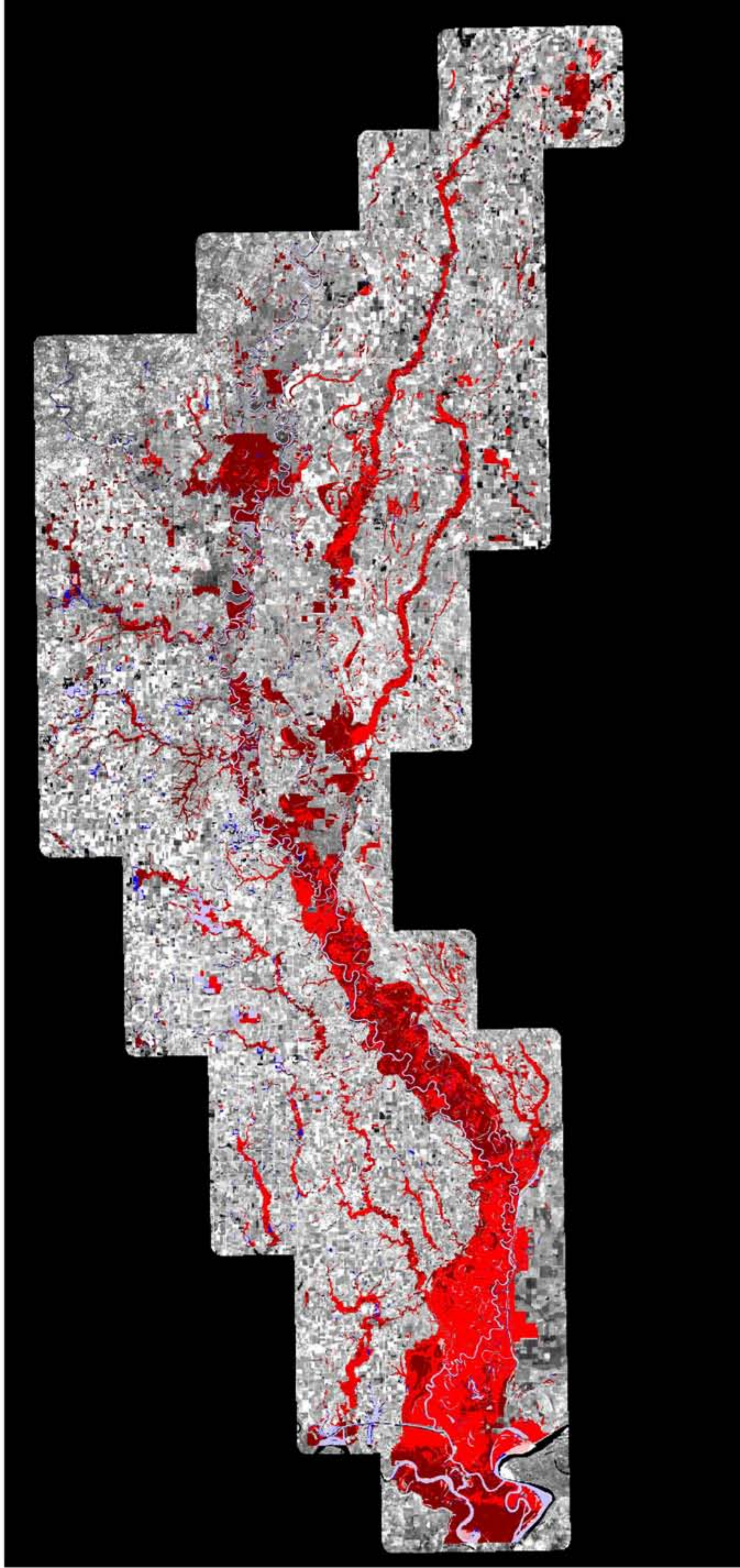


Figure 21k.

Mallard Winter Habitat Suitability (Wetlands Only) , > 2 hectares

- Fluctuating hydroperiod wetland, trees/shrubs, oak, no overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, oak, overcup oak
- Fluctuating hydroperiod wetland, trees/shrubs, no oak
- Fluctuating hydroperiod wetland, herbaceous plants
- Fluctuating hydroperiod wetland, no plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, no overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, oak, overcup oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, trees/shrubs, no oak
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, herbaceous plants
- Rarely flooded wetland , Lake, Impoundment, River, or Stream, no plants

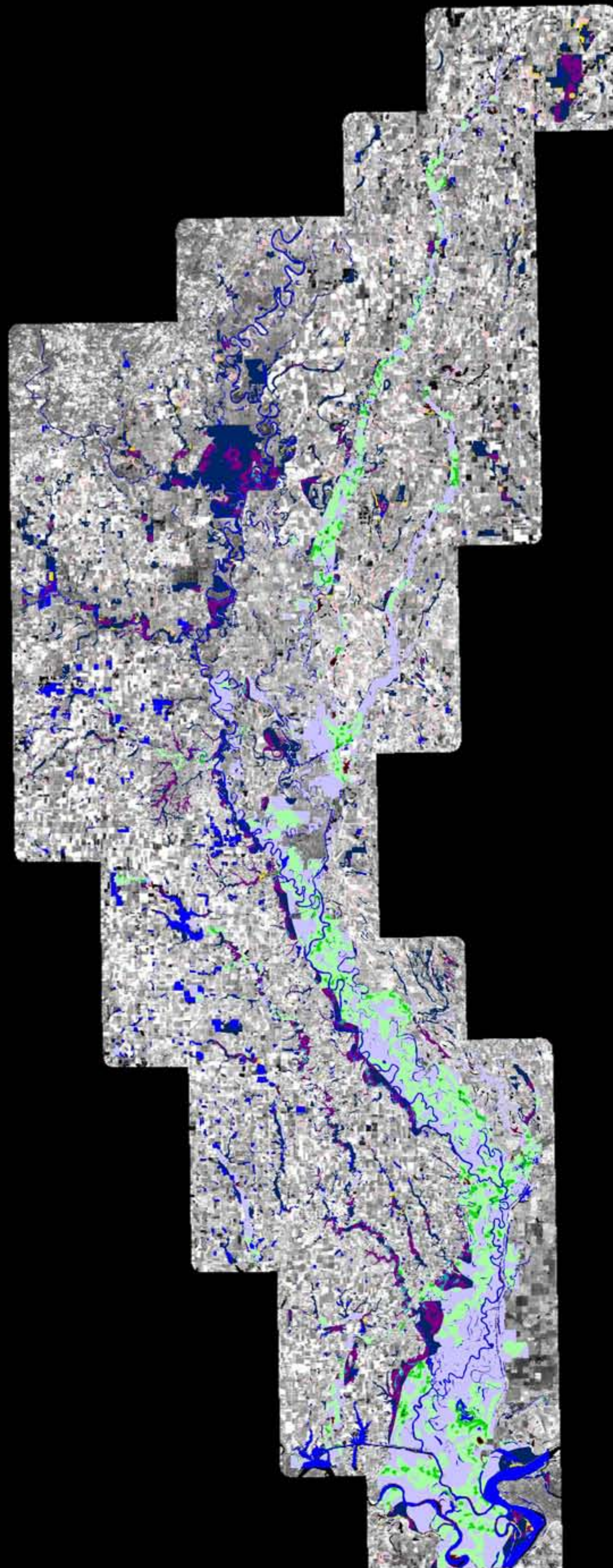


Figure 21l.

Black Bear Wetland Habitat Suitability - Wetlands > 2 hectares
- Woody wetland with 4 tree species present prior to 1950's
- Woody wetland with 3 tree species present prior to 1950's
- Woody wetland with 2 tree species present prior to 1950's
- Woody wetland with 1 tree species present prior to 1950's
- Woody wetland with 4 tree species present after 1950's
- Woody wetland with 3 tree species present after 1950's
- Woody wetland with 2 tree species present after 1950's
- Woody wetland with 1 tree species present after 1950's
- Non-woody wetland with 4 plant species present, non-forested in the 1950's
- Non-woody wetland with 3 plant species present, non-forested in the 1950's
- Non-woody wetland with 2 plant species present, non-forested in the 1950's
- Non-woody wetland with 1 plant species present, non-forested in the 1950's
- Non-woody wetland with 0 plant species present, non-forested in the 1950's
- Non-woody wetland with 4 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 3 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 2 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 1 plant species present, forested in the 1950's (i.e., disturbed)
- Non-woody wetland with 0 plant species present, forested in the 1950's (i.e., disturbed)
- Open Water

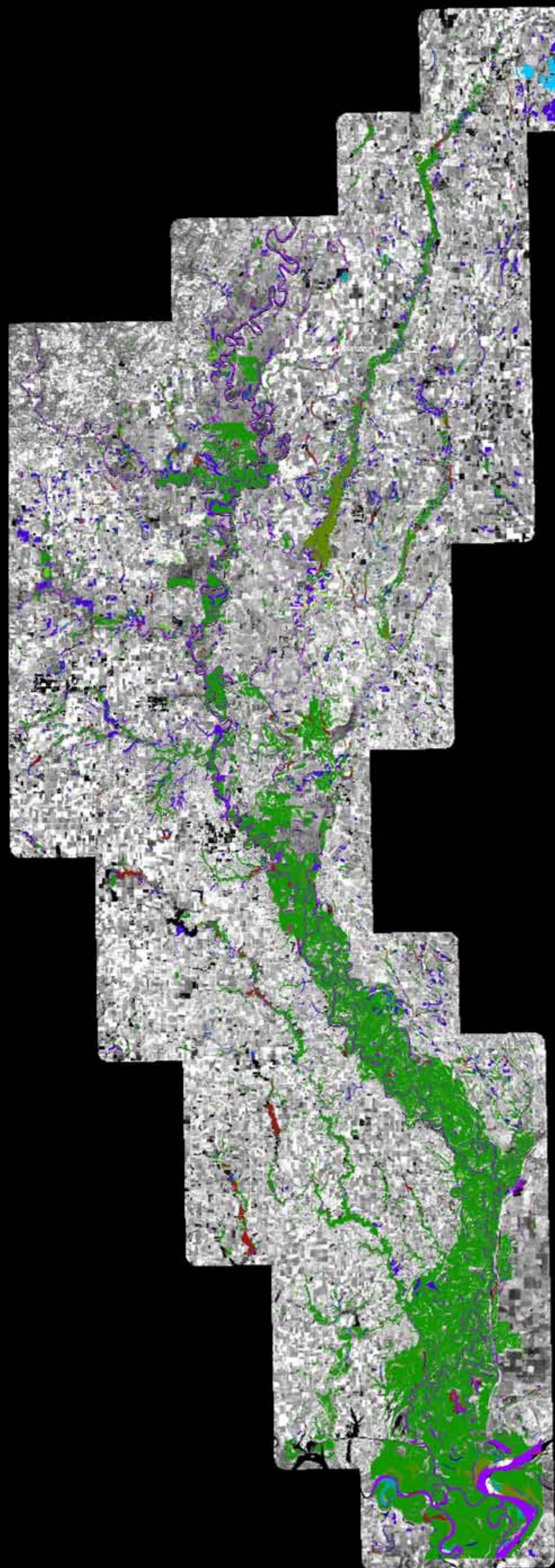


Figure 21m.

Wetland Plant Habitat Suitability (Wetlands Only), > 2 hectares

- [L] Lacustrine, [2] Littoral, [AB] Aquatic Bed, [3] Rooted Vascular, [F] Semipermanently Flooded
- [L] Lacustrine, [2] Littoral, [AB] Aquatic Bed, [3] Rooted Vascular, [H] Permanently Flooded
- [L] Lacustrine, [2] Littoral, [UB] Unconsolidated Bottom, [H] Permanently Flooded
- [P] Palustrine, [AB] Aquatic Bed, [3] Rooted Vascular, [H] Permanently Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [A] Temporarily Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [C] Seasonally Flooded
- [P] Palustrine, [EM] Emergent, [1] Persistent, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [FO] Forested, [1] Broad-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [2] Needle-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [FO] Forested, [2] Needle-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [FO] Forested, [6] Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [FO] Forested, [6] Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [A] Temporarily Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [C] Seasonally Flooded
- [P] Palustrine, [SS] Scrub-Shrub, [1] Broad-Leaved Deciduous, [F] Semipermanently Flooded
- [P] Palustrine, [UB] Unconsolidated Bottom
- [P] Palustrine, [US] Unconsolidated Shore, [C] Seasonally Flooded
- [R] Riverine, [2] Lower Perennial, [UB] Unconsolidated Bottom, [H] Permanently Flooded
- [R] Riverine, [2] Lower Perennial, [US] Unconsolidated Shore, [A] Temporarily Flooded
- [R] Riverine, [2] Lower Perennial, [US] Unconsolidated Shore, [C] Seasonally Flooded

Lower White River Region Wetland Habitat Vulnerability Models (Patch Size and Patch Shape)

Figure 22a. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total area.
Figure 22b. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total area.
Figure 22c. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total area.

Figure 22d. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total perimeter length.
Figure 22e. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total perimeter length.
Figure 22f. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total perimeter length.

Figure 22g. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch interior-to-edge ratio.
Figure 22h. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch interior-to-edge ratio.
Figure 22i. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch interior-to-edge ratio.

Figure 22j. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch circularity index.
Figure 22k. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch circularity index.
Figure 22l. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch circularity index.

Figure 22m. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch sinuosity index.
Figure 22n. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch sinuosity index.
Figure 22o. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch sinuosity index.

Figure 22p. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch unified patch index.
Figure 22q. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch unified patch index.
Figure 22r. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch unified patch index.

Lower White River Region Wetland Habitat Vulnerability Models (Total Area)

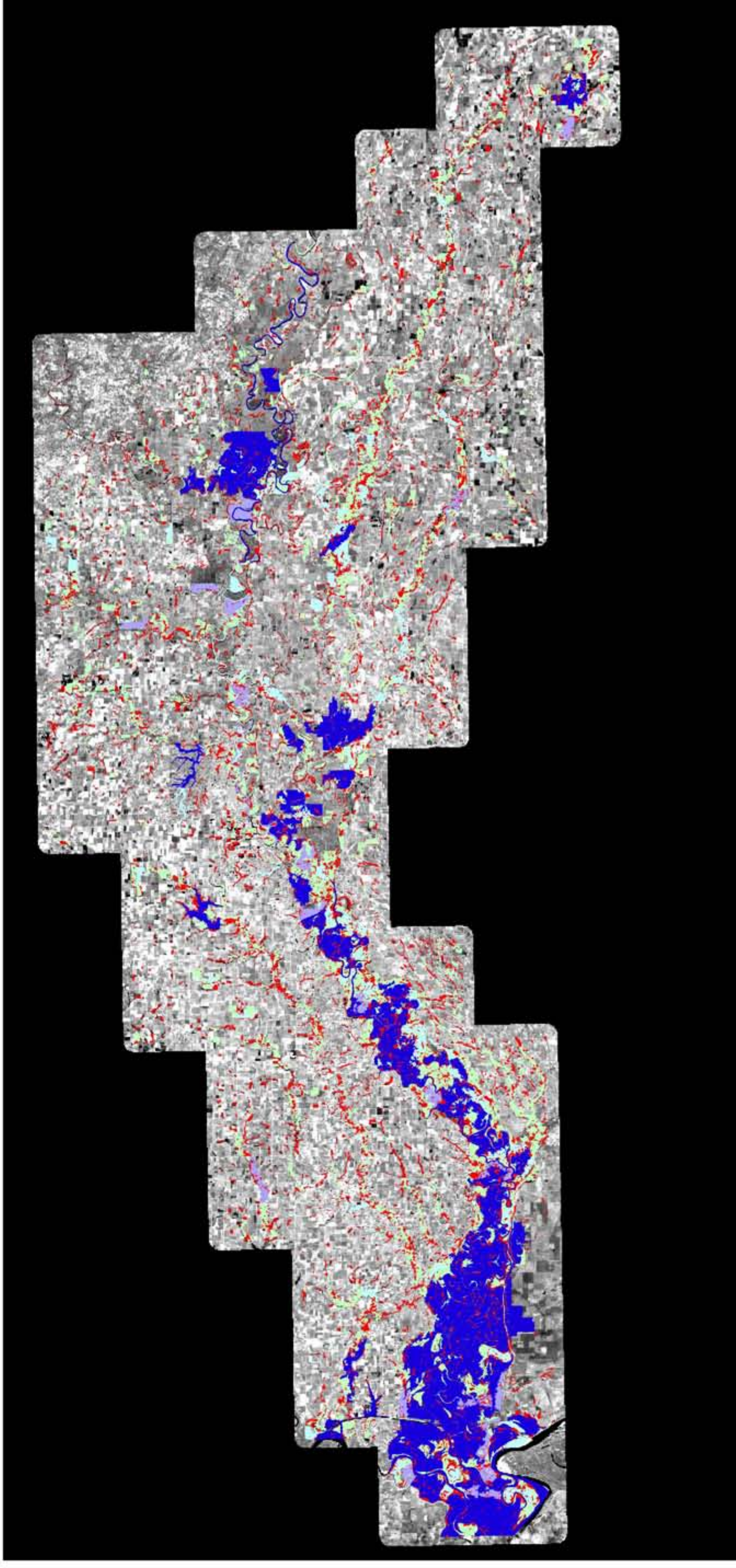


Figure 22a.

Mallard Winter Habitat - Total Area, patches > 2 hectares

-1 - 0 Std. Dev. (Greatest Vulnerability)

Mean

0 - 1 Std. Dev.

1 - 2 Std. Dev.

2 - 3 Std. Dev.

> 3 Std. Dev. (Least Vulnerability)

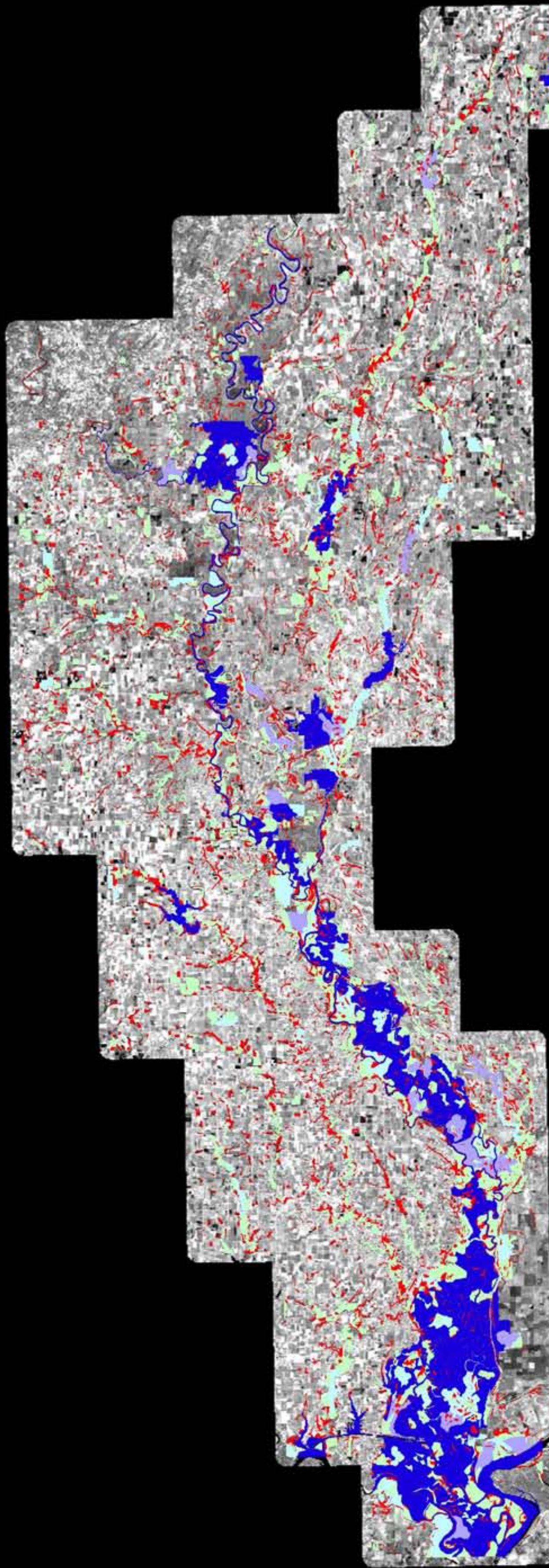


Figure 22b.

Black Bear Wetland Habitat - Total Area, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

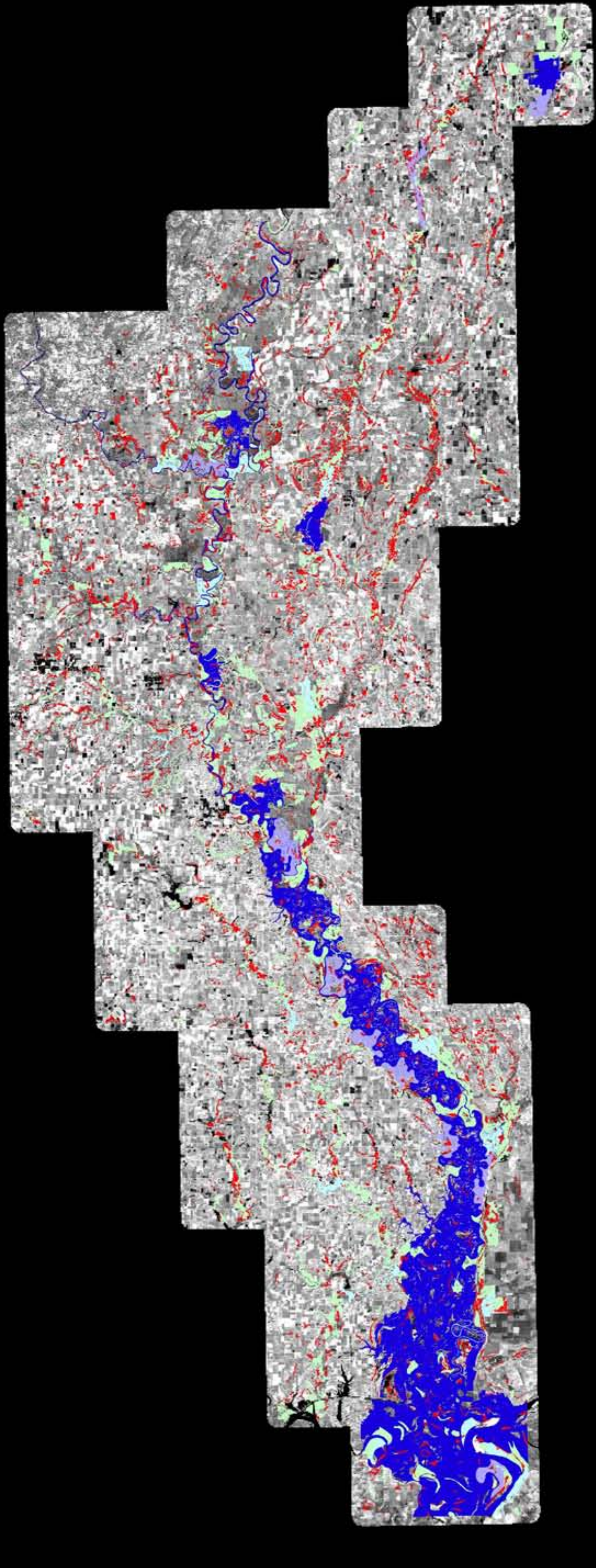


Figure 22c.

Wetland Plant Habitat - Total Area, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Total Perimeter)

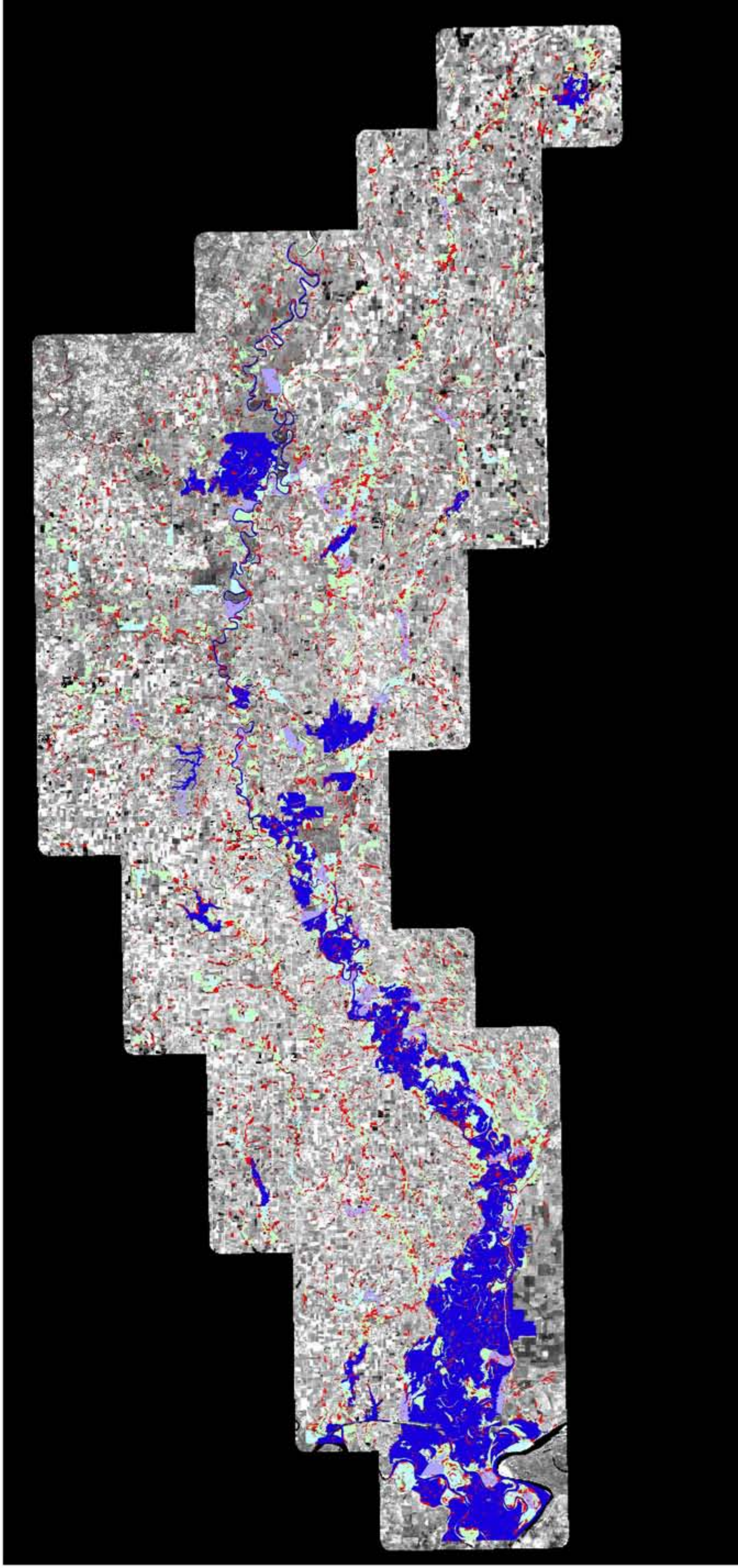


Figure 22d.

Mallard Winter Habitat - Total Perimeter Length, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

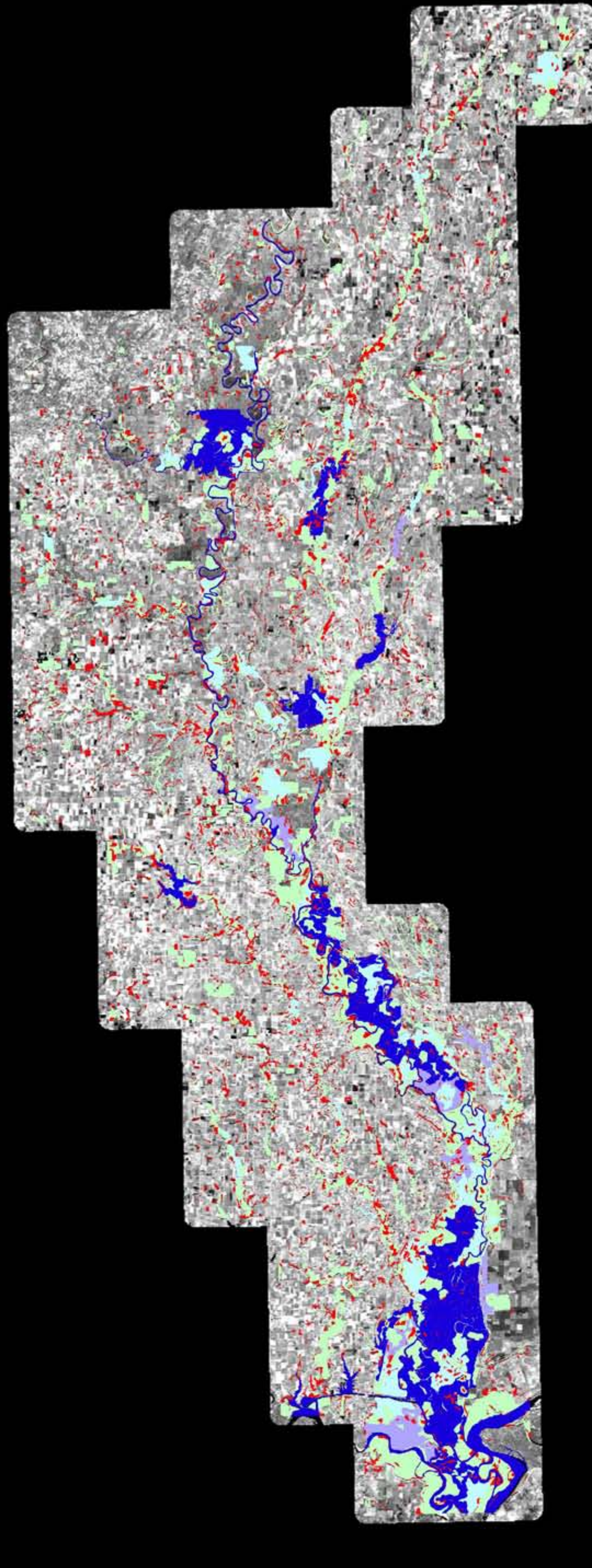


Figure 22e.

Black Bear Wetland Habitat - Total Perimeter Length, patches > 2 hectares
- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

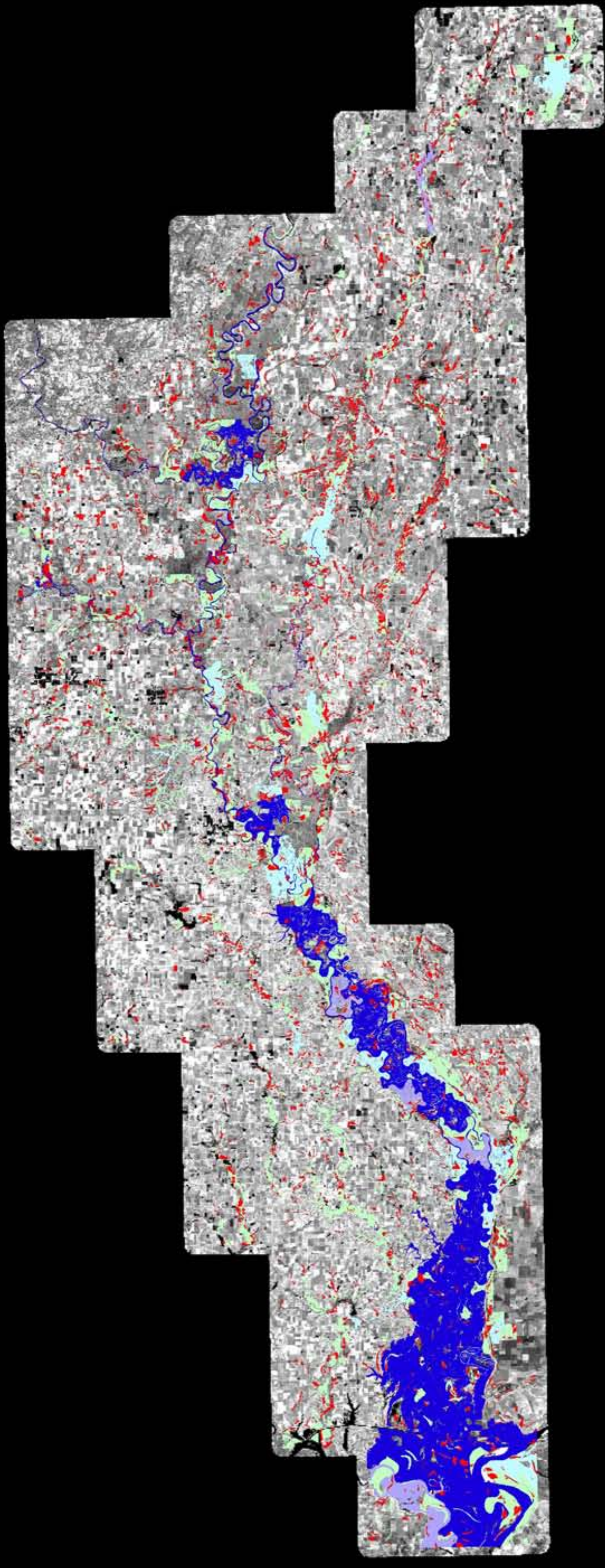


Figure 22f.

Wetland Plant Habitat - Total Perimeter, patches > 2 hectares
- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Interior-to-Edge Ratio)

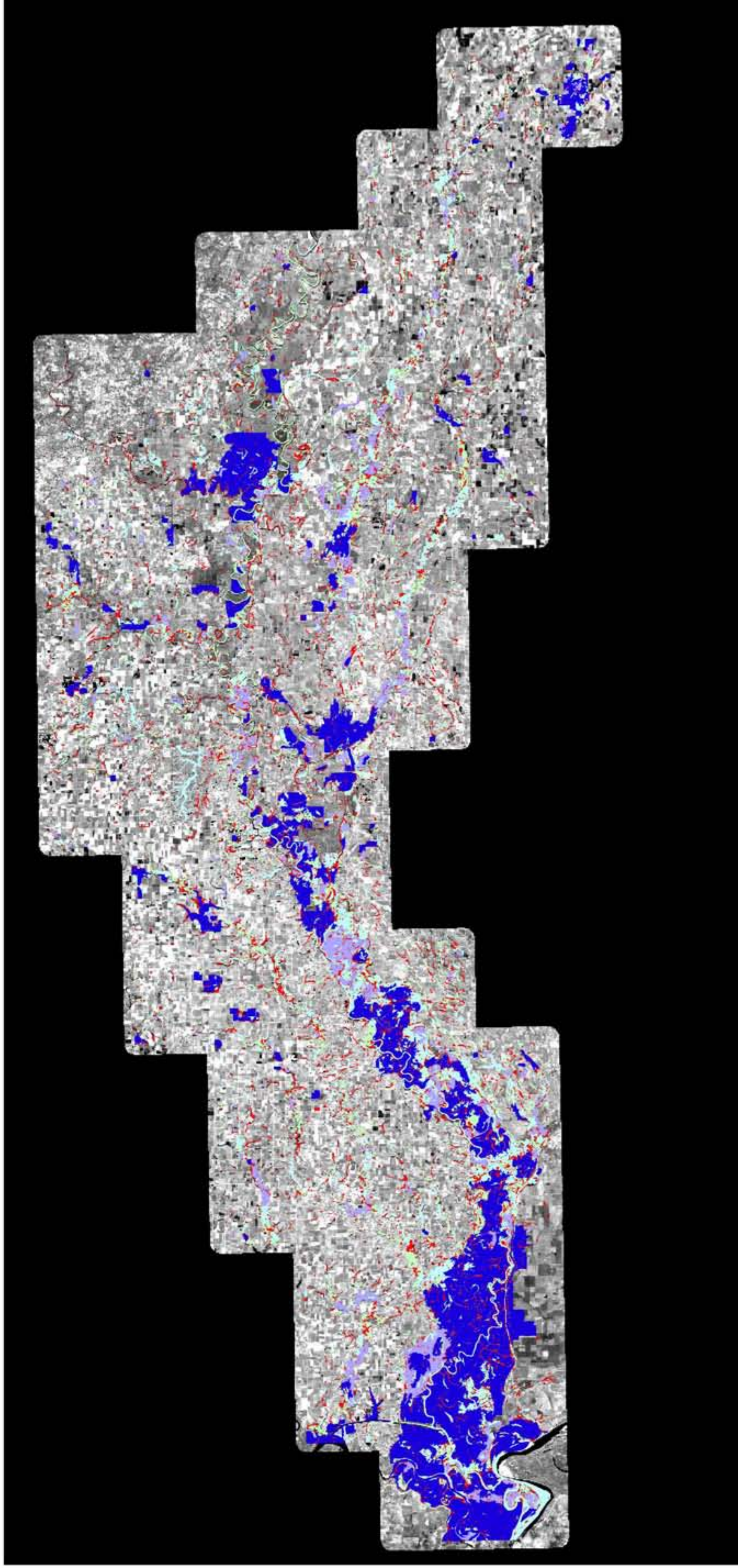


Figure 22g.

Mallard Winter Habitat - Interior to Edge Ratio, patches > 2 hectares

- -2 - -1 Std. Dev. (Greatest Vulnerability)
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

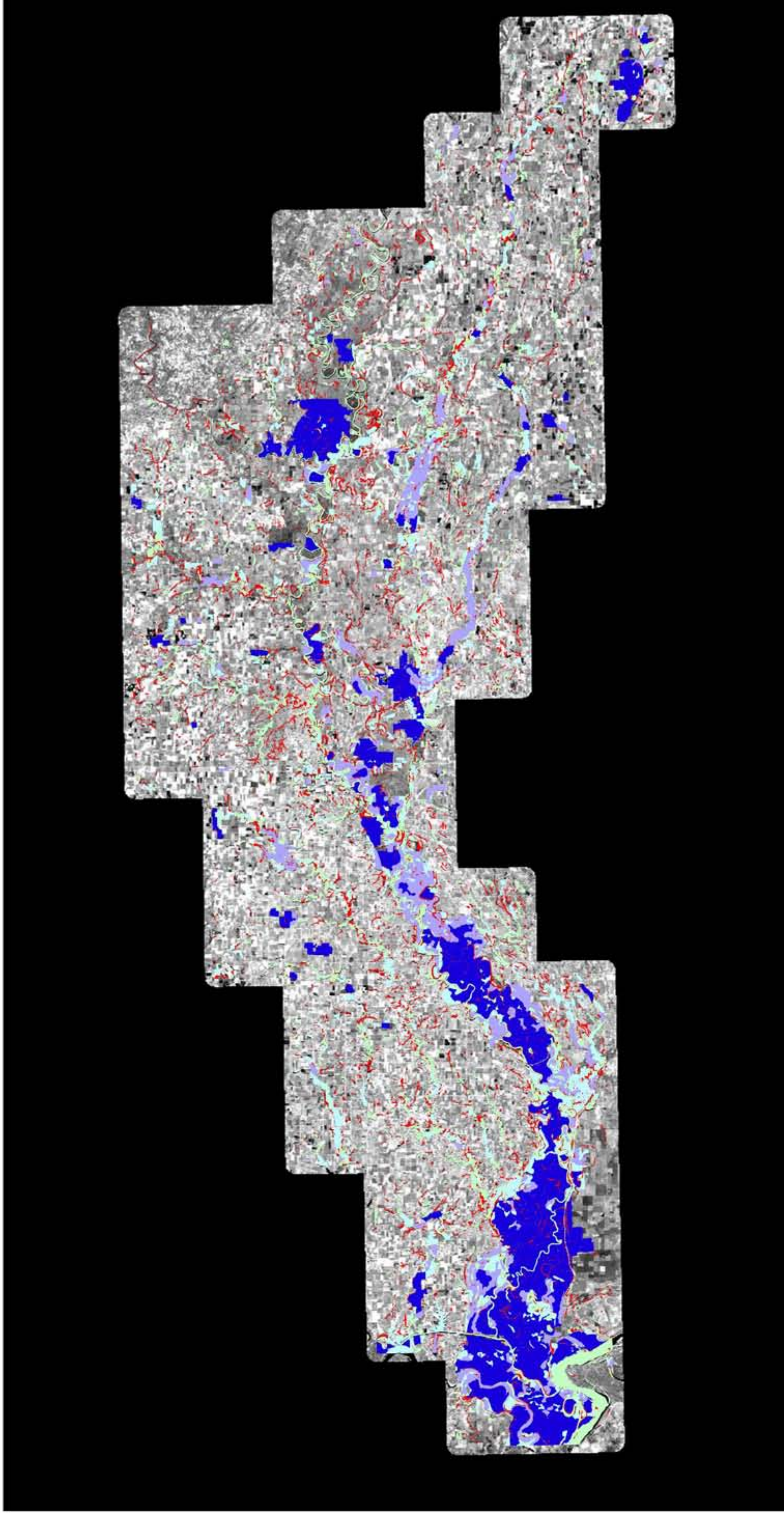


Figure 22h.

Black Bear Wetland Habitat - Interior to Edge Ratio, patches > 2 hectares
- -2 - -1 Std. Dev. (Greatest Vulnerability)
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

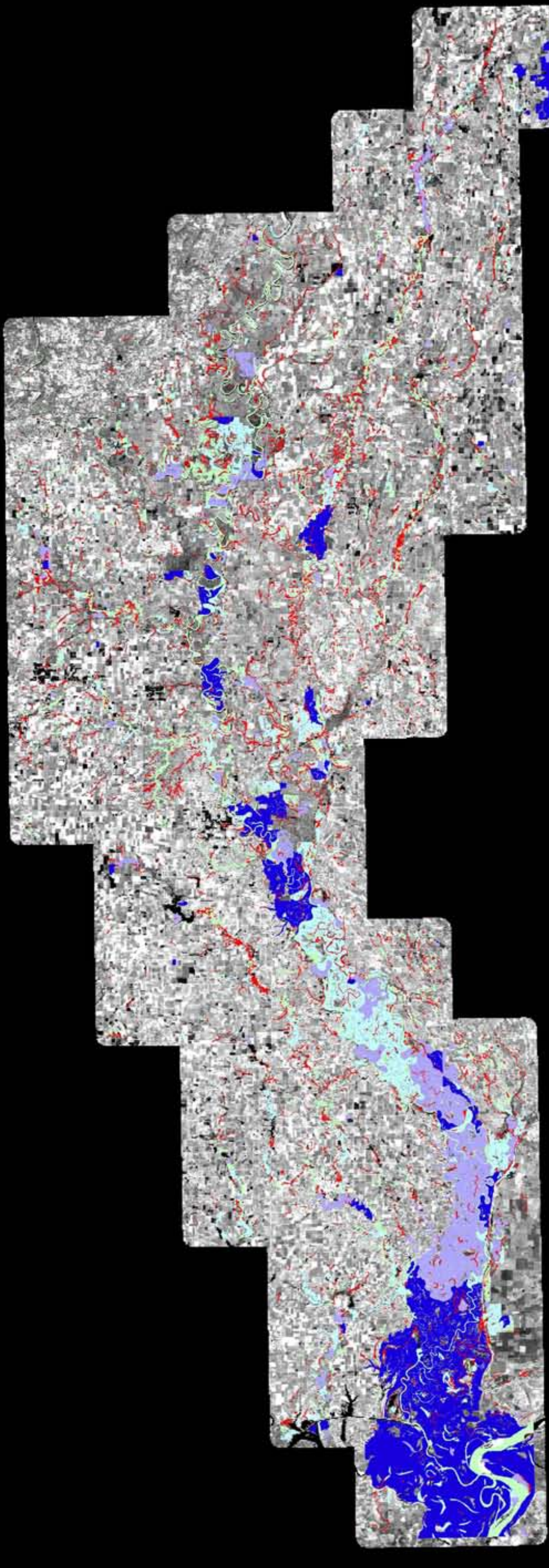


Figure 22i.

Wetland Plant Habitat -Interior to Edge Ratio, patches > 2 hectares

- -2 - -1 Std. Dev. (Greatest Vulnerability)
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Circularity Index)

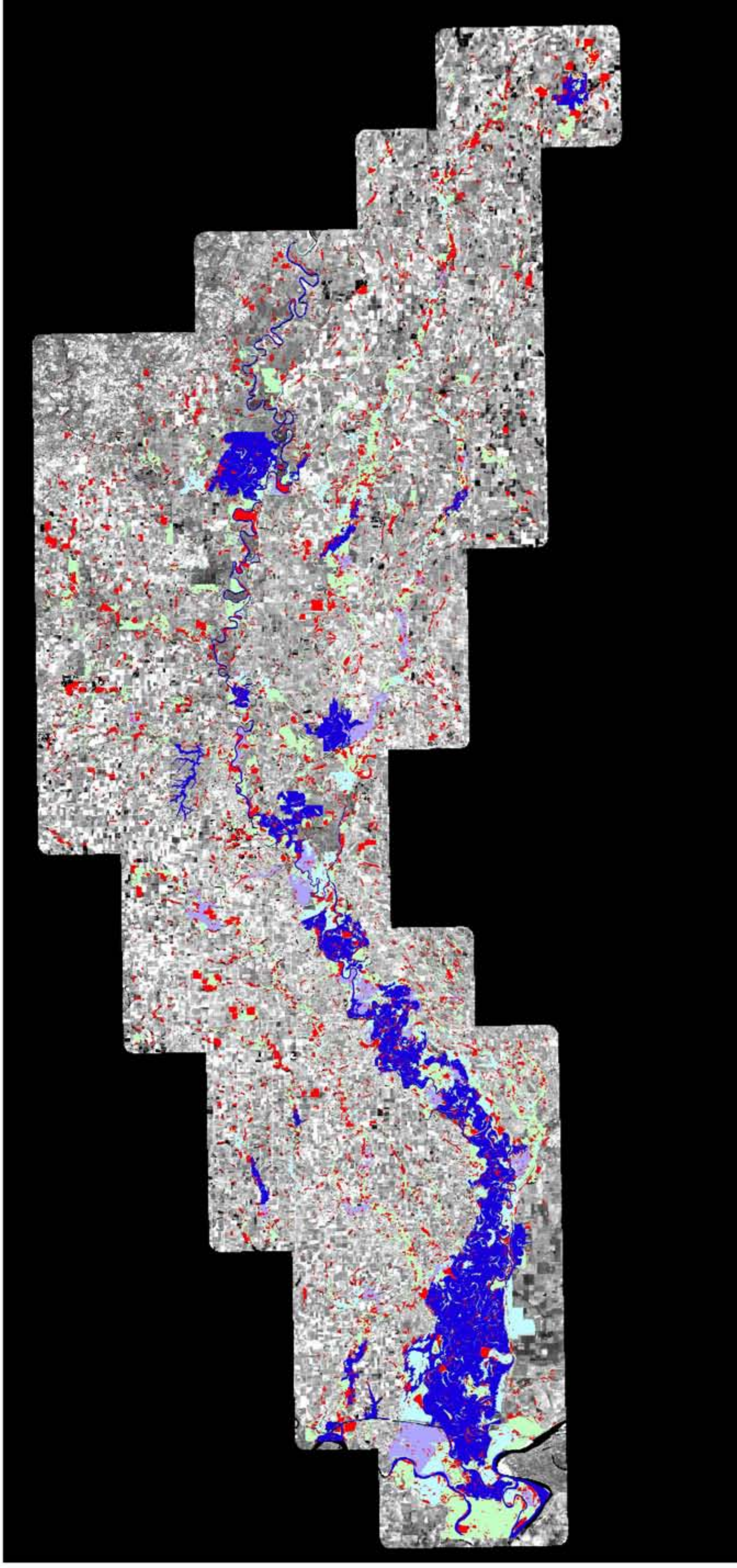


Figure 22j.

Mallard Winter Habitat - Circularity Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

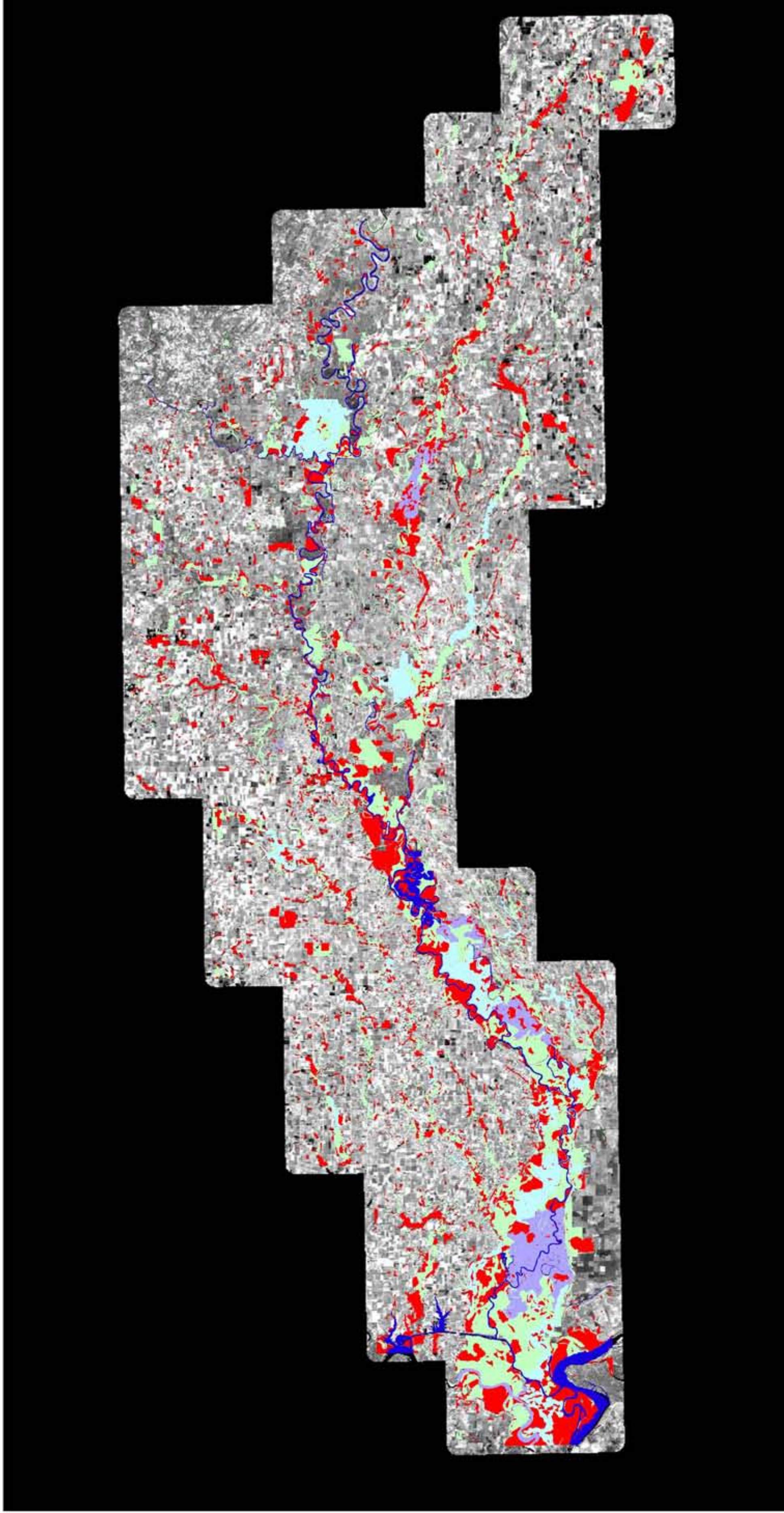


Figure 22k.

Black Bear Wetland Habitat - Circularity Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

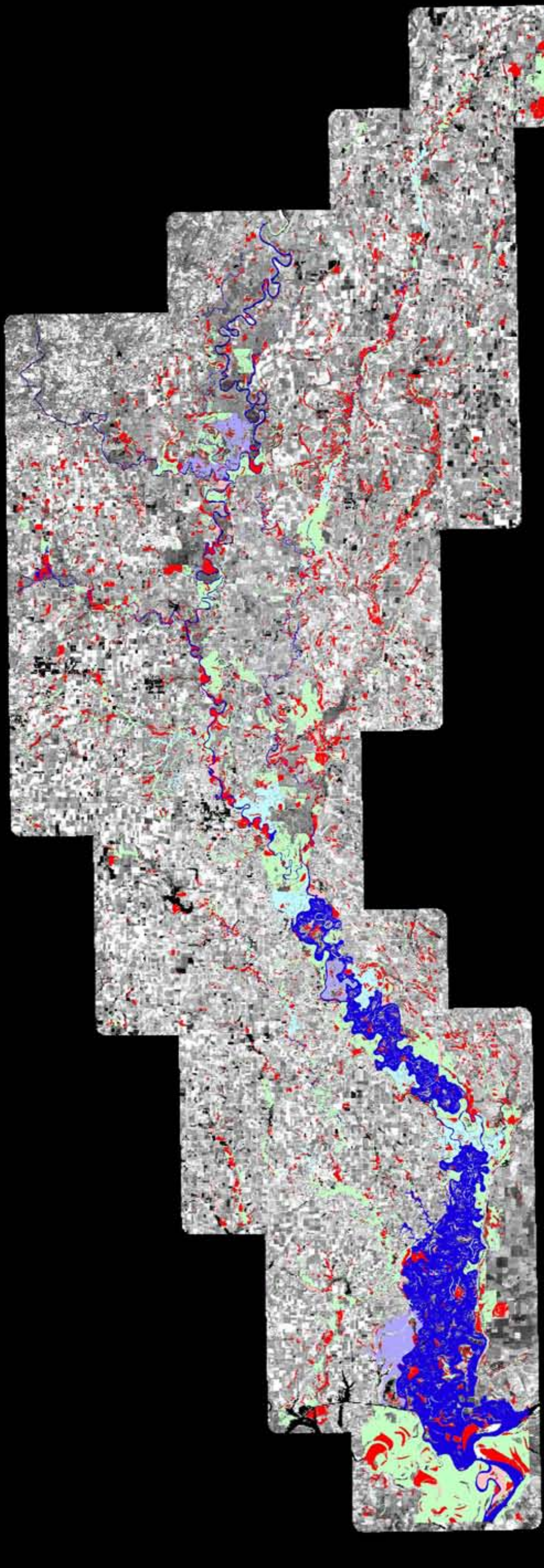


Figure 22l.

Wetland Plant Habitat - Circularity Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Sinuosity Index)

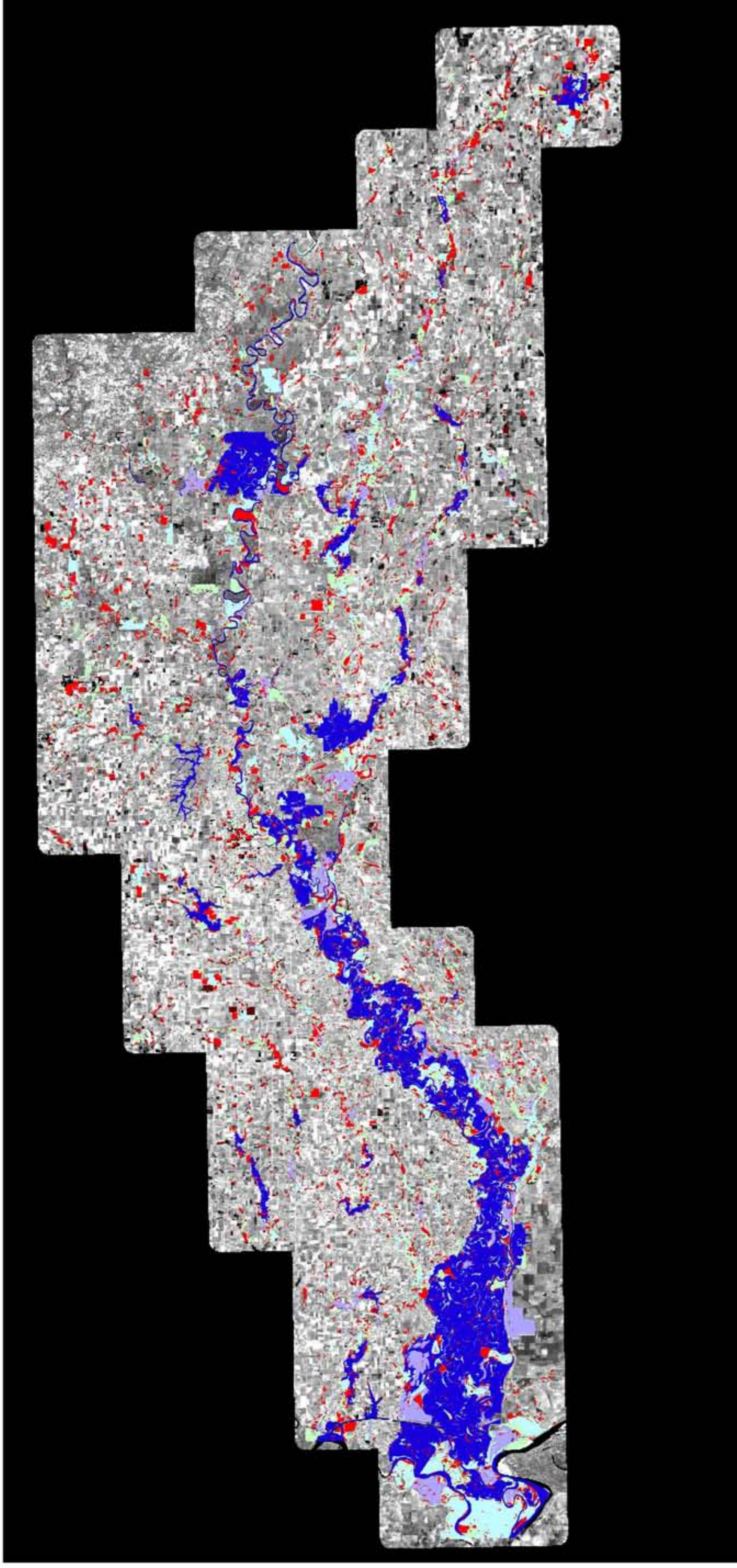


Figure 22m.

Mallard Winter Habitat - Sinuosity Index, patches > 2 hectares

- -2 - -1 Std. Dev. (Greatest Vulnerability)
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

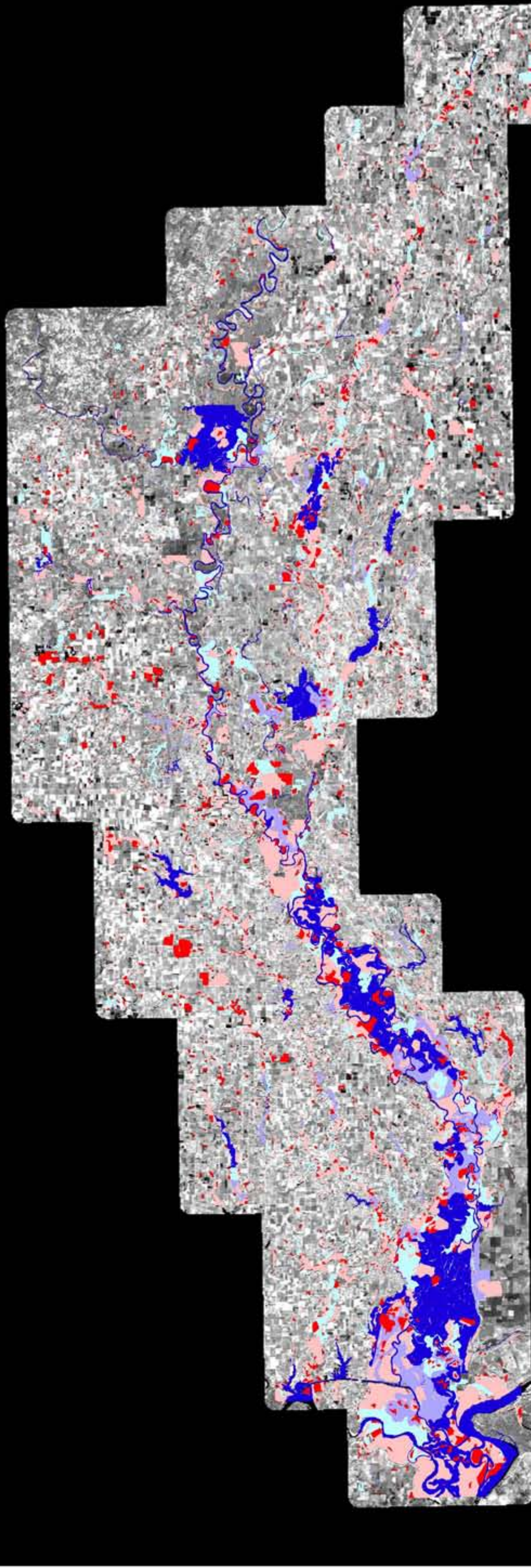


Figure 22n.

Black Bear Wetland Habitat - Sinuosity Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

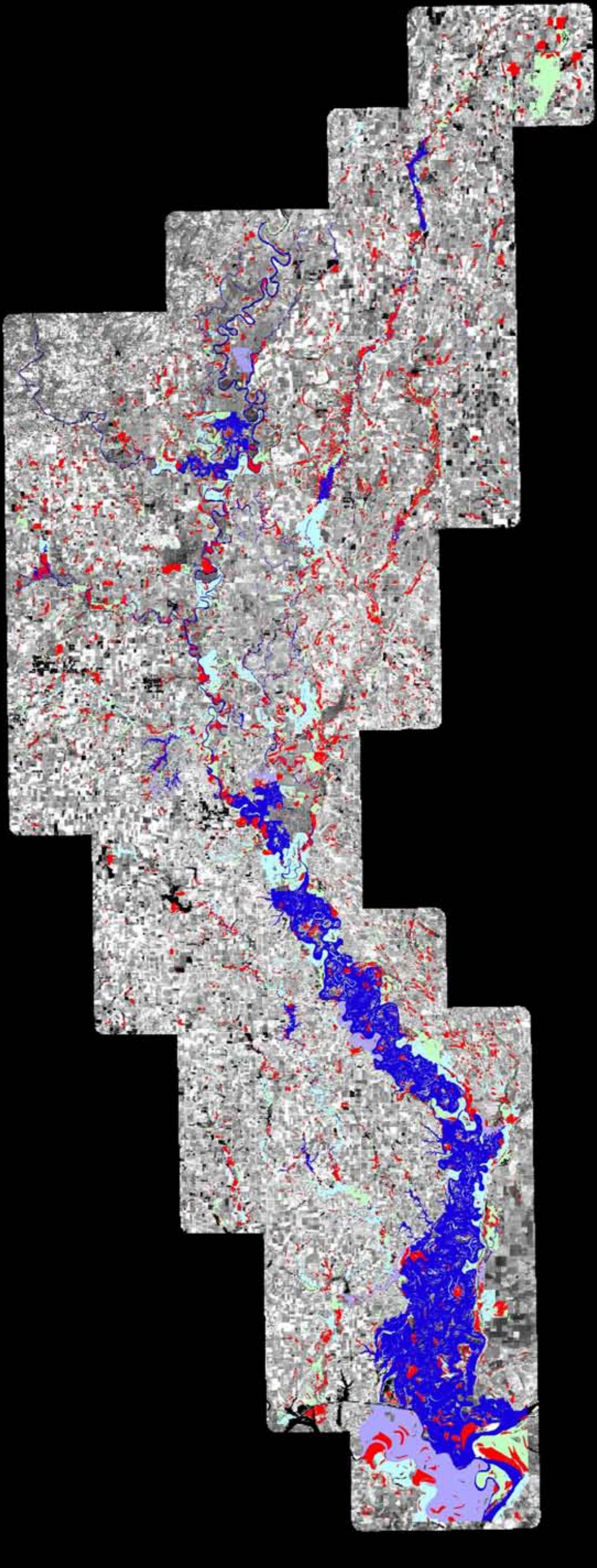


Figure 22o.

Wetland Plant Habitat - Sinuosity Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Unified Patch Index)

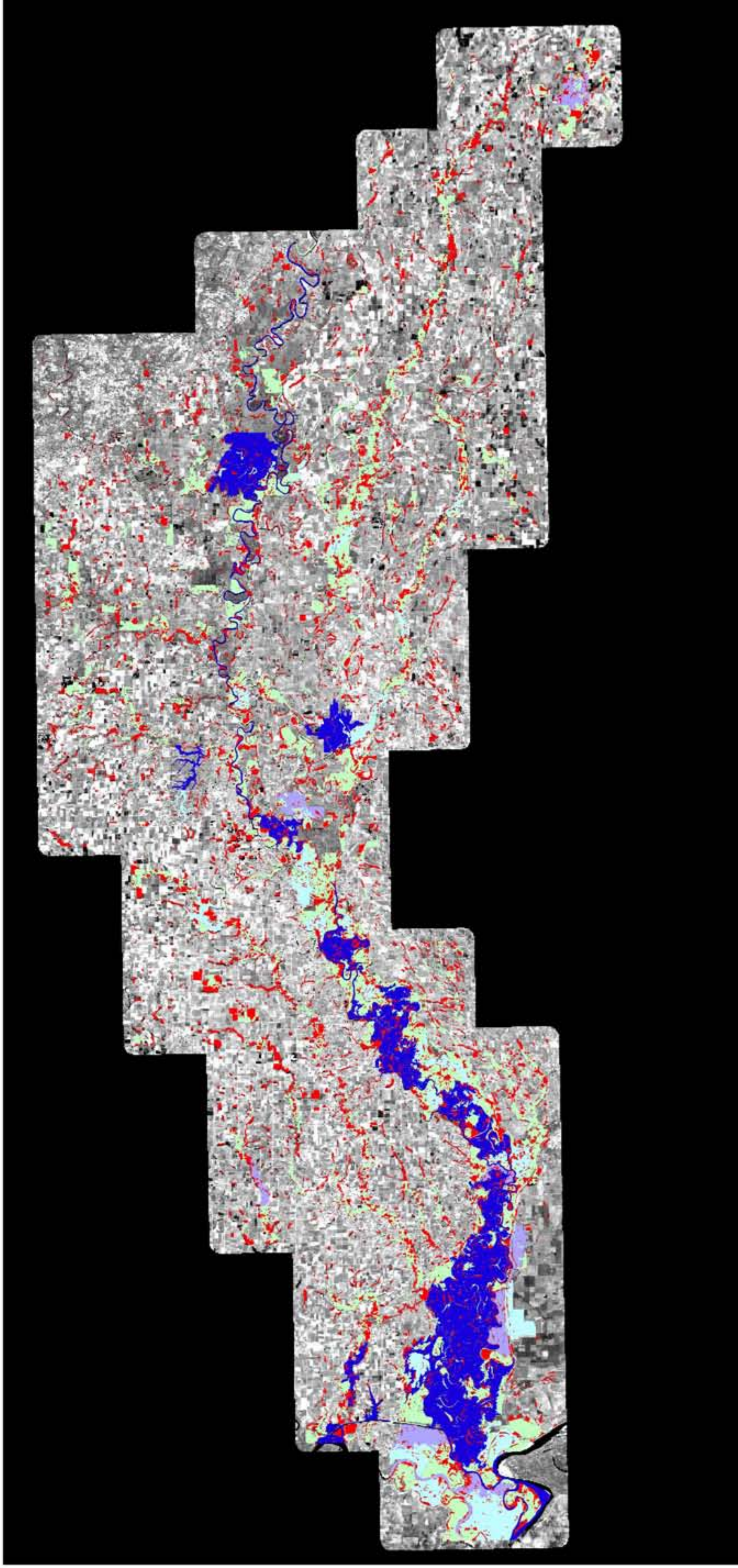


Figure 22p.

Mallard Winter Habitat - Unified Patch Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

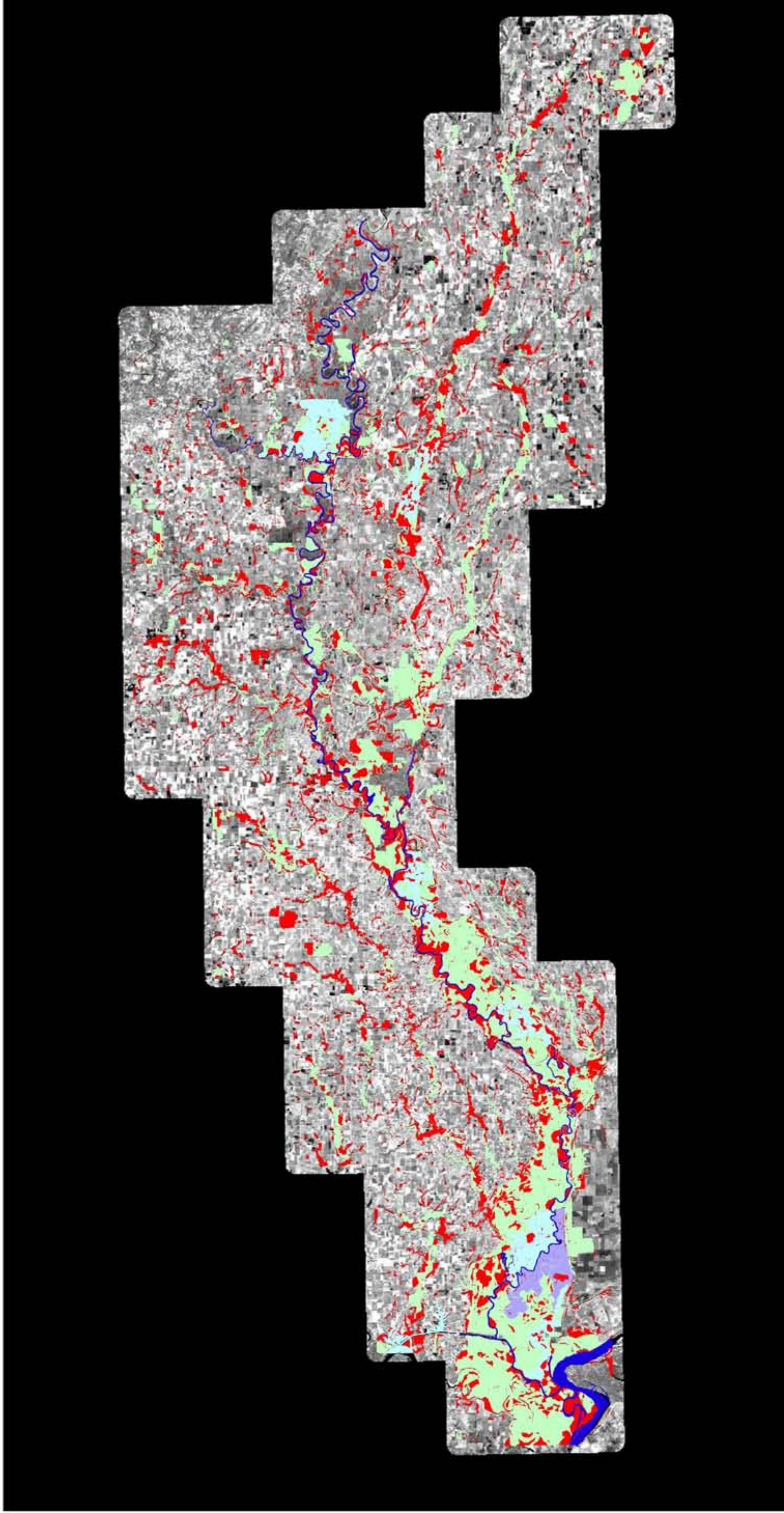


Figure 22q.

Black Bear Wetland Habitat - Unified Patch Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

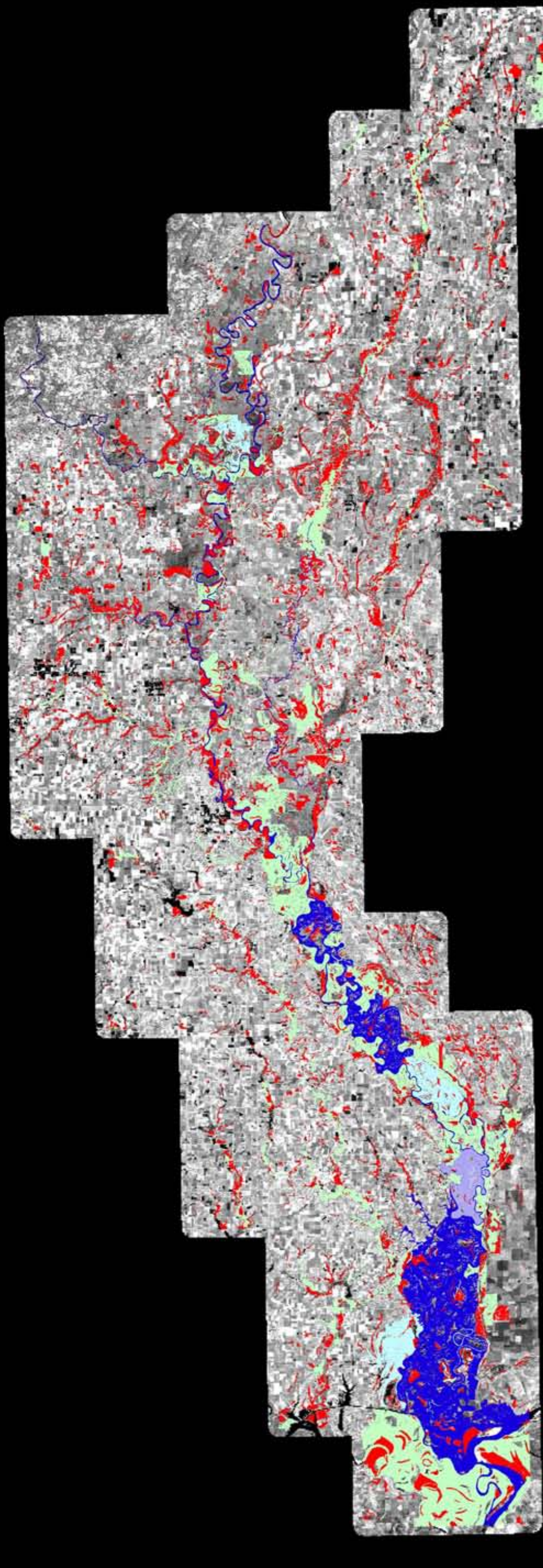


Figure 22r.

Wetland Plant Habitat - Unified Patch Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Greatest Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Patch Human-Induced Disturbance)

Figure 23a. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total road length.
Figure 23b. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total road length.
Figure 23c. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total road length.

Figure 23d. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total road density.
Figure 23e. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total road density.
Figure 23f. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total road density.

Figure 23g. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch road index.
Figure 23h. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch road index.
Figure 23i. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch road index.

Figure 23j. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch human population density in 1990.
Figure 23k. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch human population density in 1990.
Figure 23l. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch human population density in 1990.

Figure 23m. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch estimated human population density in 2011.
Figure 23n. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch estimated human population density in 2011.
Figure 23o. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch estimated human population density in 2011.

Figure 23p. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch human population density change from 1990 to 2011.
Figure 23q. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch human population density change from 1990 to 2011.
Figure 23r. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch human population density change from 1990 to 2011.

Figure 23s. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch unified human index.
Figure 23t. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch unified human index.
Figure 23u. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch unified human index.

Figure 23v. Lower White River Region (LWRR) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch unified vulnerability index.
Figure 23w. Lower White River Region (LWRR) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch unified vulnerability index.
Figure 23x. Lower White River Region (LWRR) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch unified vulnerability index.

Lower White River Region Wetland Habitat Vulnerability Models (Total Road Length)

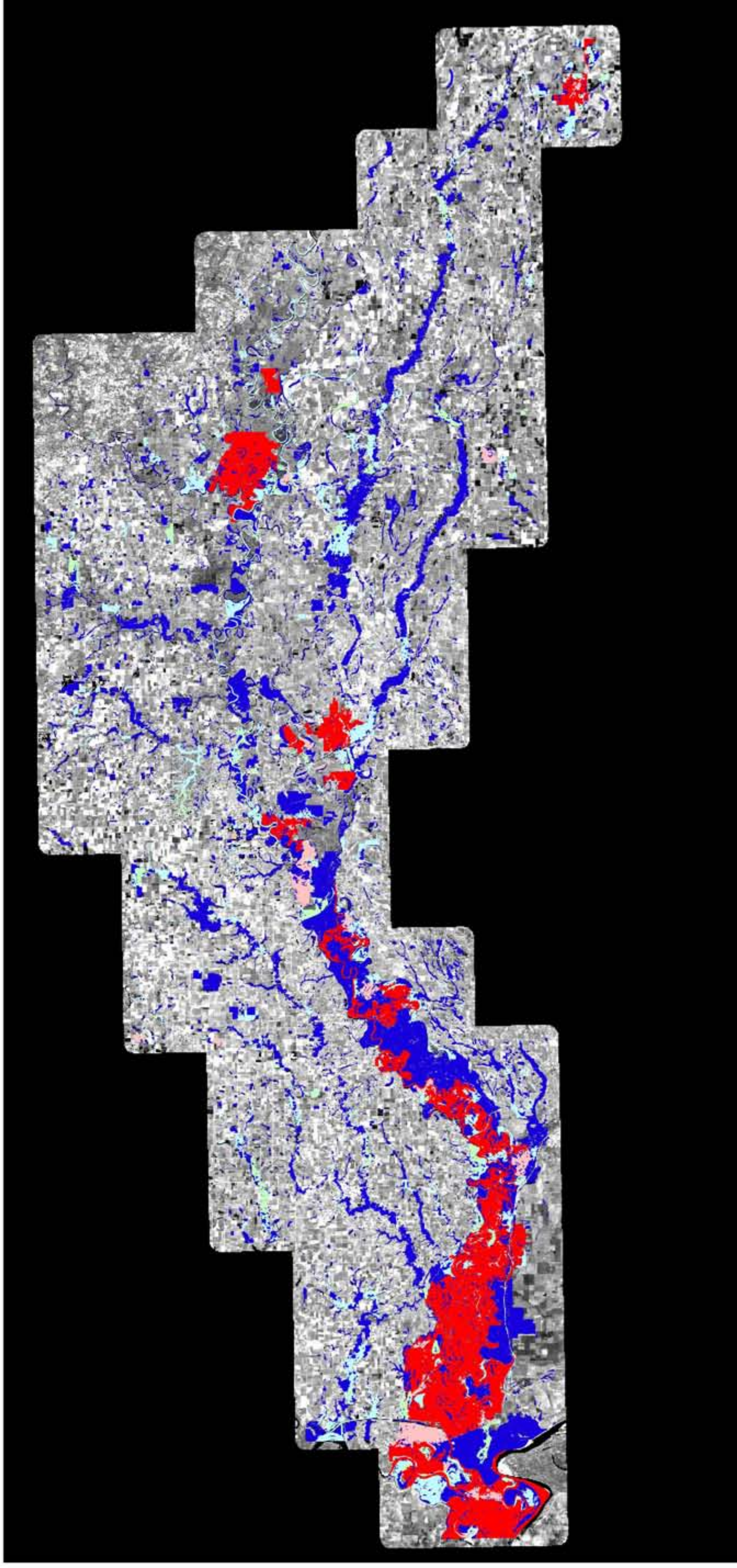


Figure 23a.

Mallard Winter Habitat - Total Road Length, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

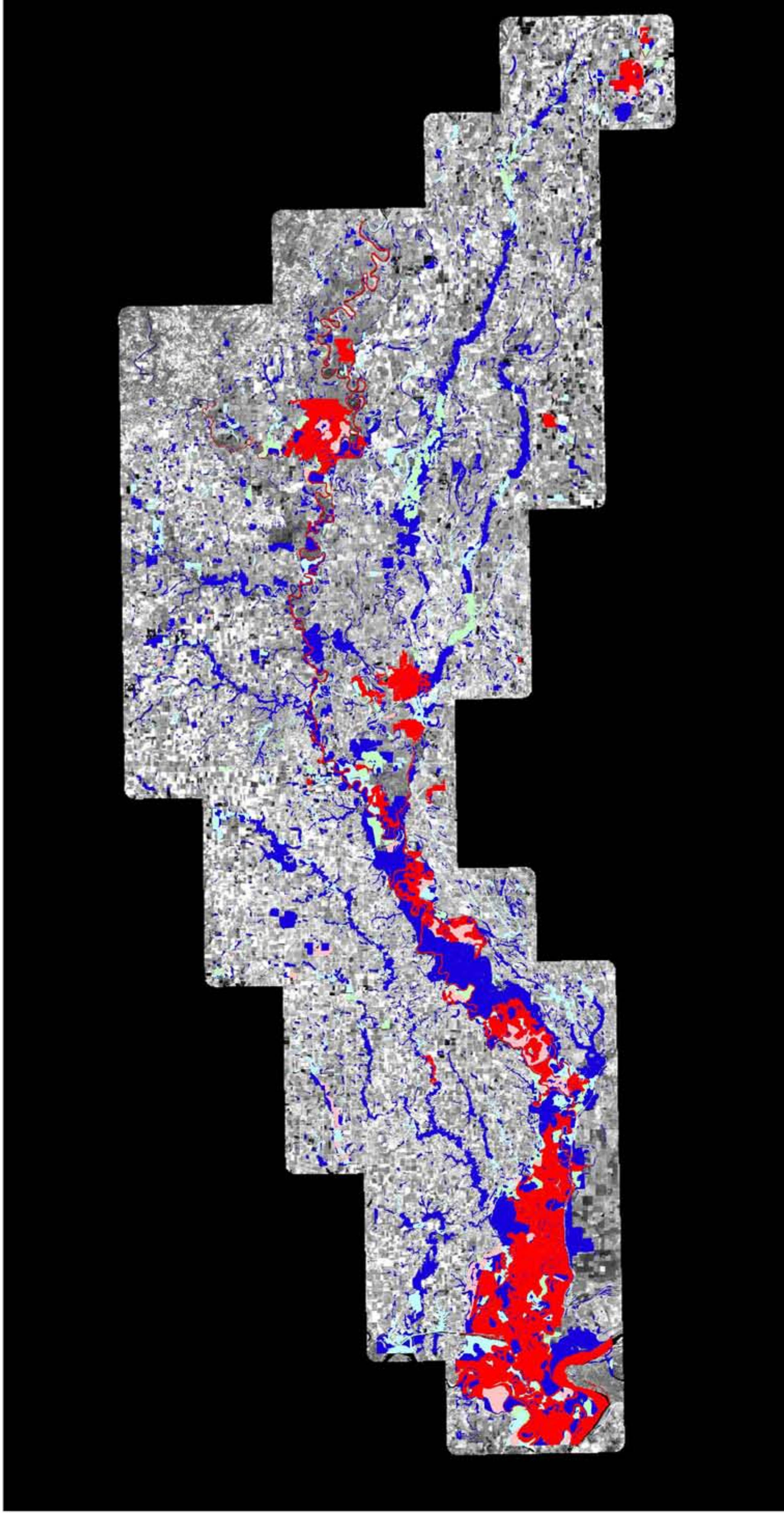


Figure 23b.

Black Bear Wetland Habitat - Total Road Length, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

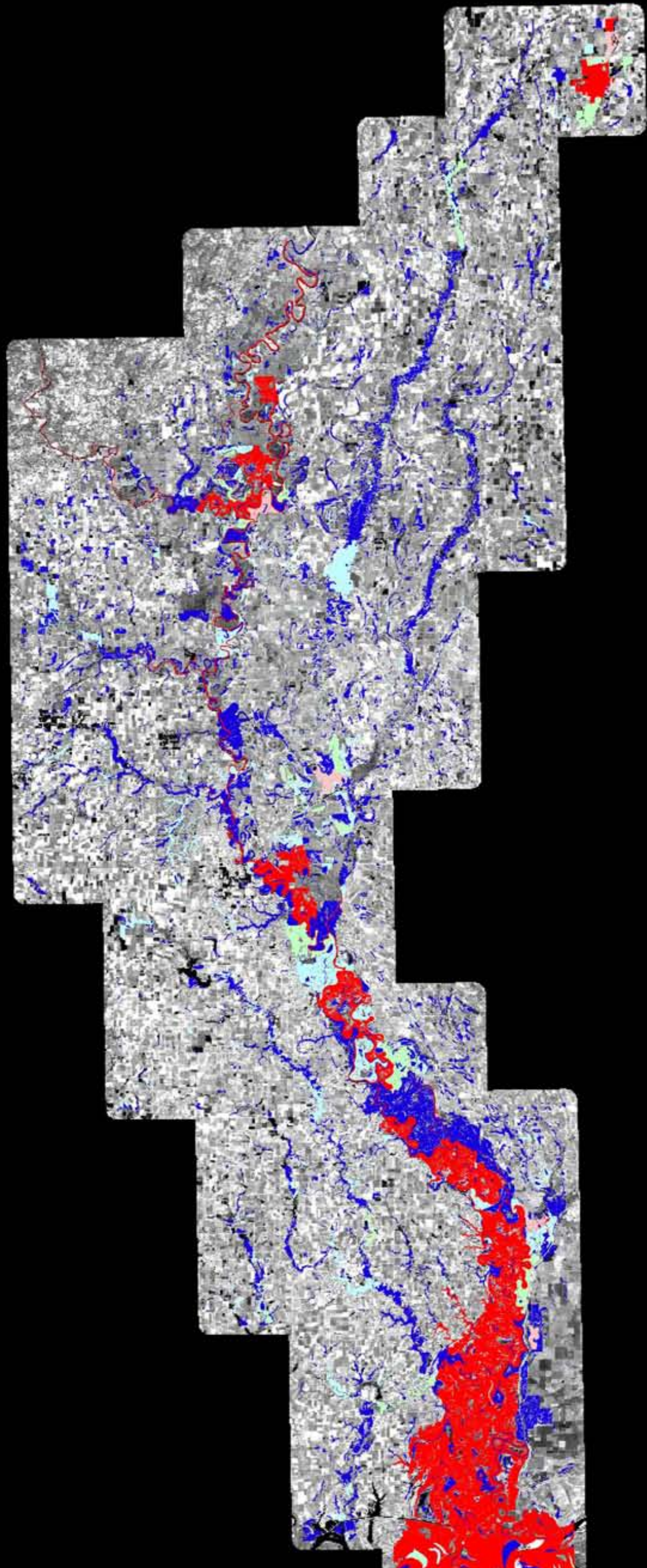


Figure 23c.

Wetland Plant Habitat - Road Length, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Total Road Density)

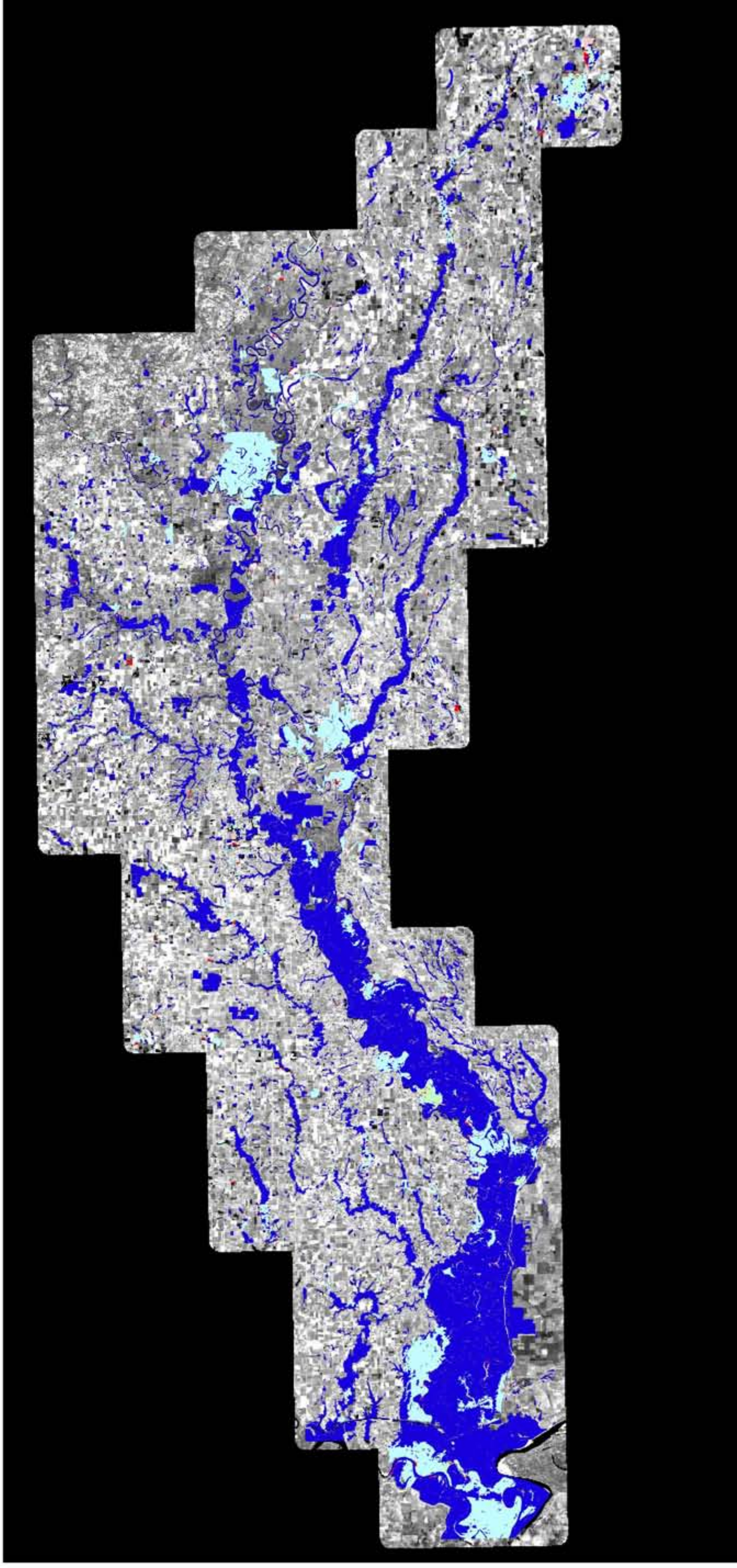


Figure 23d.

Mallard Winter Habitat - Road Density, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

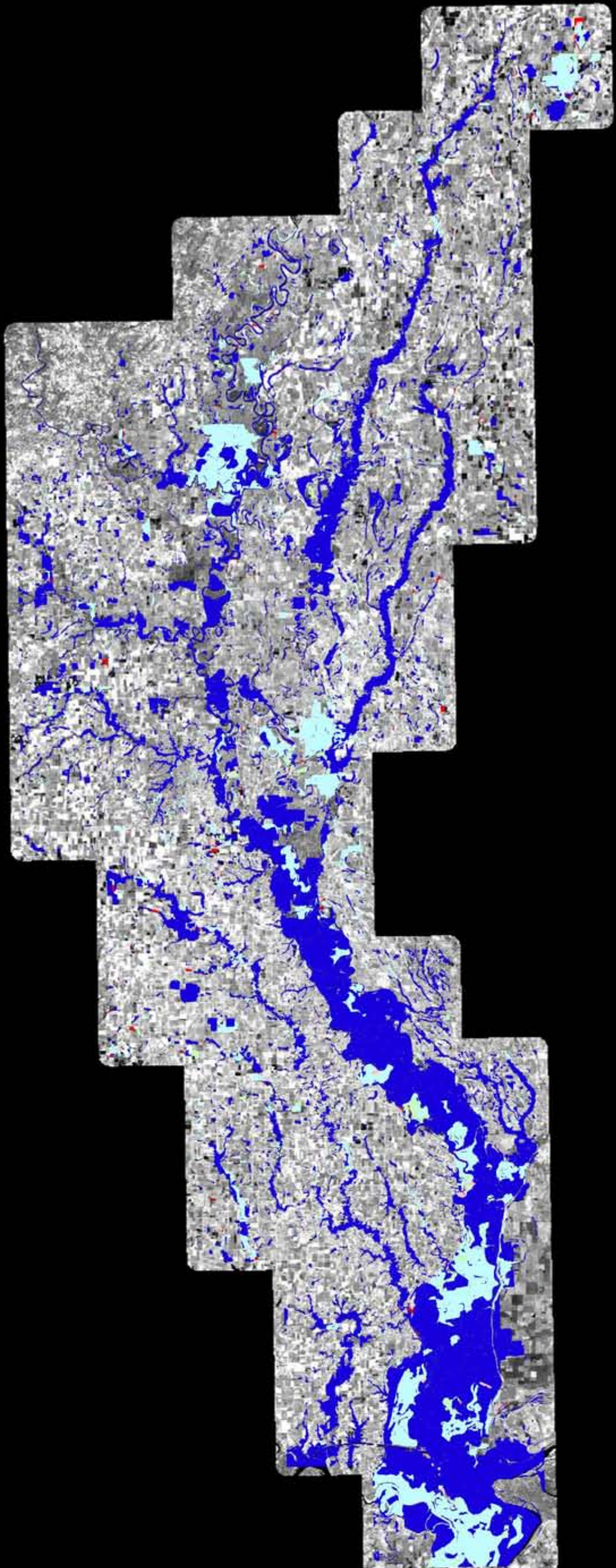


Figure 23e.

Black Bear Wetland Habitat - Road Density, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

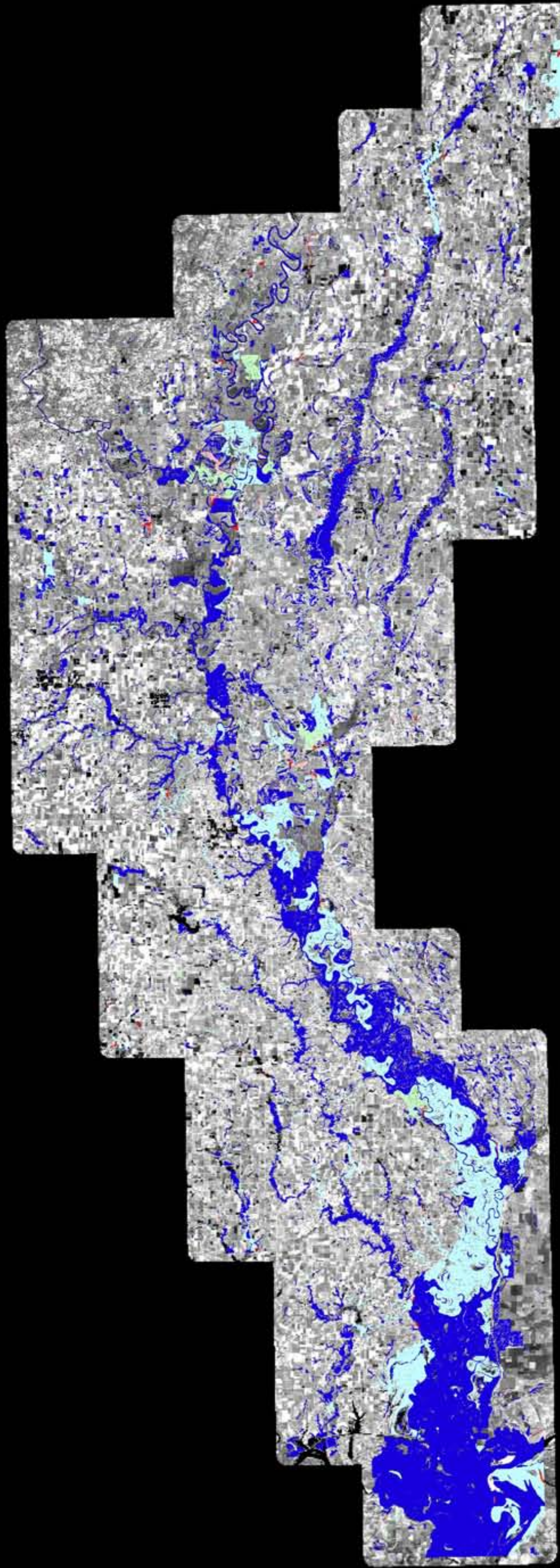


Figure 23f.

Wetland Plant Habitat - Road Density, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Road Index)

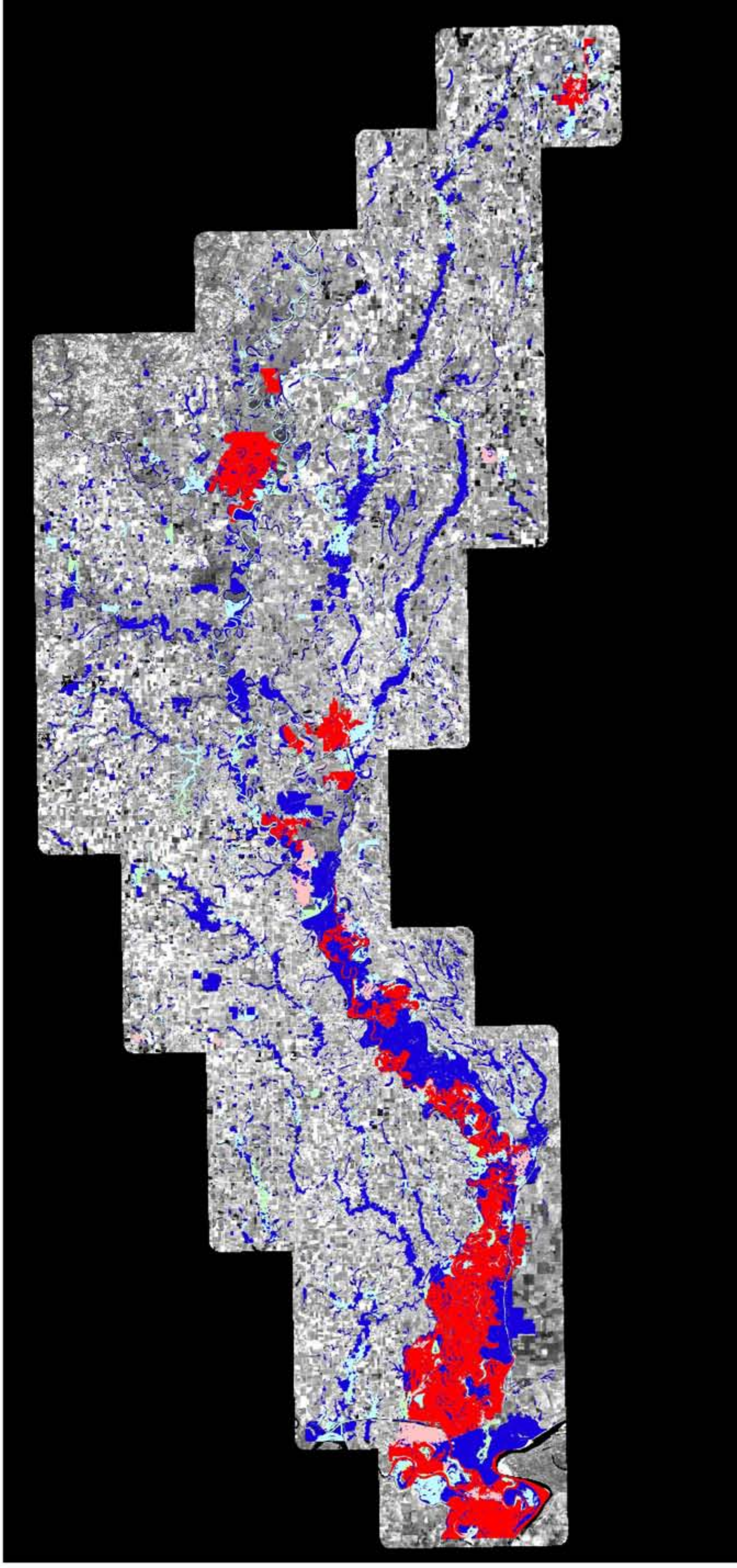


Figure 23g.

Mallard Winter Habitat - Road Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

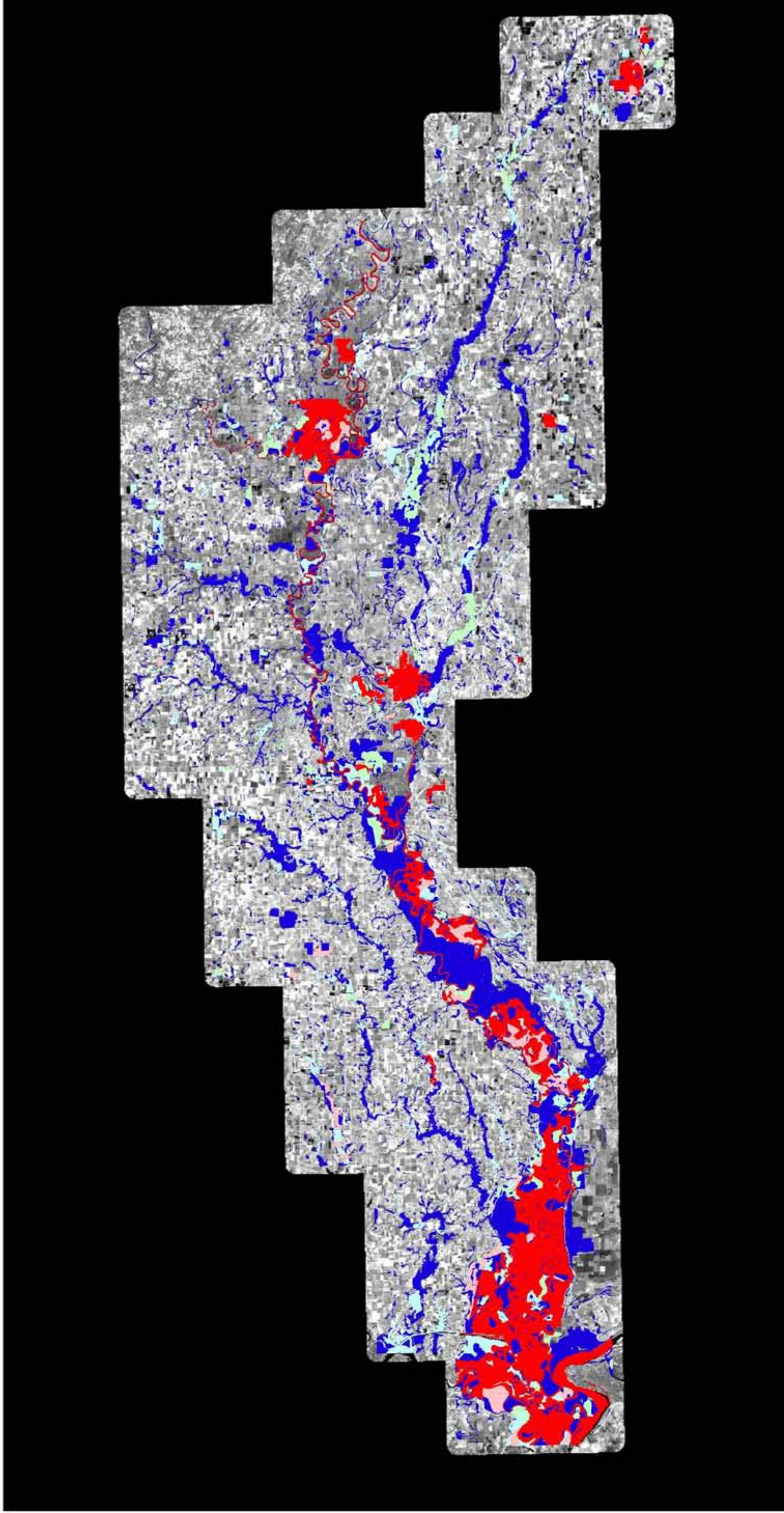


Figure 23h.

Black Bear Wetland Habitat - Road Index, patches > 2 hectares
- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

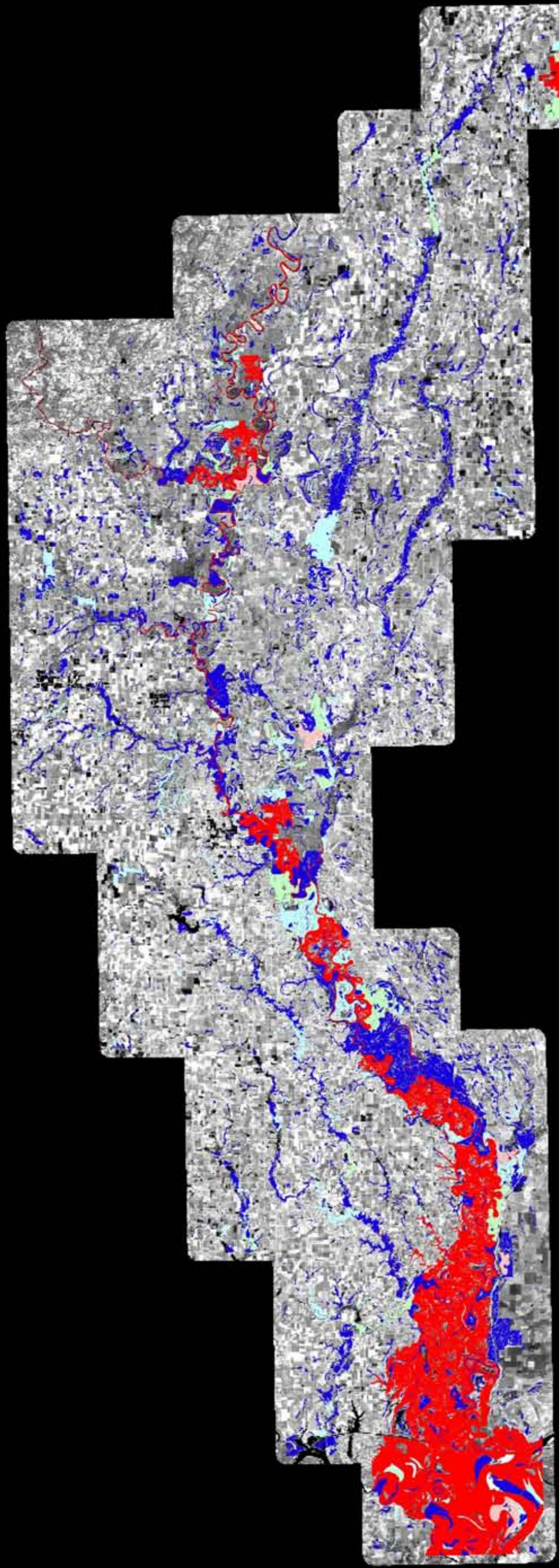


Figure 23i.

Wetland Plant Habitat - Road Index, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Human Population Density in 1990)

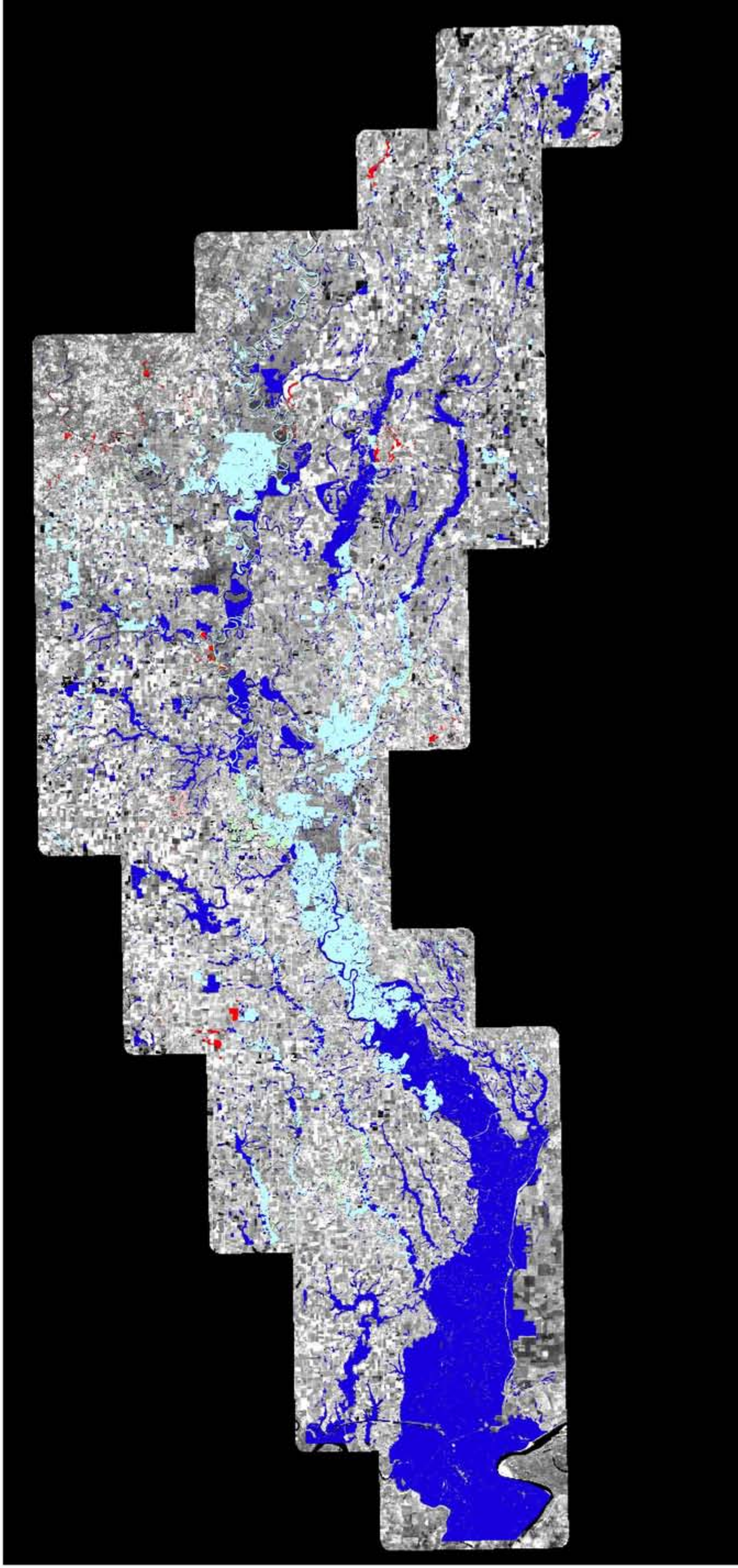


Figure 23j.

Mallard Winter Habitat - Human Population Density in 1990, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

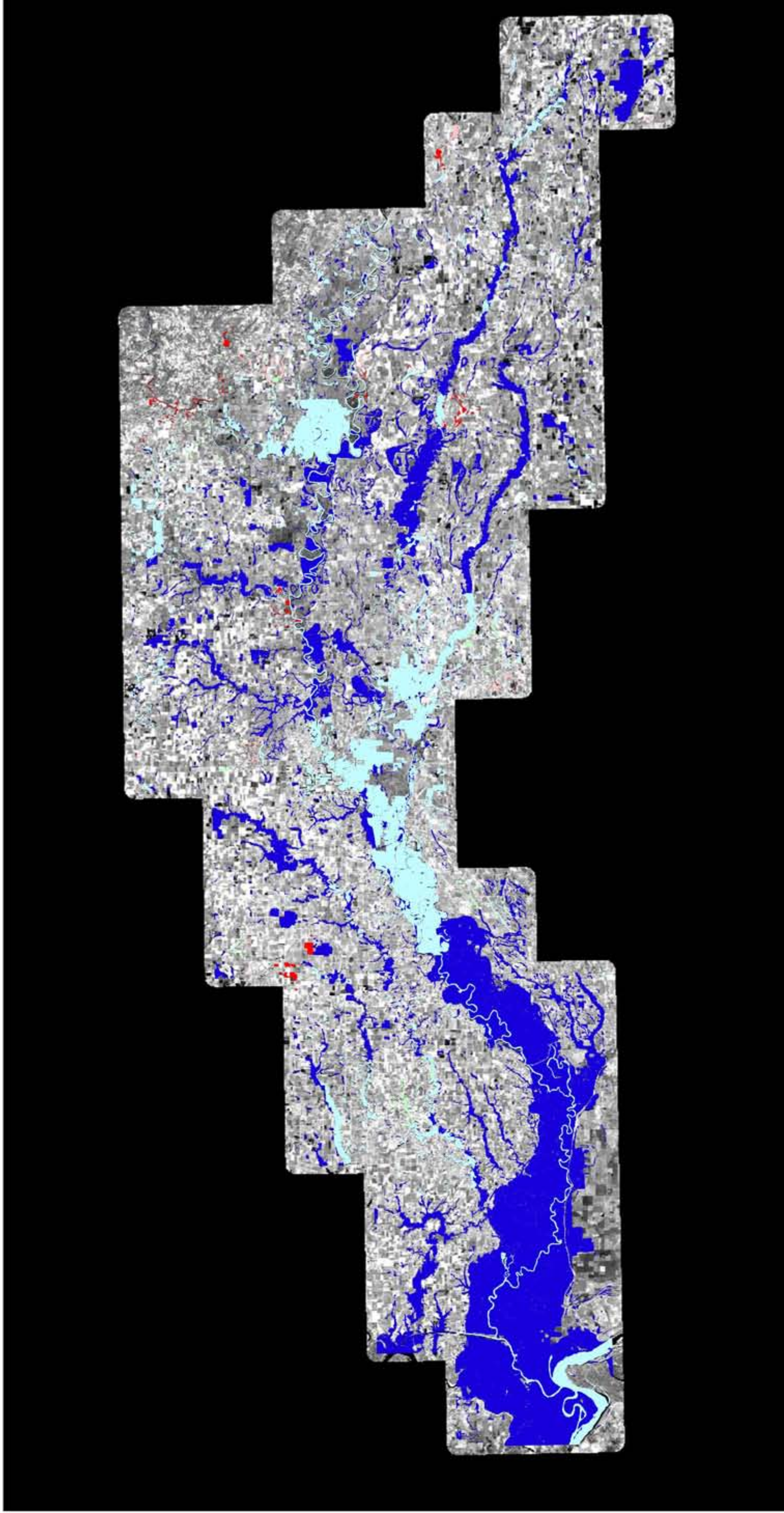


Figure 23k.

Black Bear Wetland Habitat - Human Population Density in 1990, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

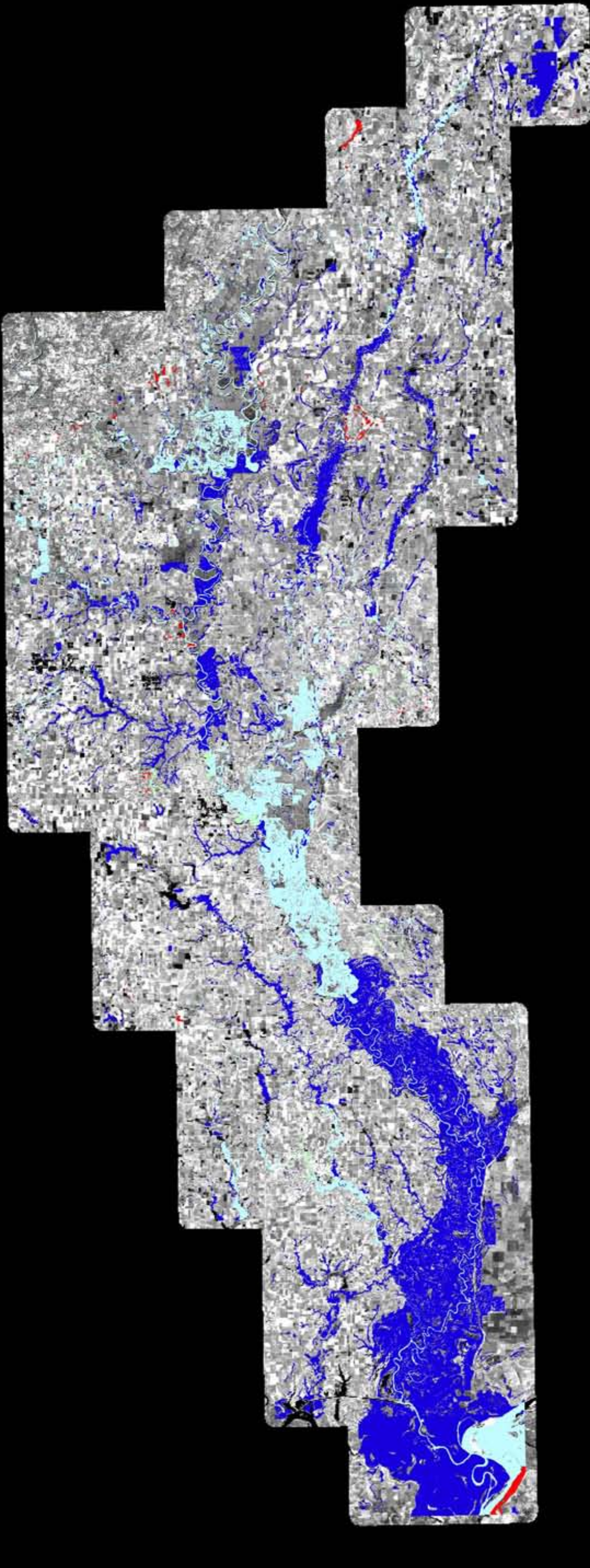


Figure 23l.

Wetland Plant Habitat - Human Population Density in 1990, patches > 2 hectares
- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Estimated Human Population Density in 2011)

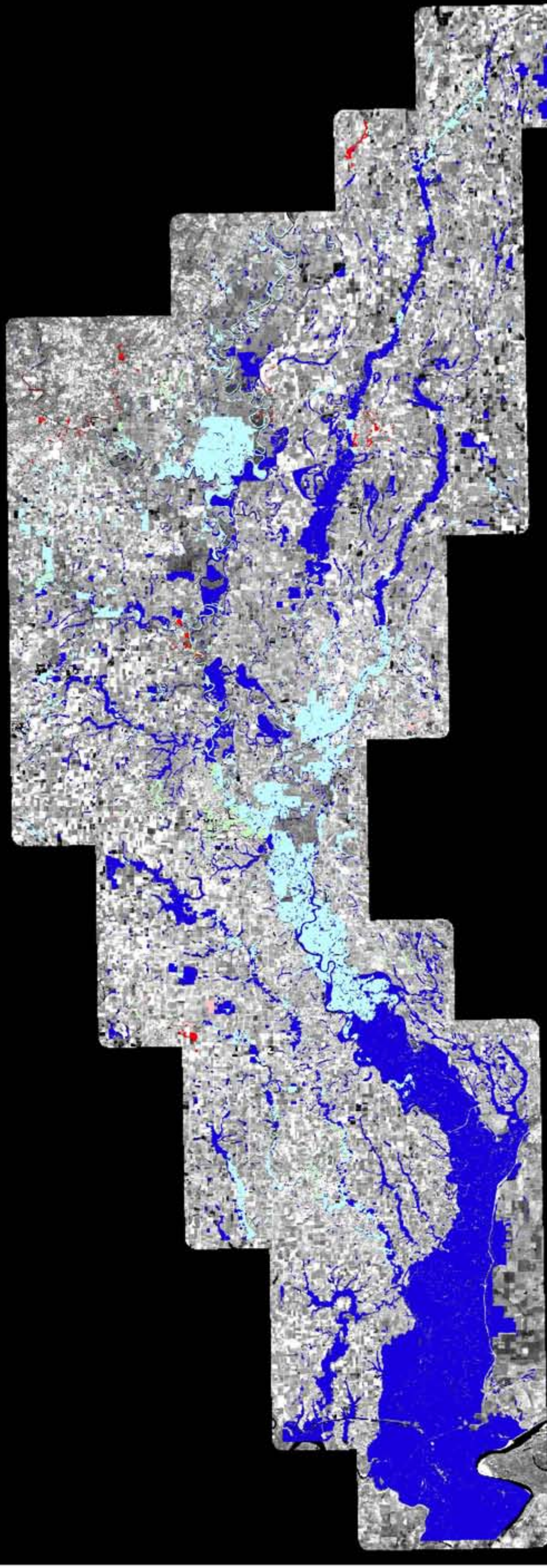


Figure 23m.

Mallard Winter Habitat - Human Population Density in 2011, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

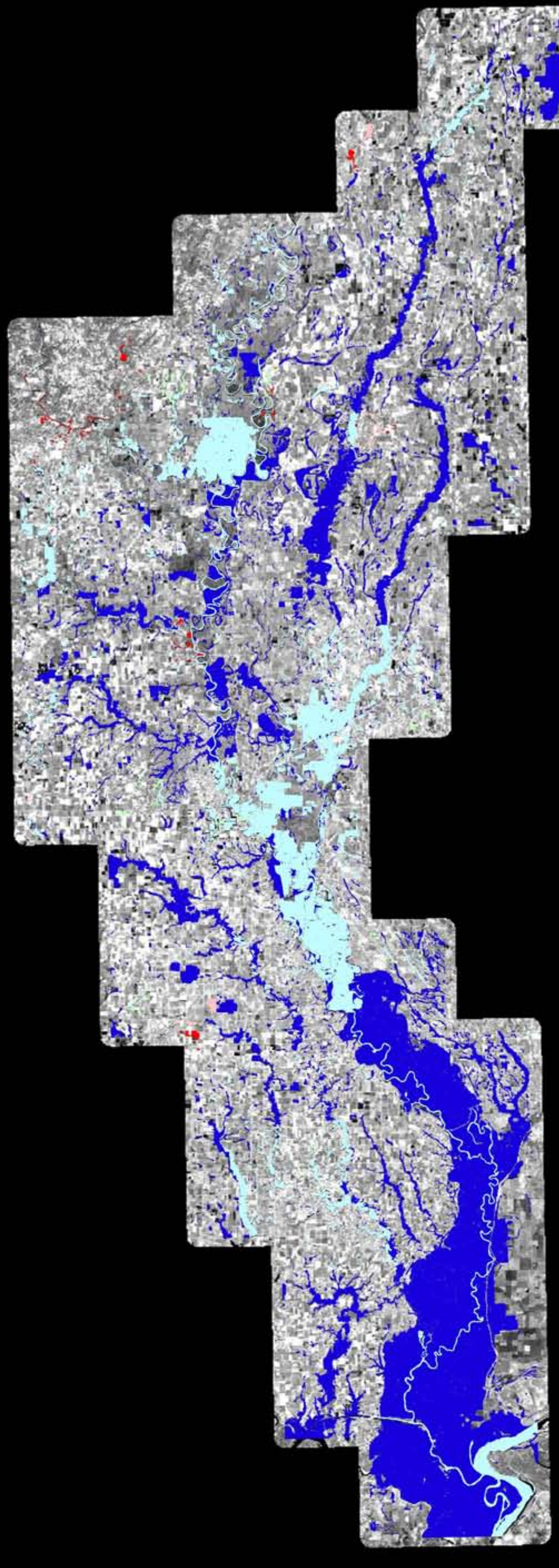


Figure 23n.

Black Bear Wetland Habitat - Human Population Density in 2011, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

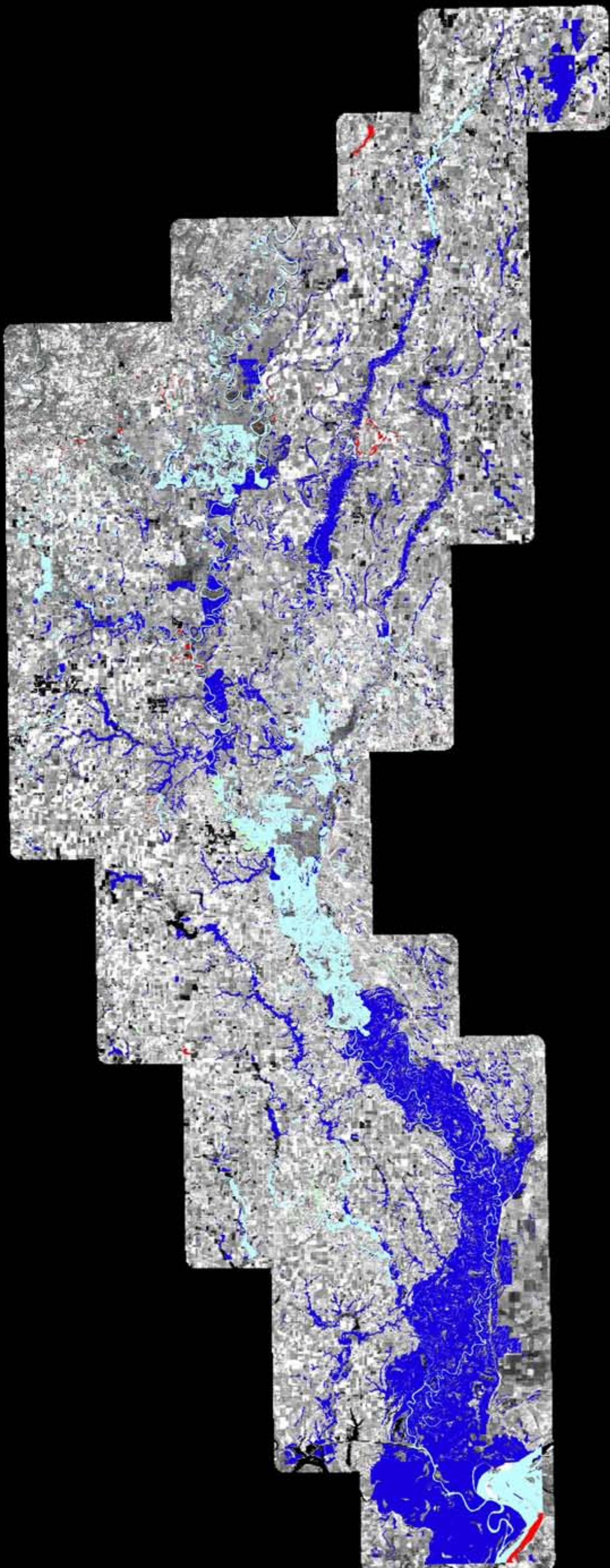


Figure 23o.

Wetland Plant Habitat - Human Population Density in 2011, patches > 2 hectares
- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Estimated Human Population Density Change from 1990 to 2011)

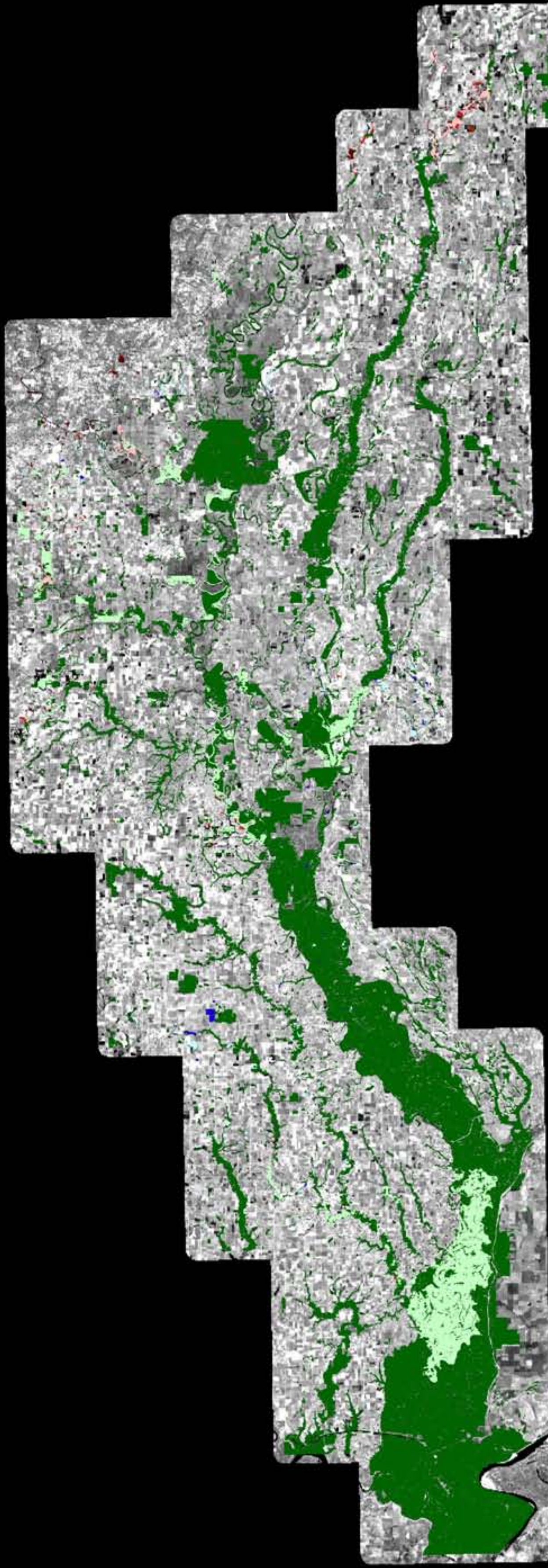


Figure 23p.

Mallard Winter Habitat - Human Population Density Change from 1990 to 2011, patches > 2 hectares

- < -3 Std. Dev. (Least Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

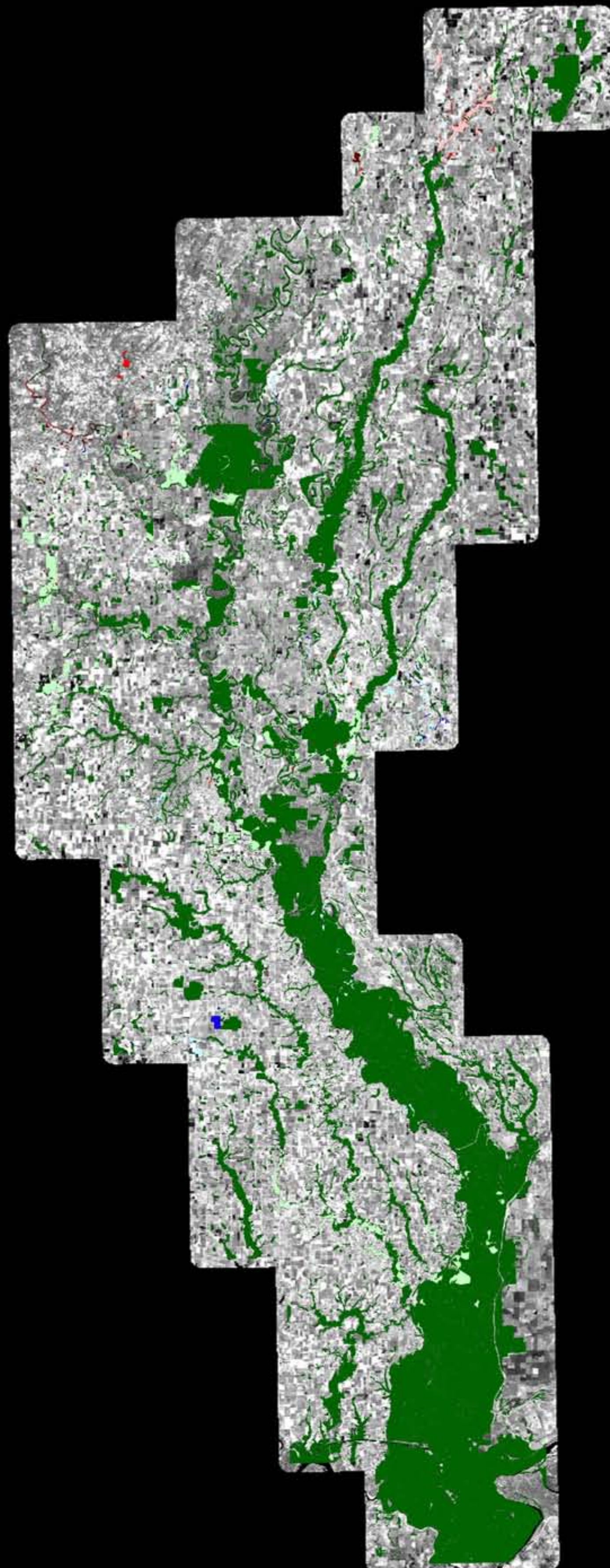


Figure 23q.

Black Bear Wetland Habitat - Human Population Density Change from 1990 to 2011, patches > 2 hectares

- < -3 Std. Dev. (Least Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

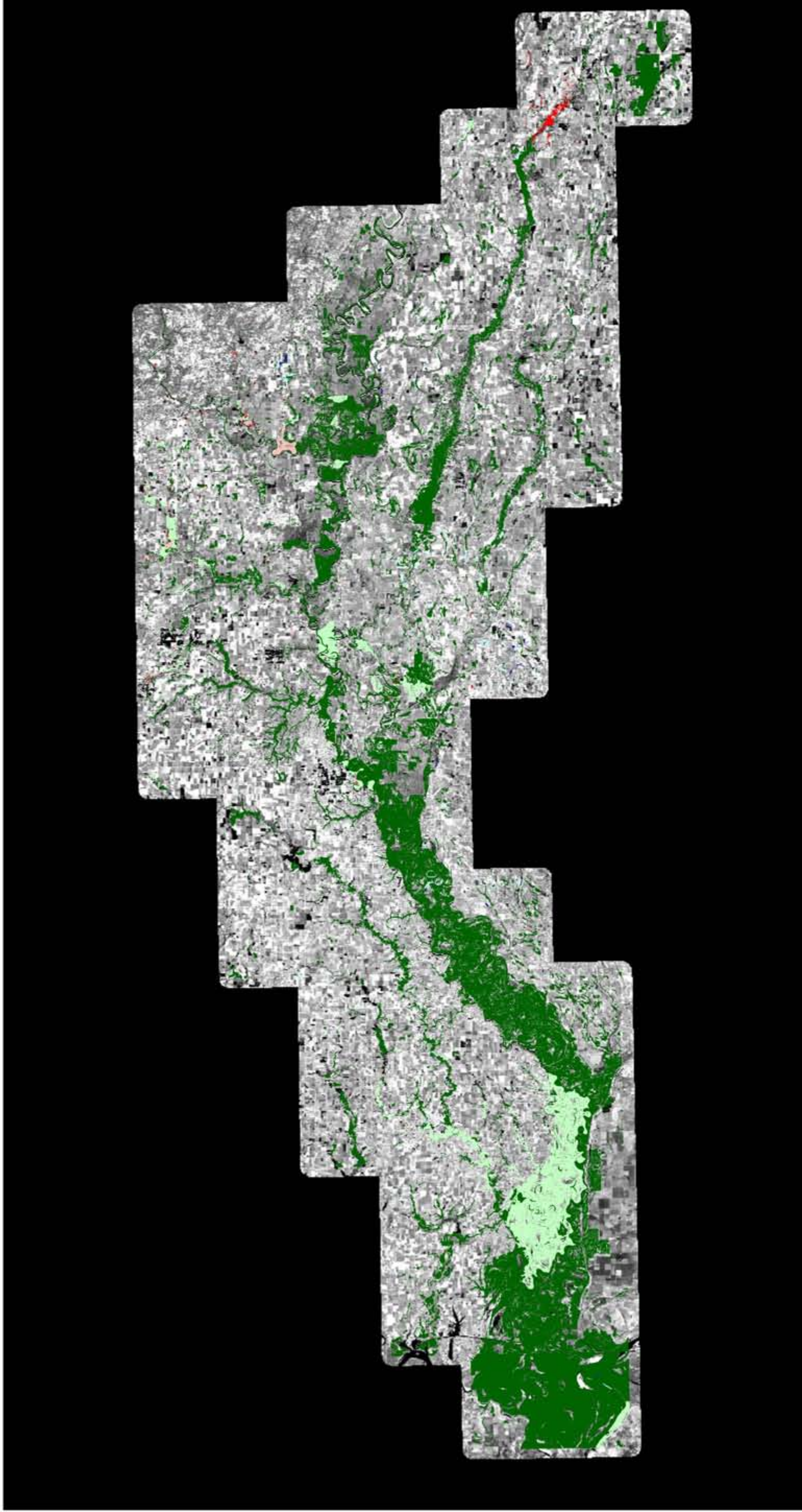


Figure 23r.

Wetland Plant Habitat - Human Population Density Change from 1990 to 2011, patches > 2 hectares

- < -3 Std. Dev. (Least Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Unified Human Index)

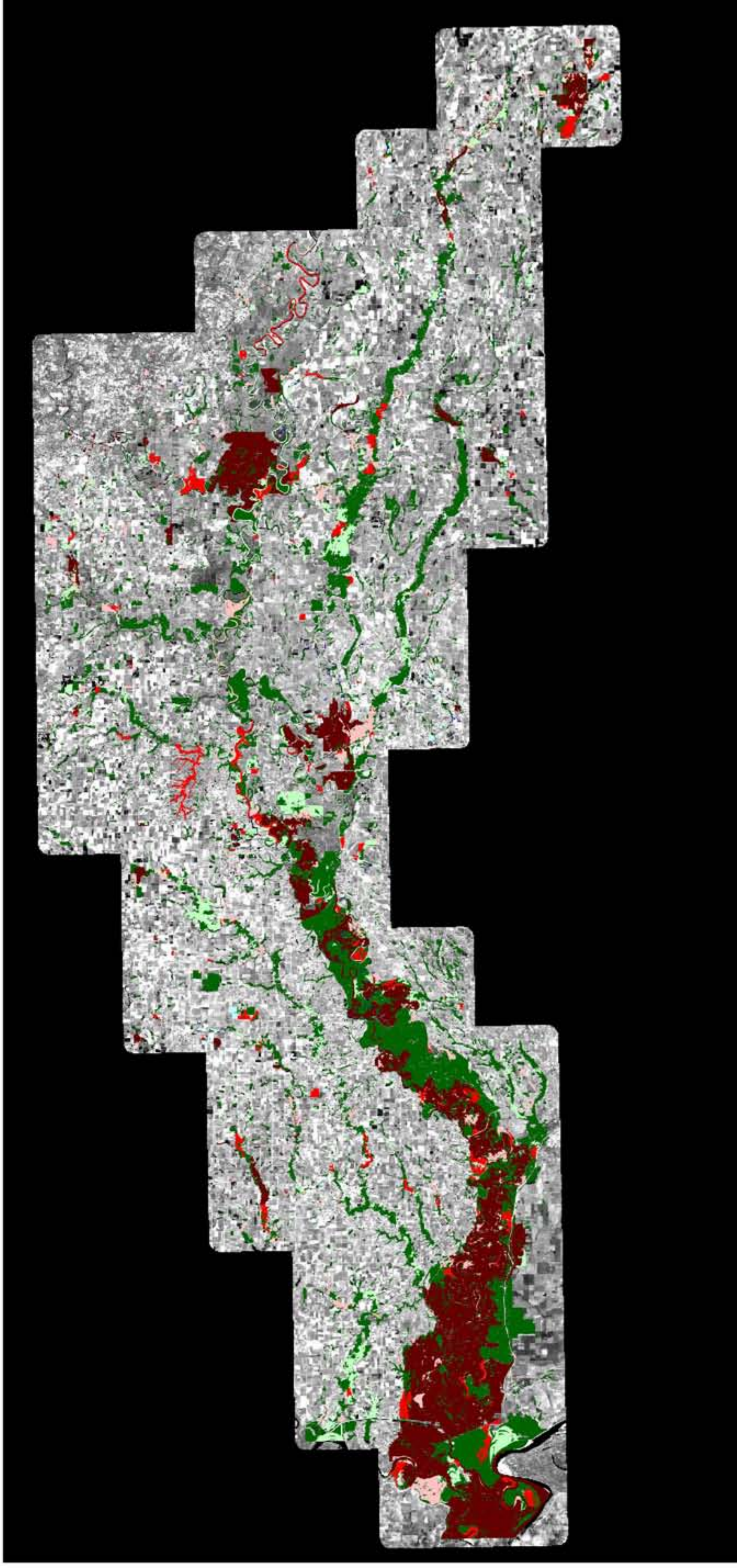


Figure 23s.

Mallard Winter Habitat - Unified Human Index, patches > 2 hectares

- < -3 Std. Dev. (Least Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

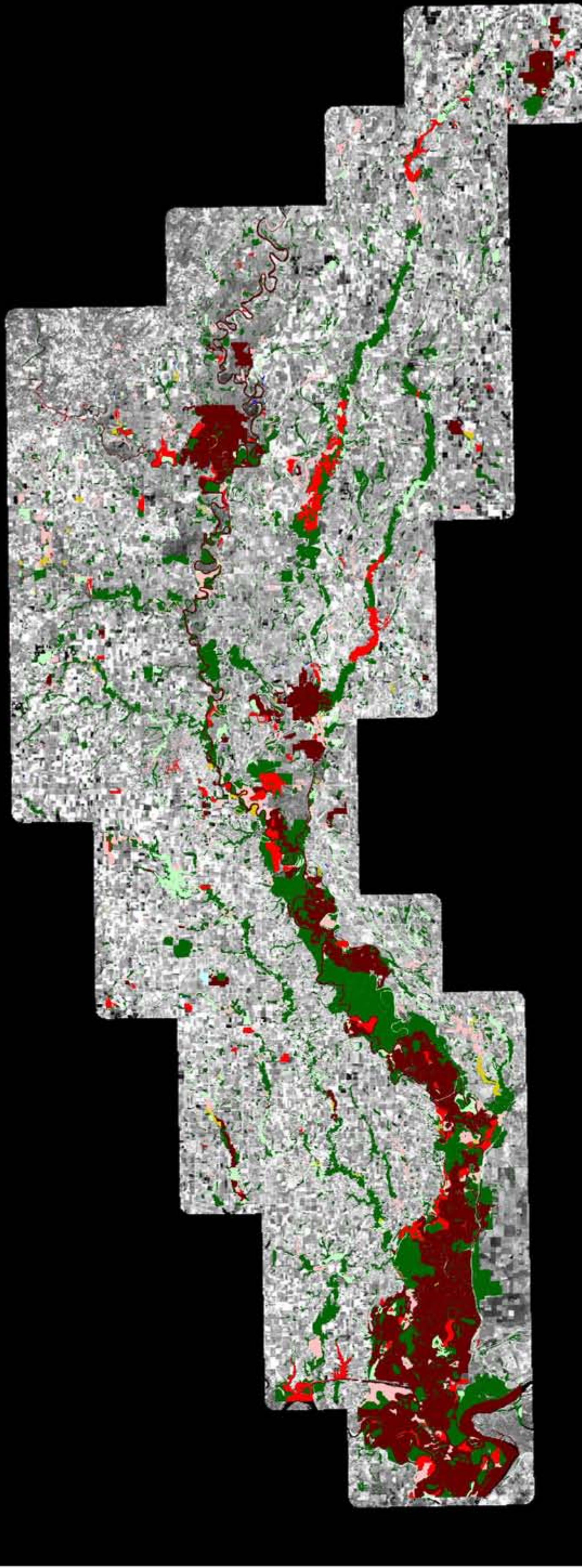


Figure 23t.

Black Bear Wetland Habitat - Unified Human Index, patches > 2 hectares

- < -3 Std. Dev. (Least Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

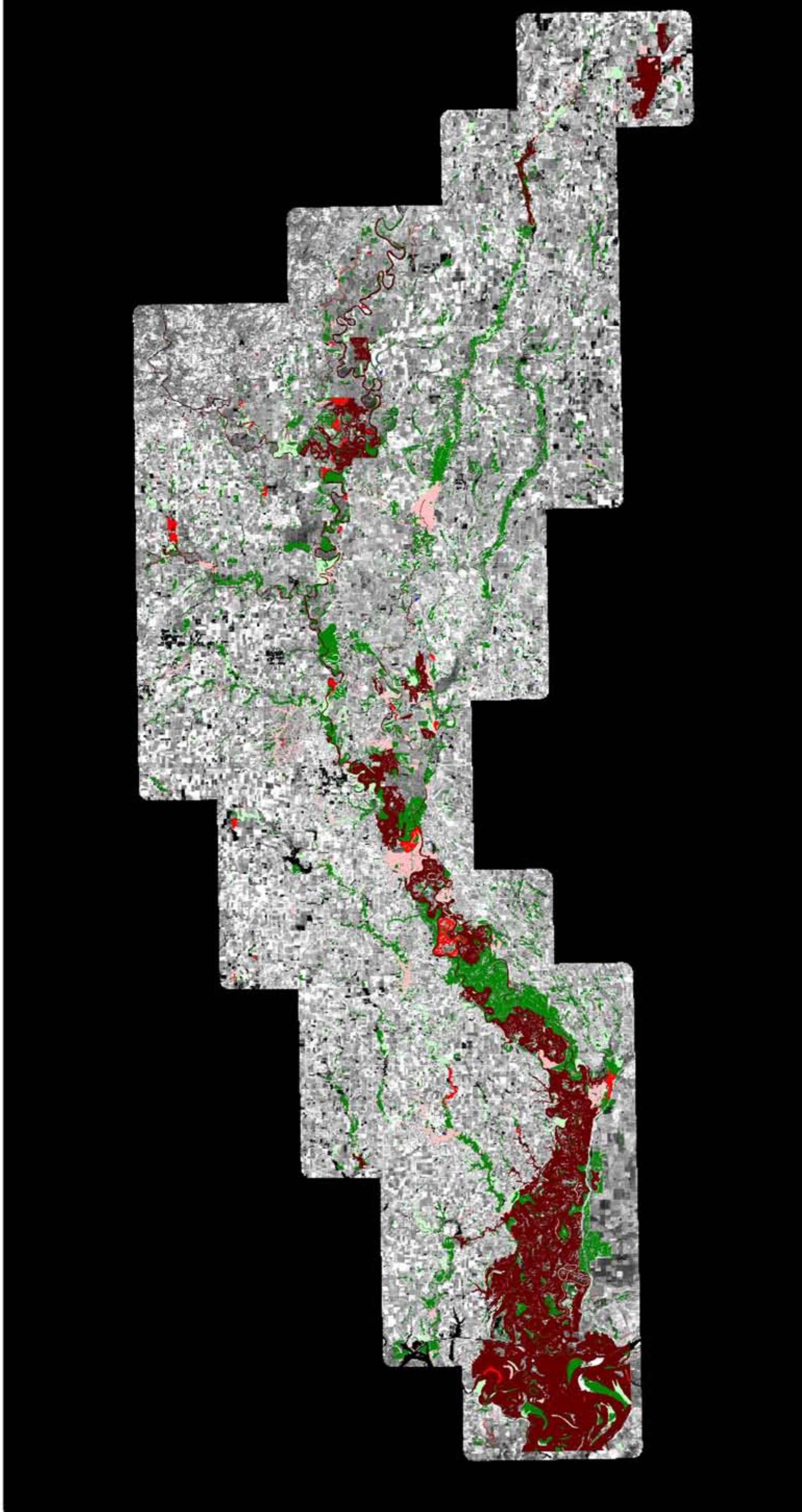


Figure 23u.

Wetland Plant Habitat - Unified Human Index, patches > 2 hectares

- < -3 Std. Dev. (Least Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Lower White River Region Wetland Habitat Vulnerability Models (Unified Vulnerability Index)

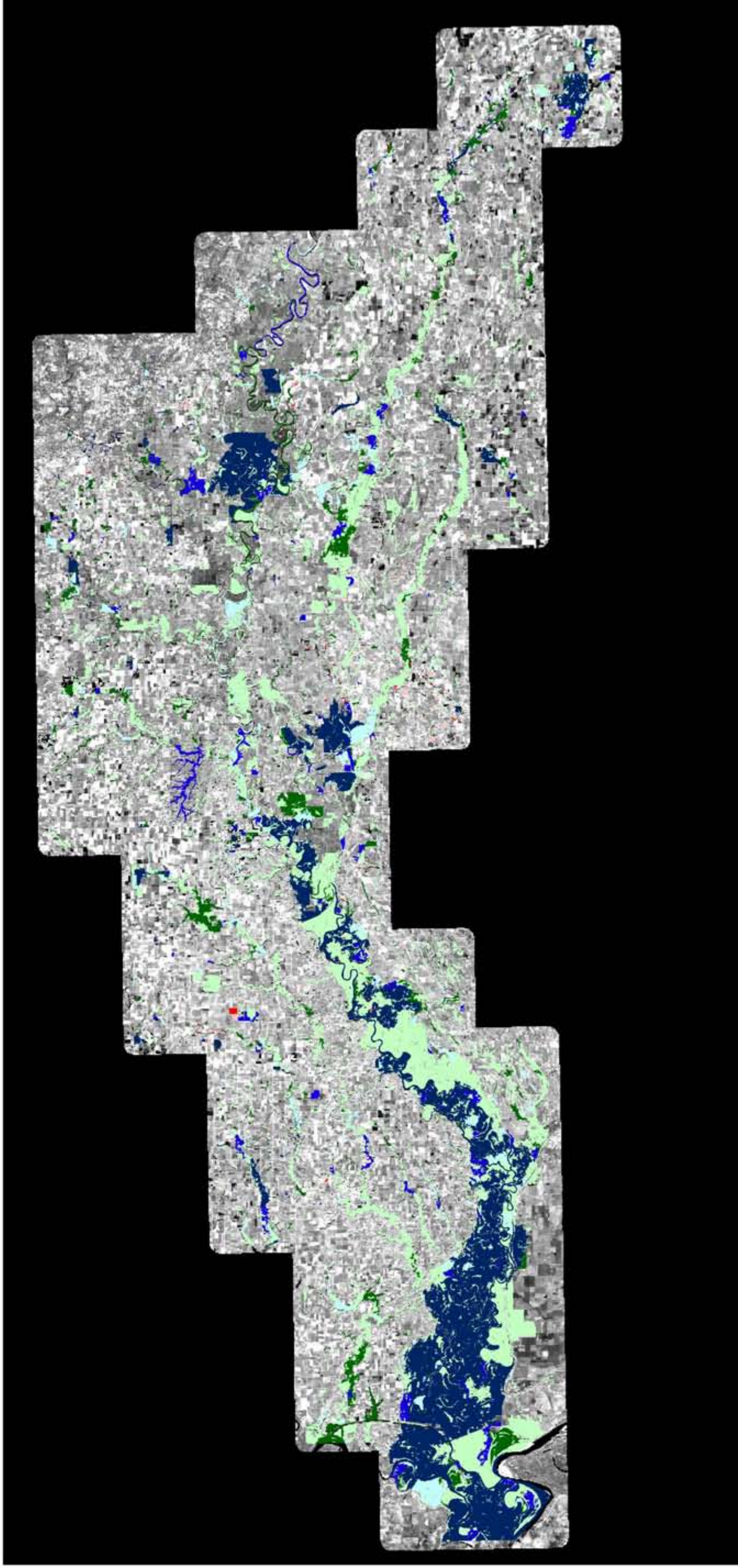


Figure 23v.

Mallard Winter Habitat - Unified Vulnerability Index, patches > 2 hectares

- < -3 Std. Dev. (Greatest Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

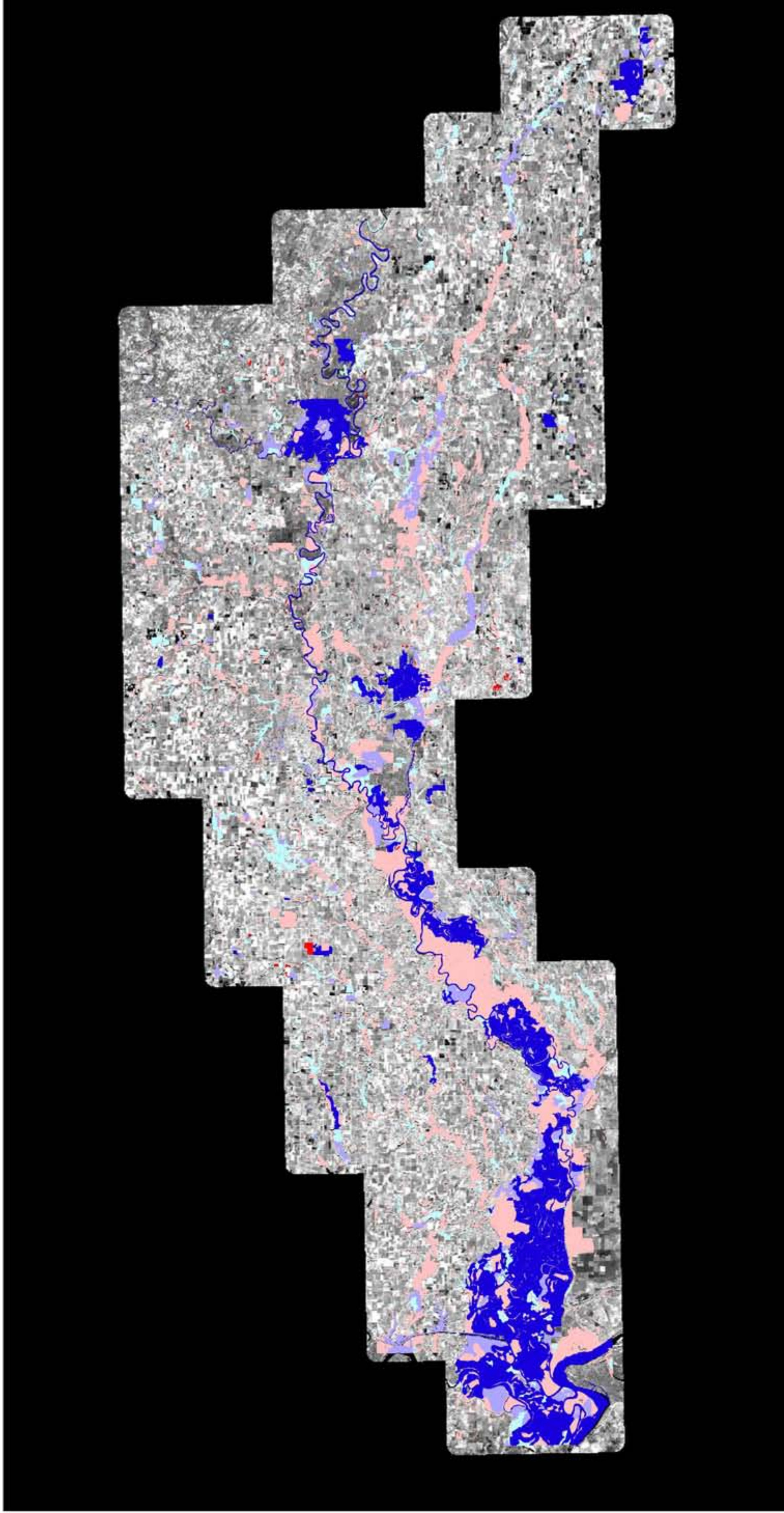


Figure 23w.

Black Bear Wetland Habitat - Unified Vulnerability Index, patches > 2 hectares

- < -3 Std. Dev. (Greatest Vulnerability)
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

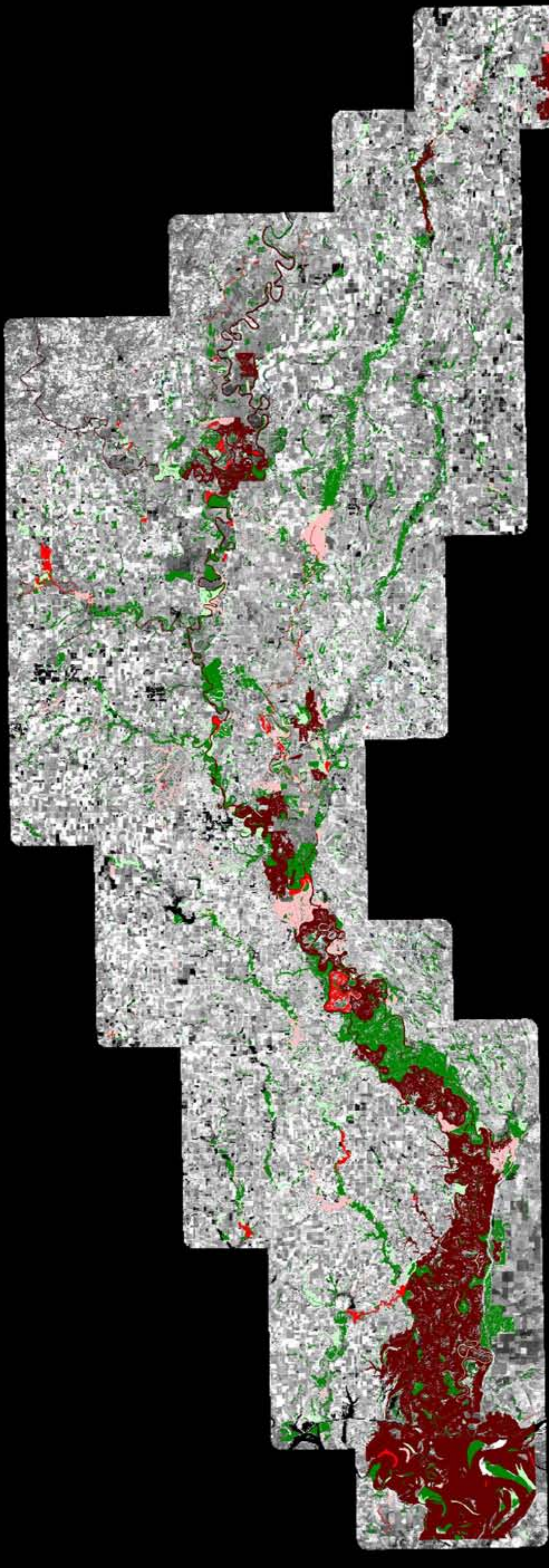


Figure 23x.

Wetland Plant Habitat - Unified Vulnerability Index, patches > 2 hectares

- < -3 Std. Dev. (Least Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

Mississippi Alluvial Valley Ecoregion Habitat Suitability Models

Figure 24a. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat suitability (All Land), All Sizes.
Figure 24b. Mississippi Alluvial Valley Ecoregion (MAVE) black bear habitat suitability (All Land), All Sizes.
Figure 24c. Mississippi Alluvial Valley Ecoregion (MAVE) least tern habitat suitability reference aid (All Land), All Sizes.
Figure 24d. Mississippi Alluvial Valley Ecoregion (MAVE) least tern habitat image overlay (All Land), All Sizes.

Figure 24e. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat suitability (Wetlands and Open Water Only), All Sizes.
Figure 24f. Mississippi Alluvial Valley Ecoregion (MAVE) black bear habitat suitability (Wetlands and Open Water Only), All Sizes.
Figure 24g. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat suitability (Wetlands and Open Water Only), All Sizes.

Figure 24h. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat suitability (Wetlands and Open Water Only), ≤ 2 ha.
Figure 24i. Mississippi Alluvial Valley Ecoregion (MAVE) black bear habitat suitability (Wetlands and Open Water Only), ≤ 2 ha.
Figure 24j. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat suitability (Wetlands and Open Water Only), ≤ 2 ha.

Figure 24k. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat suitability (Wetlands and Open Water Only), > 2 ha.
Figure 24l. Mississippi Alluvial Valley Ecoregion (MAVE) black bear habitat suitability (Wetlands and Open Water Only), > 2 ha.
Figure 24m. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat suitability (Wetlands and Open Water Only), > 2 ha.

Mississippi Alluvial Valley Ecoregion Habitat Suitability Models (All Land, All Sizes)

Figure 24a.

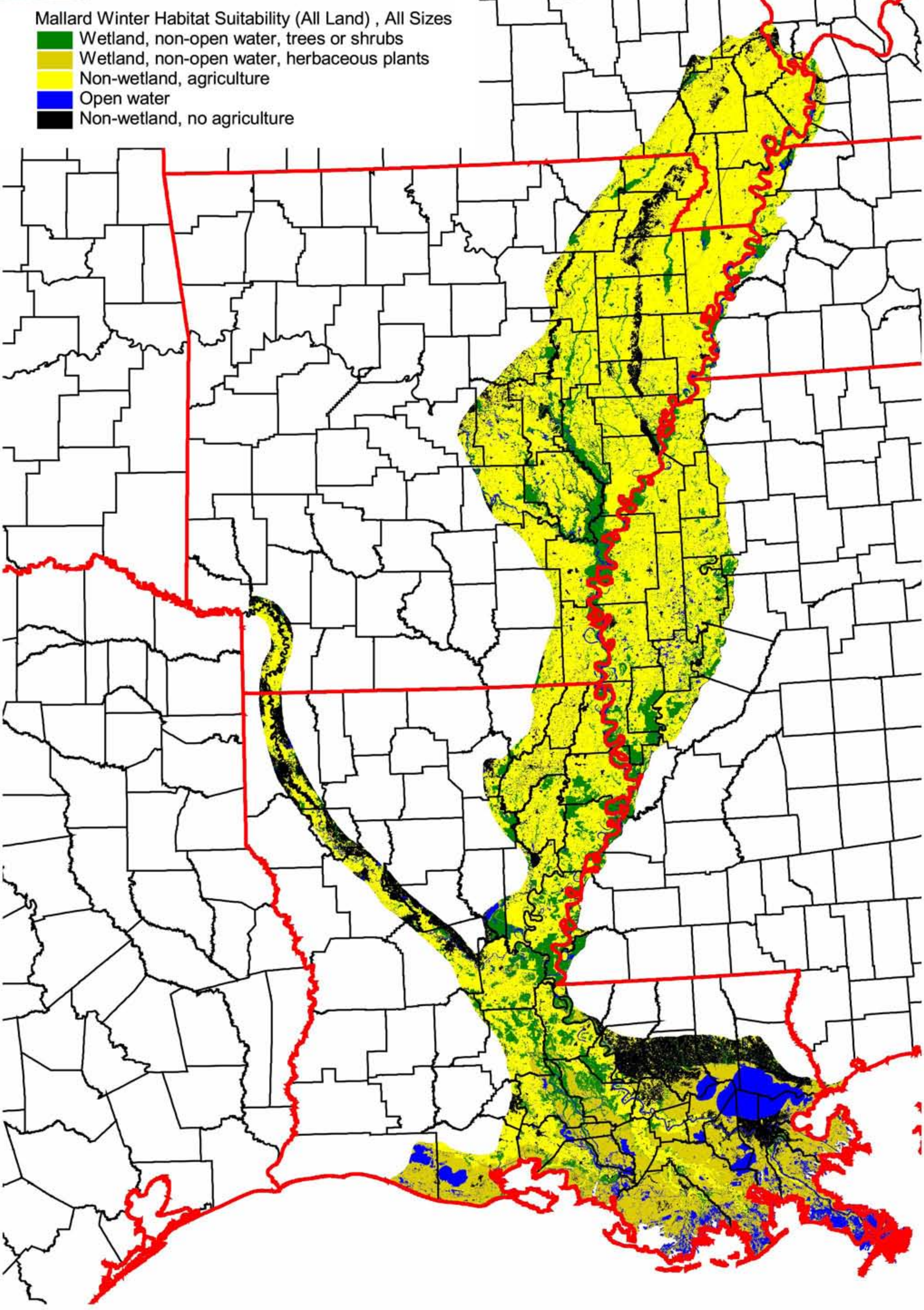
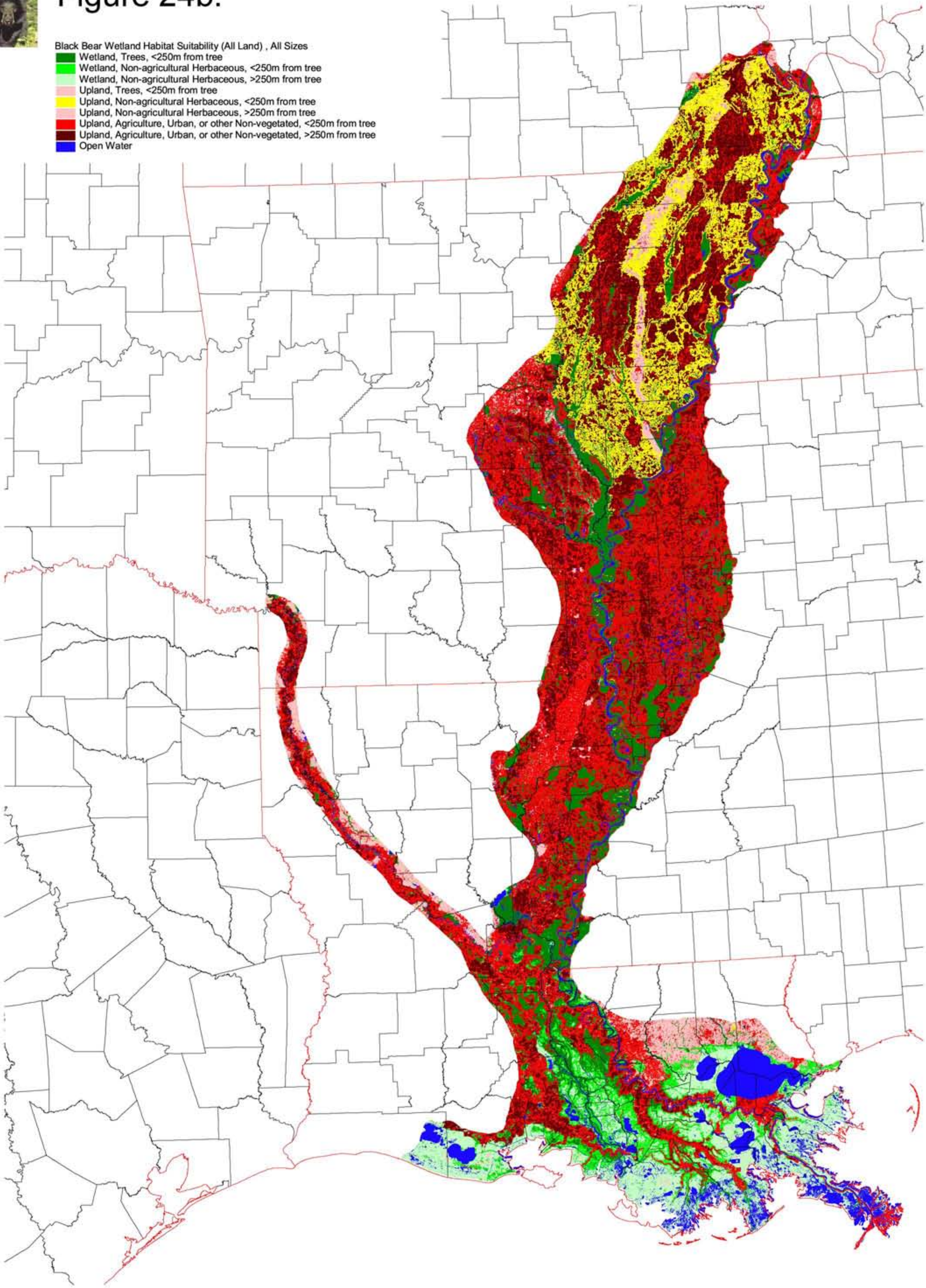

Mallard Winter Habitat Suitability (All Land) , All Sizes
Wetland, non-open water, trees or shrubs
Wetland, non-open water, herbaceous plants
Non-wetland, agriculture
Open water
Non-wetland, no agriculture

Figure 24b.



Black Bear Wetland Habitat Suitability (All Land) , All Sizes
Wetland, Trees, <250m from tree
Wetland, Non-agricultural Herbaceous, <250m from tree
Wetland, Non-agricultural Herbaceous, >250m from tree
Upland, Trees, <250m from tree
Upland, Non-agricultural Herbaceous, <250m from tree
Upland, Non-agricultural Herbaceous, >250m from tree
Upland, Agriculture, Urban, or other Non-vegetated, <250m from tree
Upland, Agriculture, Urban, or other Non-vegetated, >250m from tree
Open Water

Figure 24c.

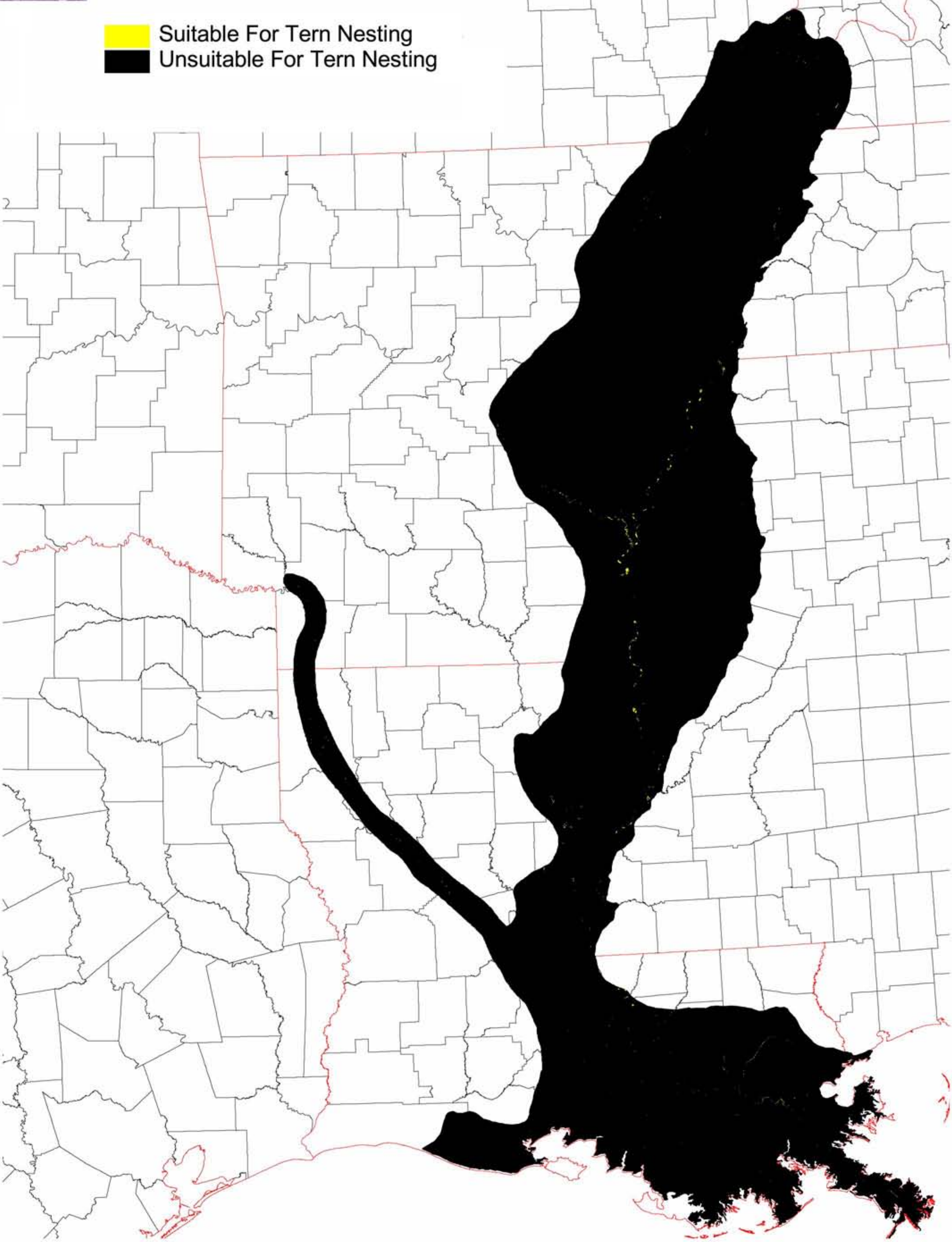
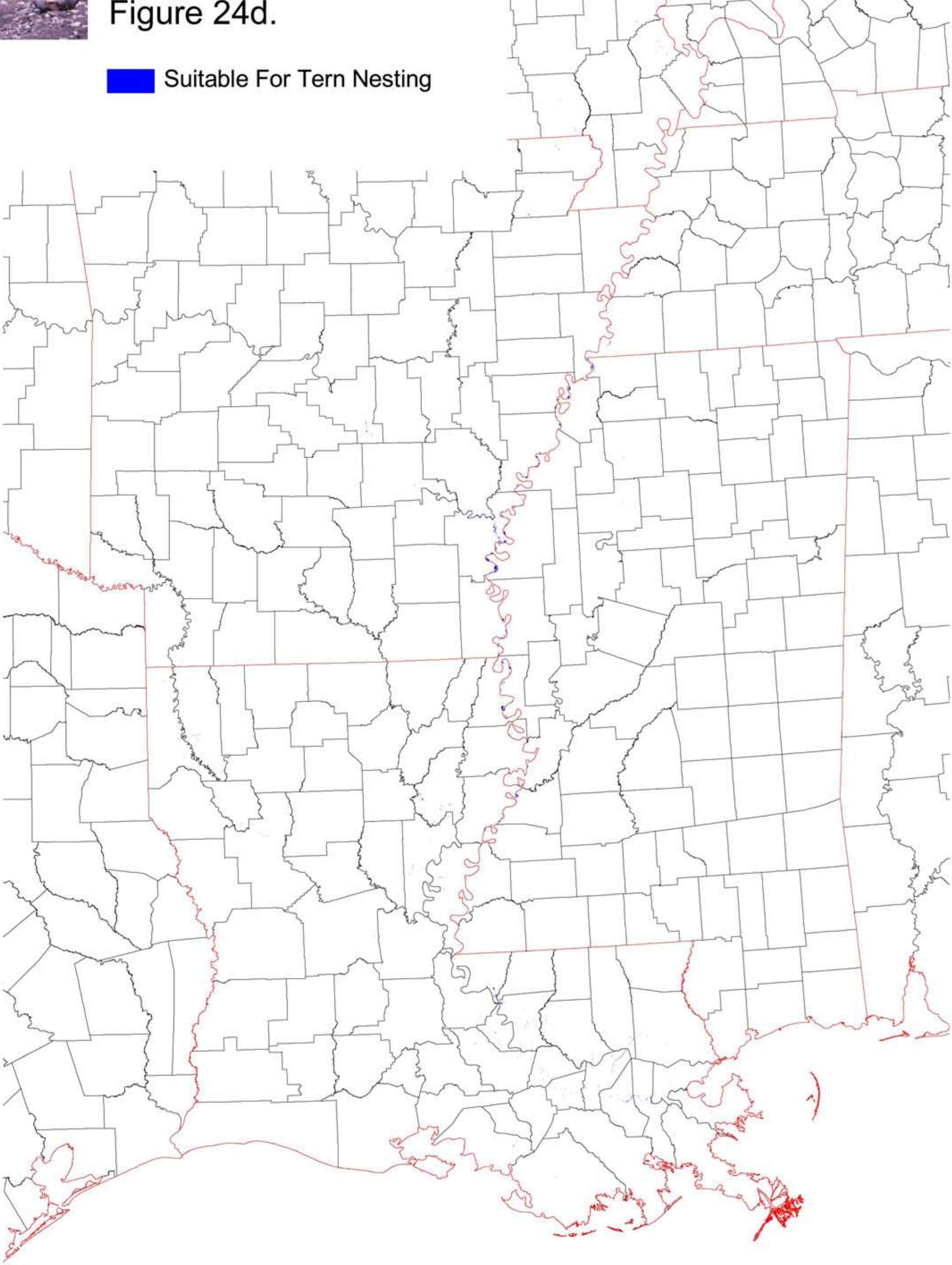
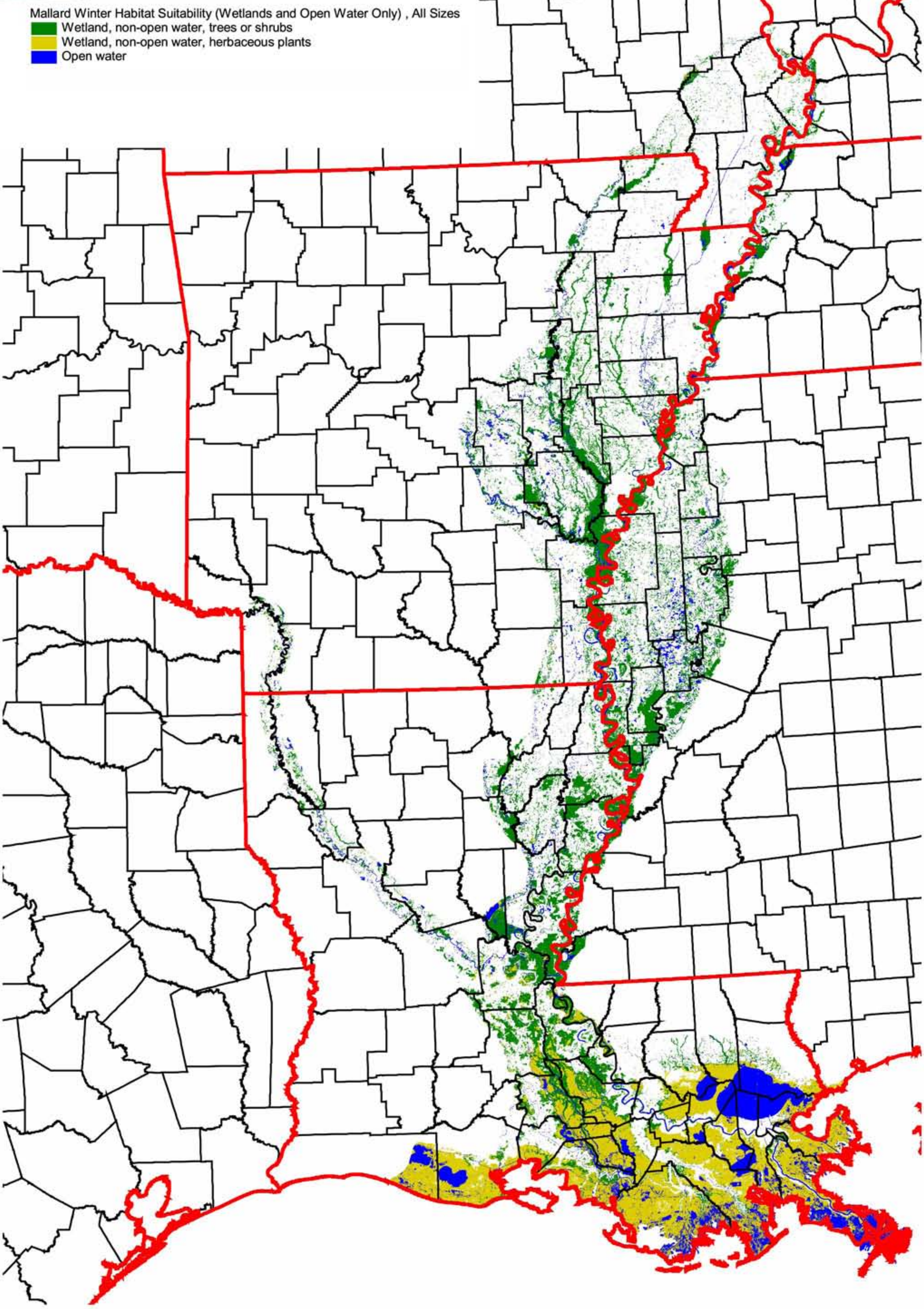


Figure 24d.



Mississippi Alluvial Valley Ecoregion Wetland Habitat Suitability Models (All Sizes)

Figure 24e.



Mallard Winter Habitat Suitability (Wetlands and Open Water Only) , All Sizes
Wetland, non-open water, trees or shrubs
Wetland, non-open water, herbaceous plants
Open water

Figure 24f.

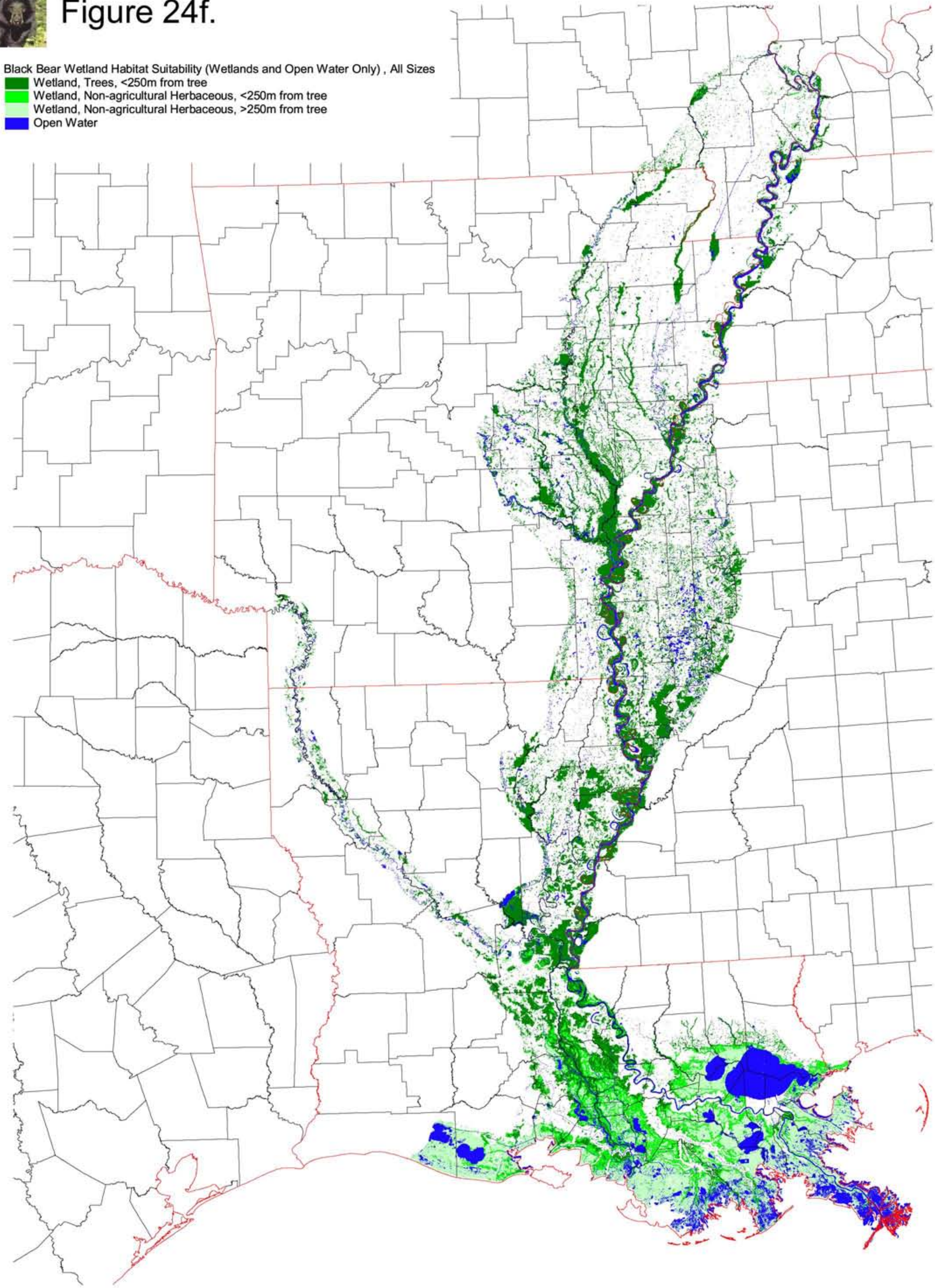
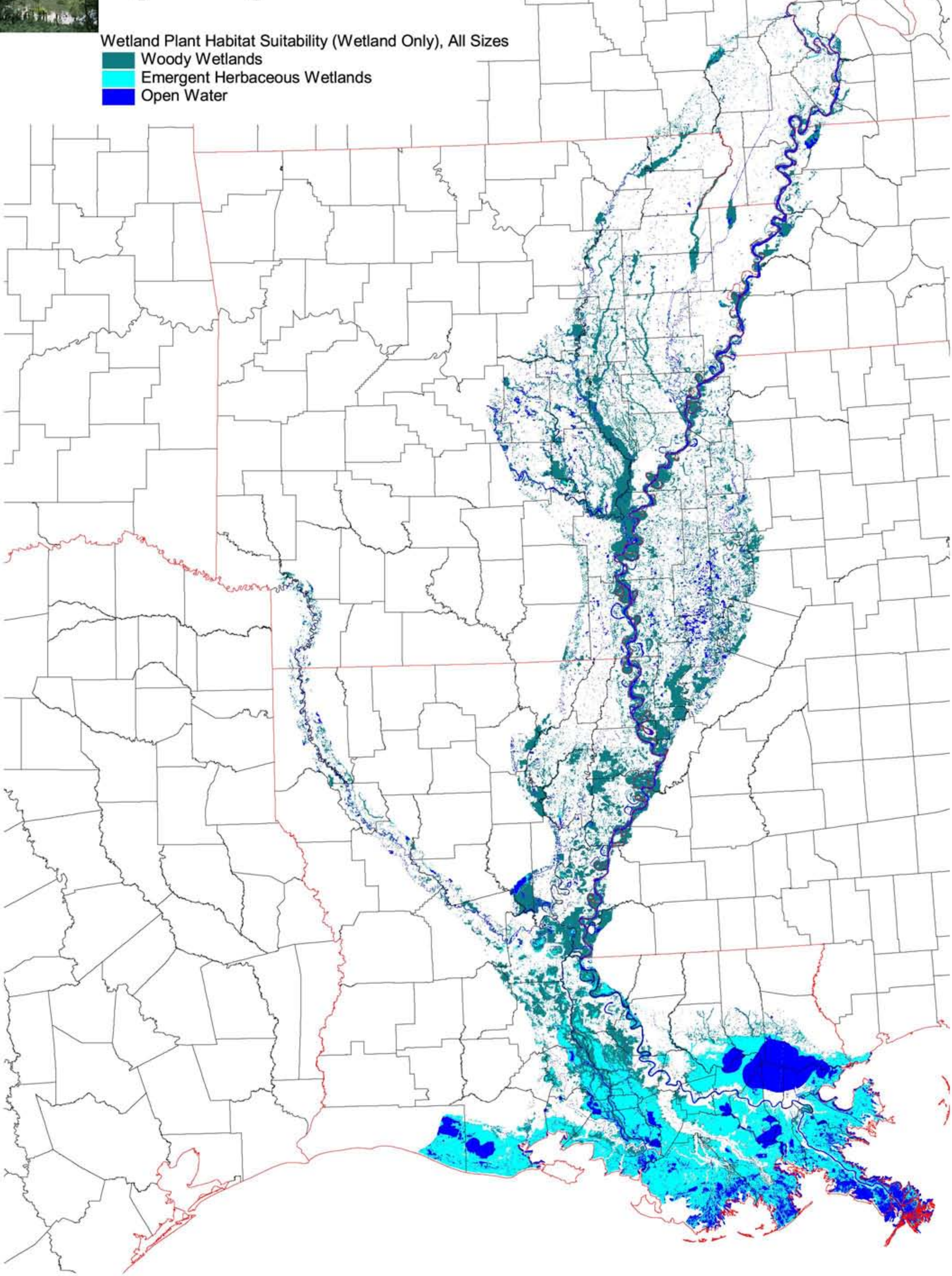

Black Bear Wetland Habitat Suitability (Wetlands and Open Water Only) , All Sizes
Wetland, Trees, <250m from tree
Wetland, Non-agricultural Herbaceous, <250m from tree
Wetland, Non-agricultural Herbaceous, >250m from tree
Open Water

Figure 24g.


Wetland Plant Habitat Suitability (Wetland Only), All Sizes
Woody Wetlands
Emergent Herbaceous Wetlands
Open Water

Mississippi Alluvial Valley Ecoregion Wetland Habitat Suitability Models ($\leq$ 2 ha)

Figure 24h.

Mallard Winter Habitat Suitability (Wetlands and Open Water Only), less than or equal to 2 hectares

- Wetland, non-open water, trees or shrubs
- Wetland, non-open water, herbaceous plants
- Open water

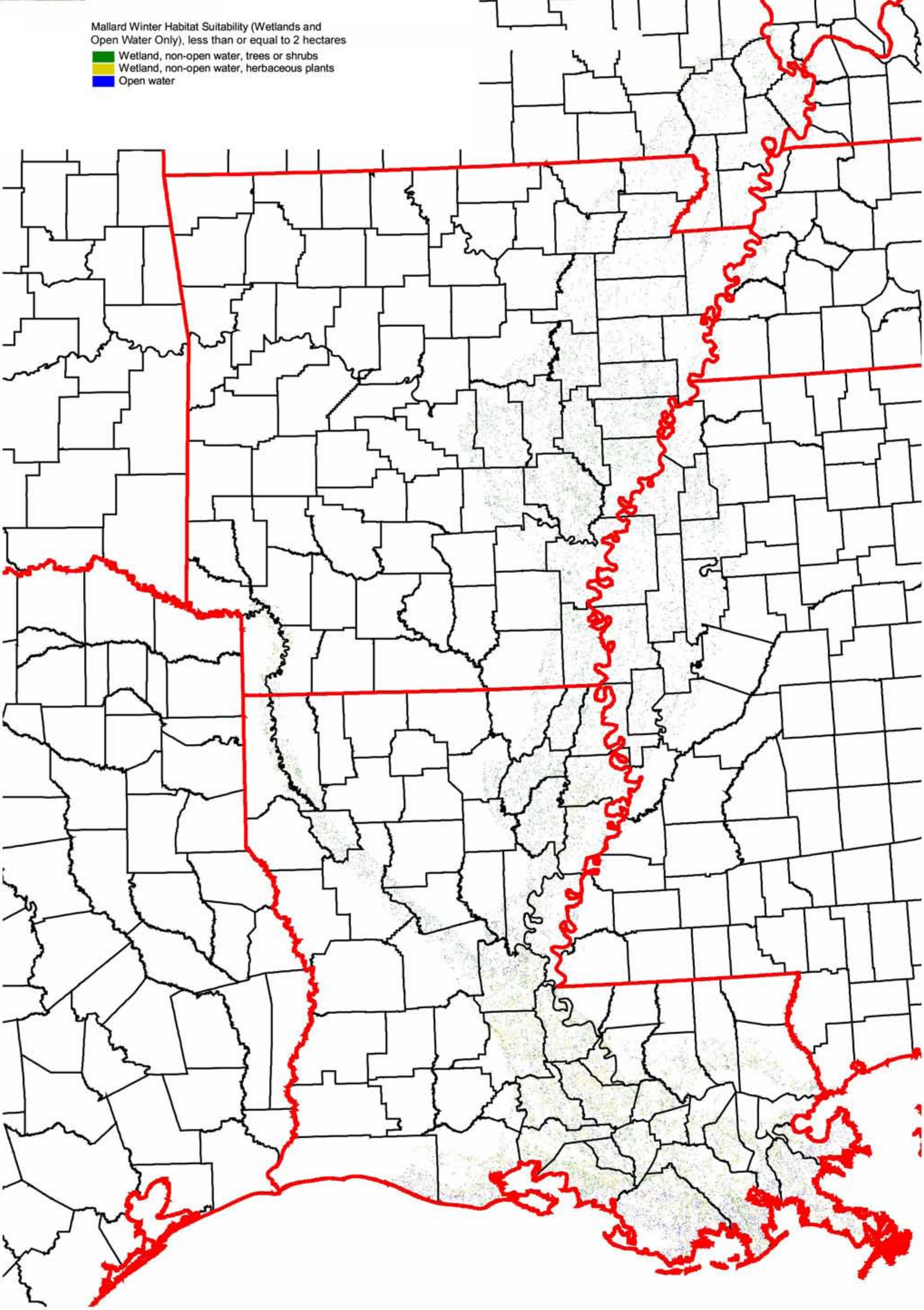


Figure 24i.

Black Bear Wetland Habitat Suitability (Wetlands and Open Water Only), less than or equal to 2 hectares

- Wetland, Trees, <250m from tree
- Wetland, Non-agricultural Herbaceous, <250m from tree
- Wetland, Non-agricultural Herbaceous, >250m from tree
- Open Water

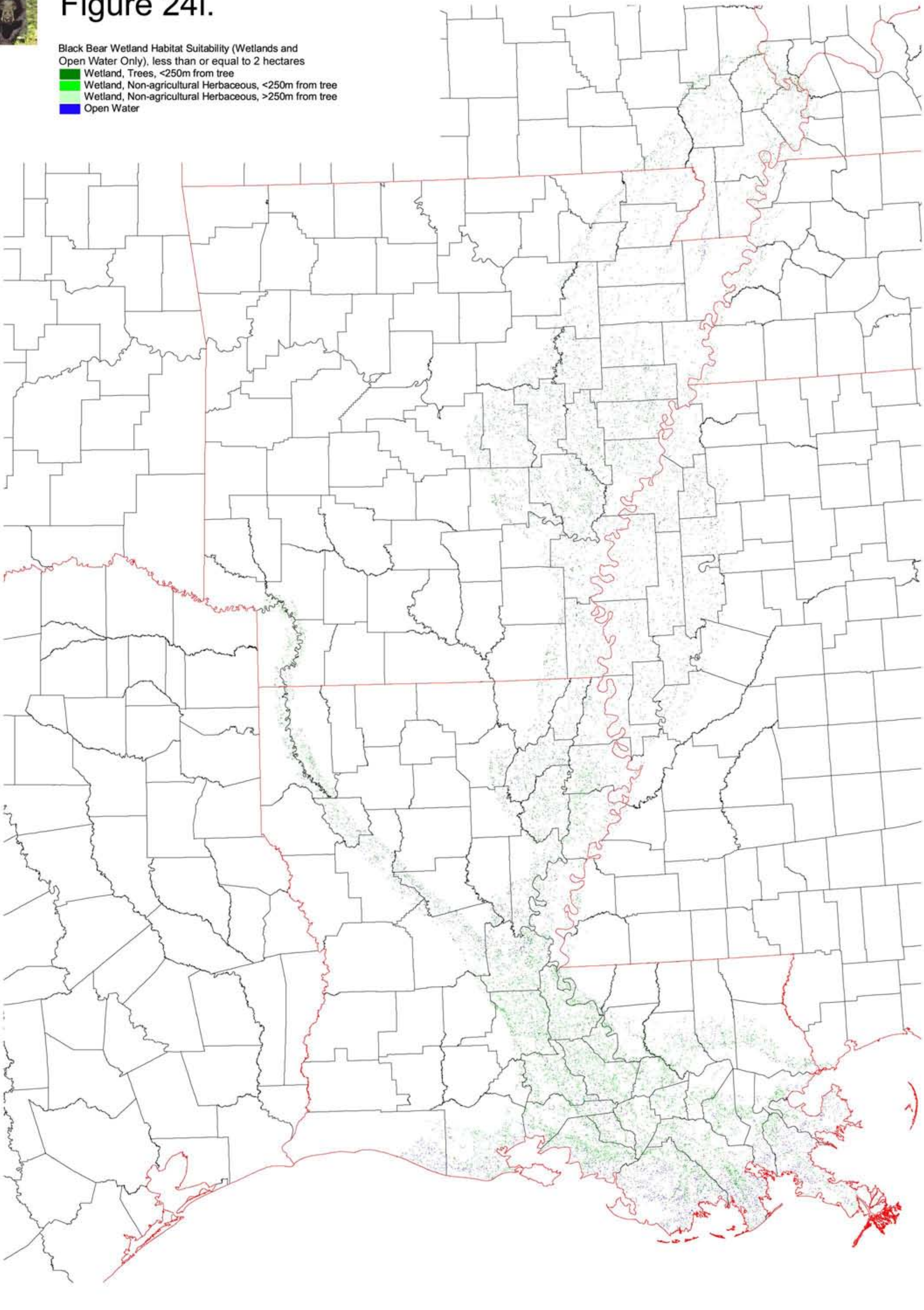


Figure 24j.

Wetland Plant Habitat Suitability (Wetland Only), less than or equal to 2 hectares

- Woody Wetlands
- Emergent Herbaceous Wetlands
- Open Water

Mississippi Alluvial Valley Ecoregion Wetland Habitat Suitability Models (> 2 ha)

Figure 24k.

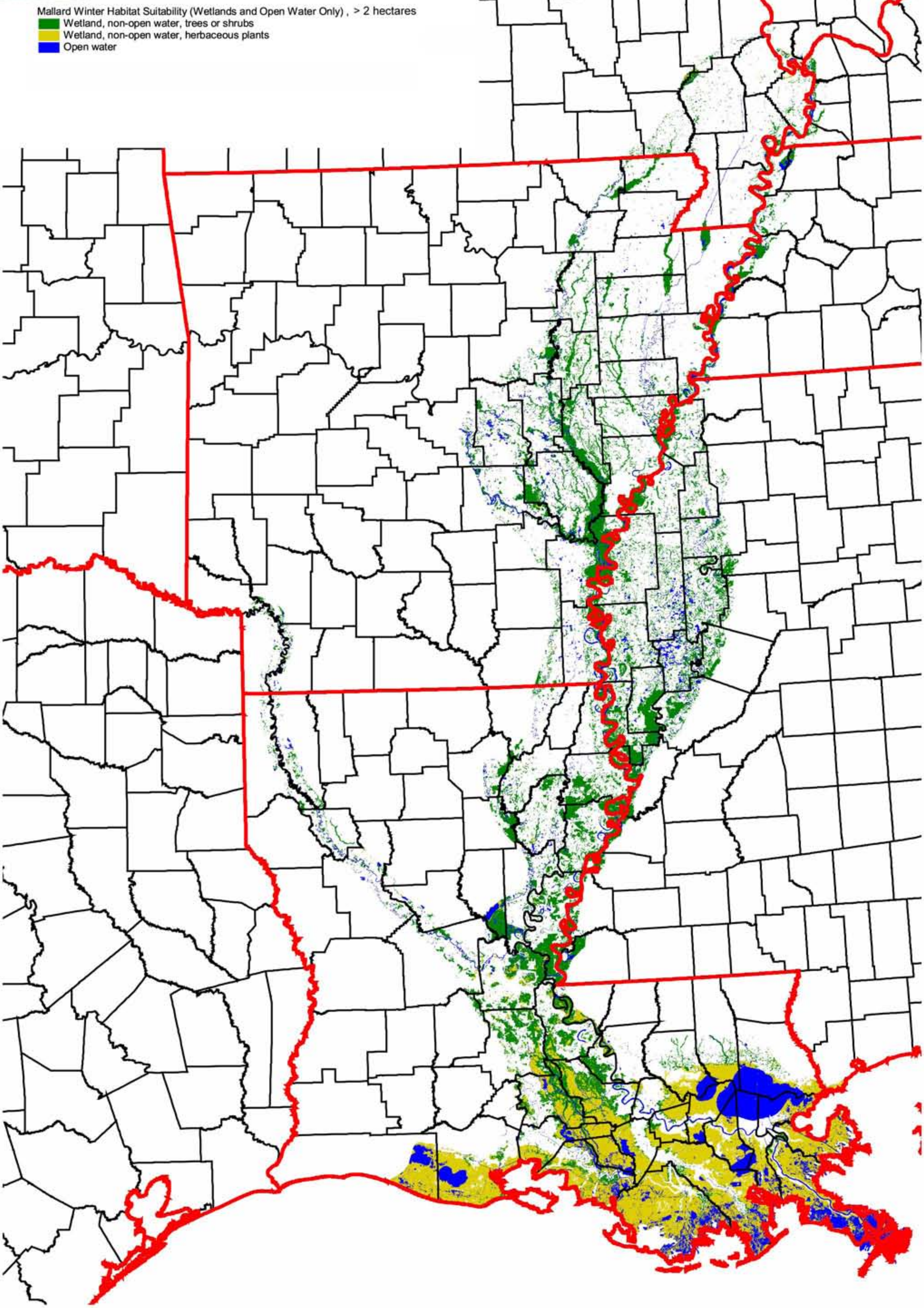
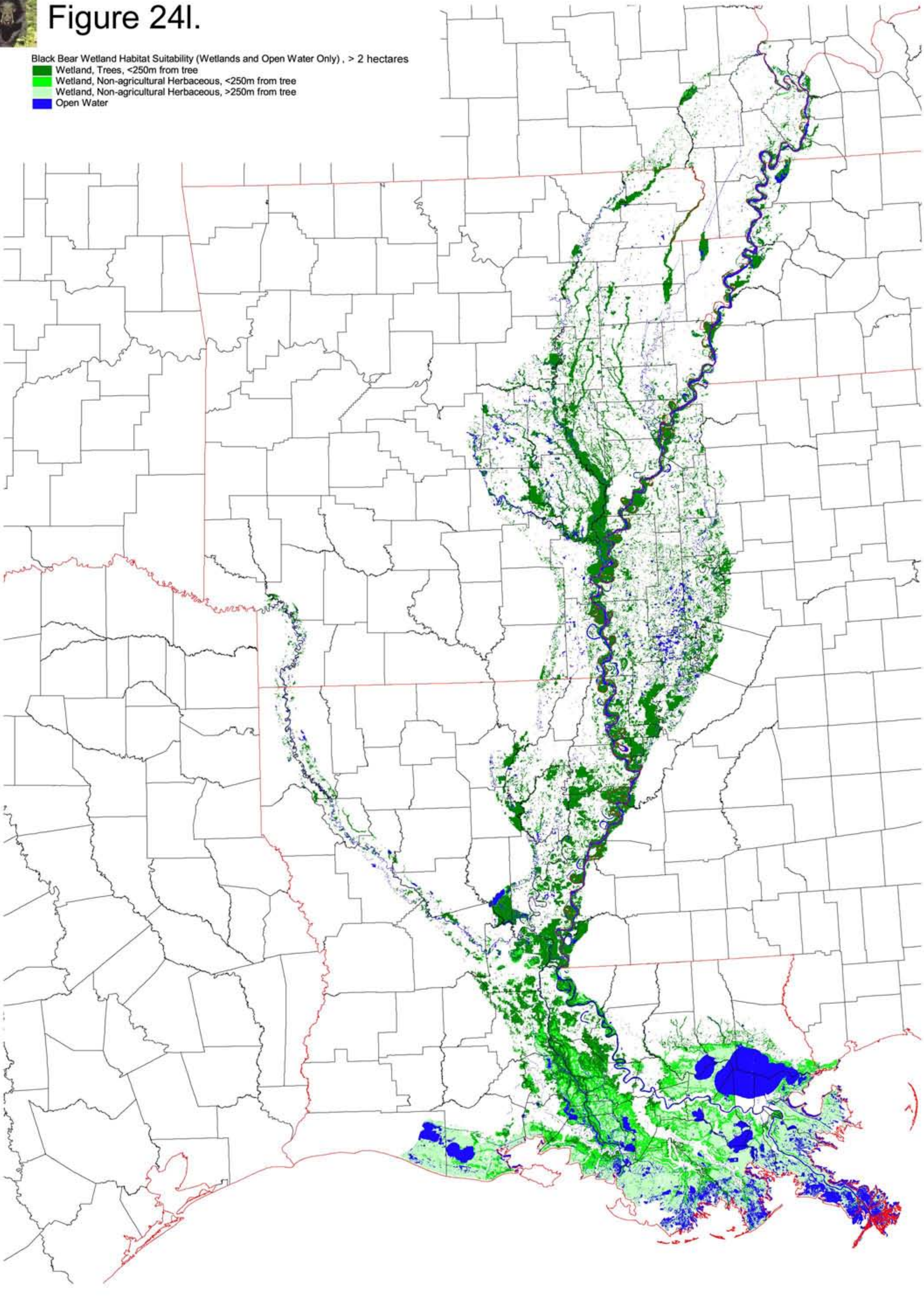
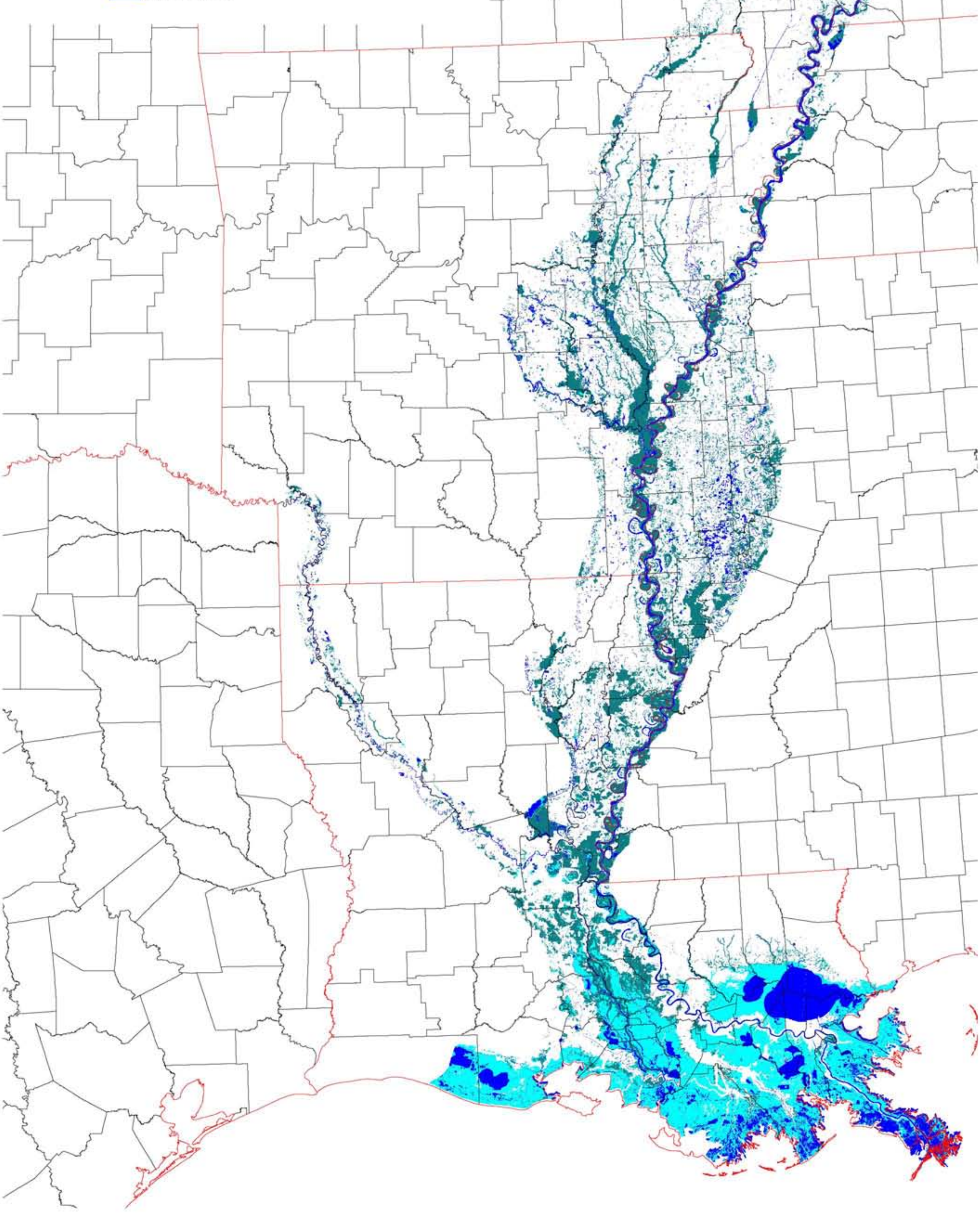

Mallard Winter Habitat Suitability (Wetlands and Open Water Only) , > 2 hectares
Wetland, non-open water, trees or shrubs
Wetland, non-open water, herbaceous plants
Open water

Figure 24l.



Black Bear Wetland Habitat Suitability (Wetlands and Open Water Only) , > 2 hectares
Wetland, Trees, <250m from tree
Wetland, Non-agricultural Herbaceous, <250m from tree
Wetland, Non-agricultural Herbaceous, >250m from tree
Open Water

Figure 24m.


Wetland Plant Habitat Suitability (Wetland Only), > 2 hectares
Woody Wetlands
Emergent Herbaceous Wetlands
Open Water

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Patch Size and Patch Shape)

Figure 25a. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total area.
Figure 25b. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total area.
Figure 25c. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total area.

Figure 25d. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total perimeter length.
Figure 25e. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total perimeter length.
Figure 25f. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total perimeter length.

Figure 25g. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch interior-to-edge ratio.
Figure 25h. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch interior-to-edge ratio.
Figure 25i. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch interior-to-edge ratio.

Figure 25j. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch circularity index.
Figure 25k. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch circularity index.
Figure 25l. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch circularity index.

Figure 25m. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch sinuosity index.
Figure 25n. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch sinuosity index.
Figure 25o. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch sinuosity index.

Figure 25p. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch unified patch index.
Figure 25q. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch unified patch index.
Figure 25r. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch unified patch index.

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Total Area)

Figure 25a.

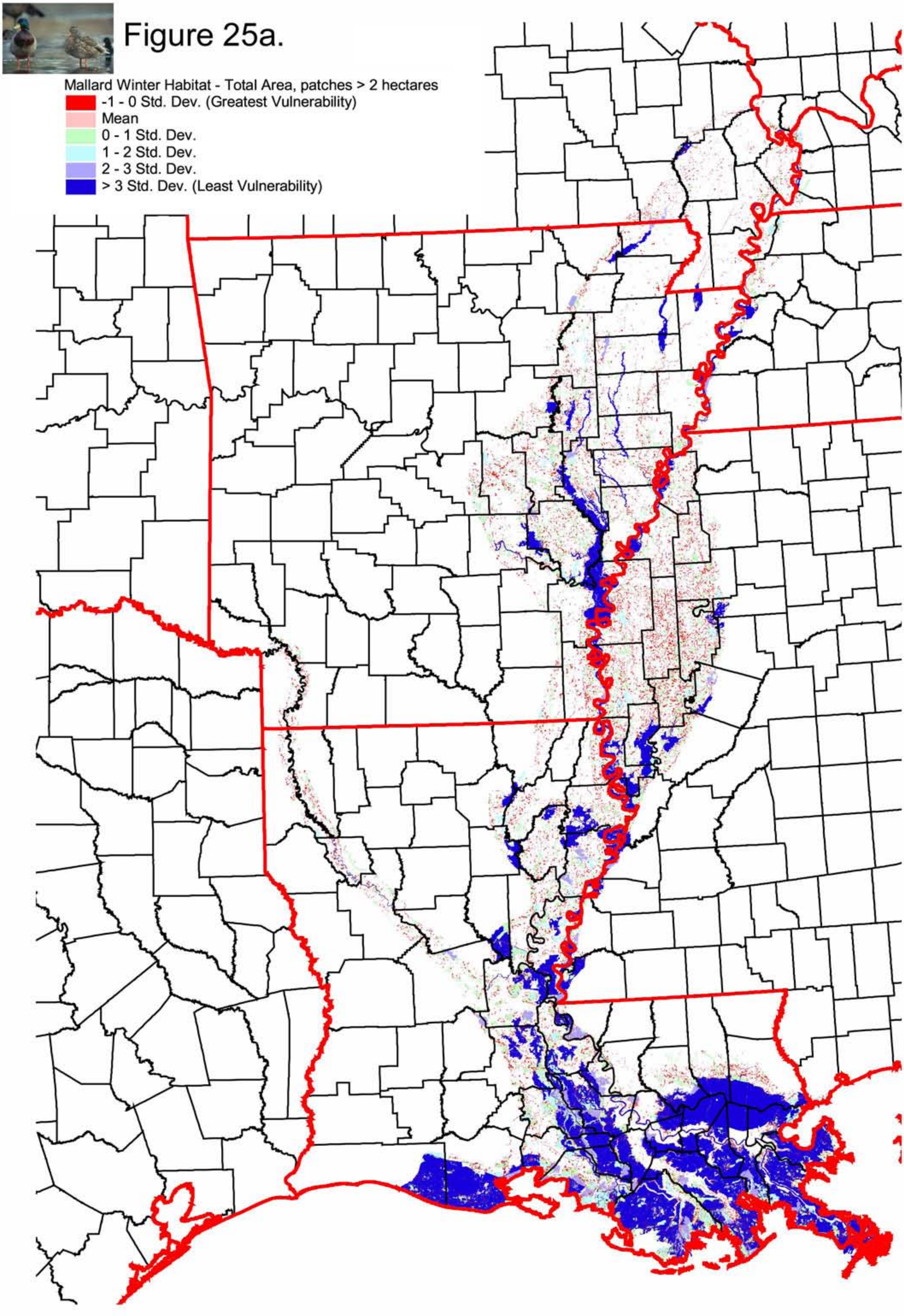
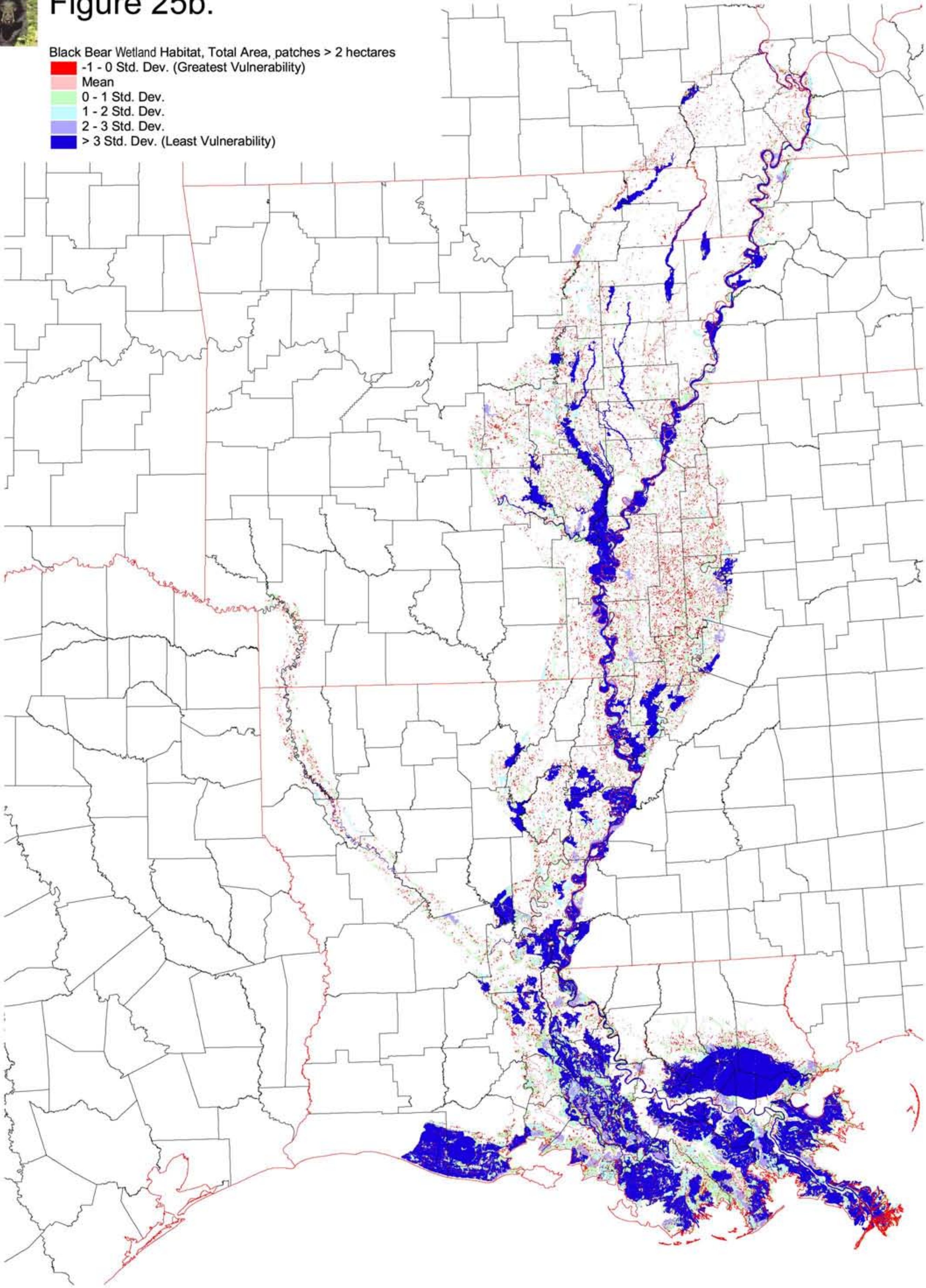
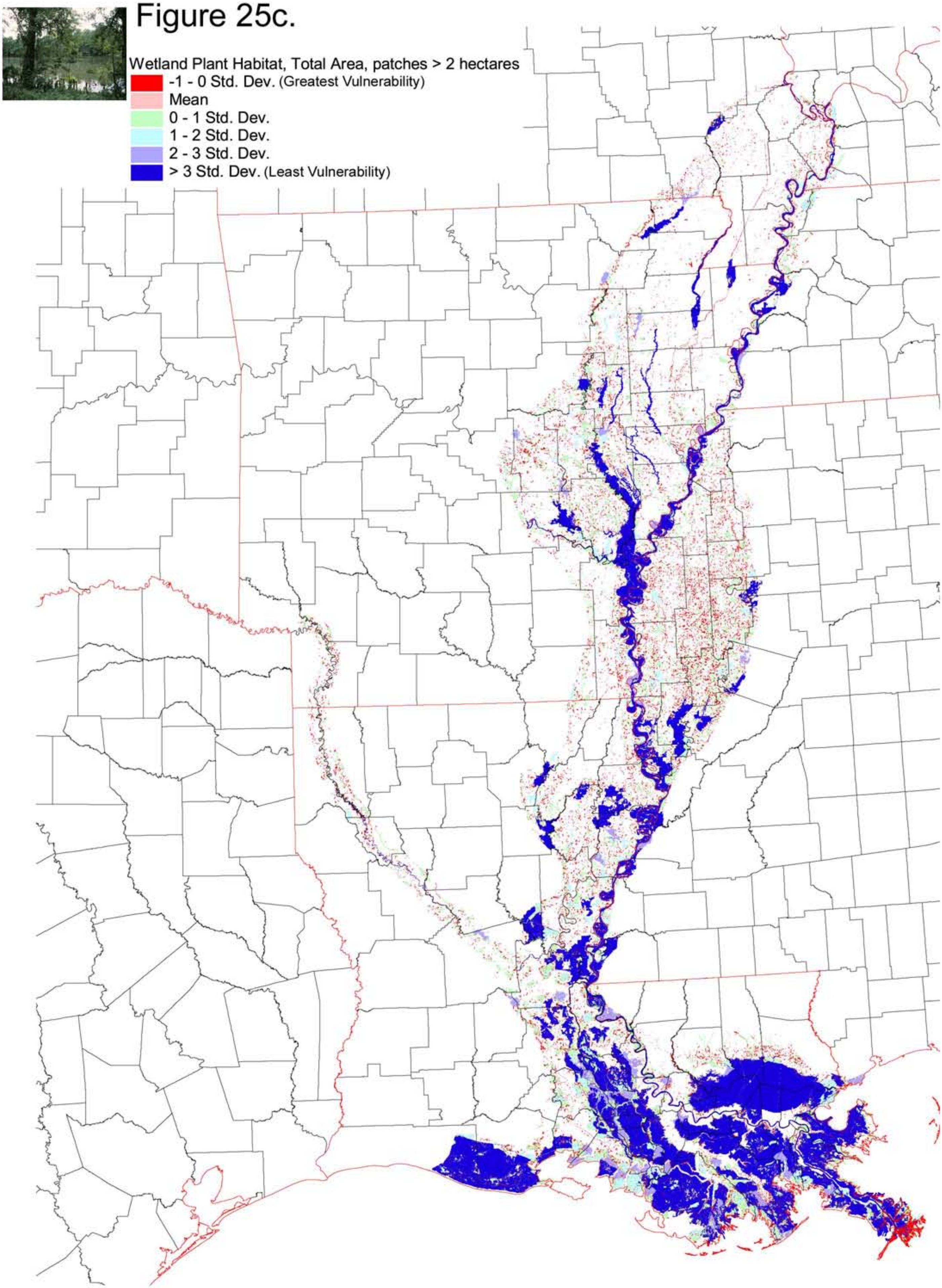

Mallard Winter Habitat - Total Area, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25b.



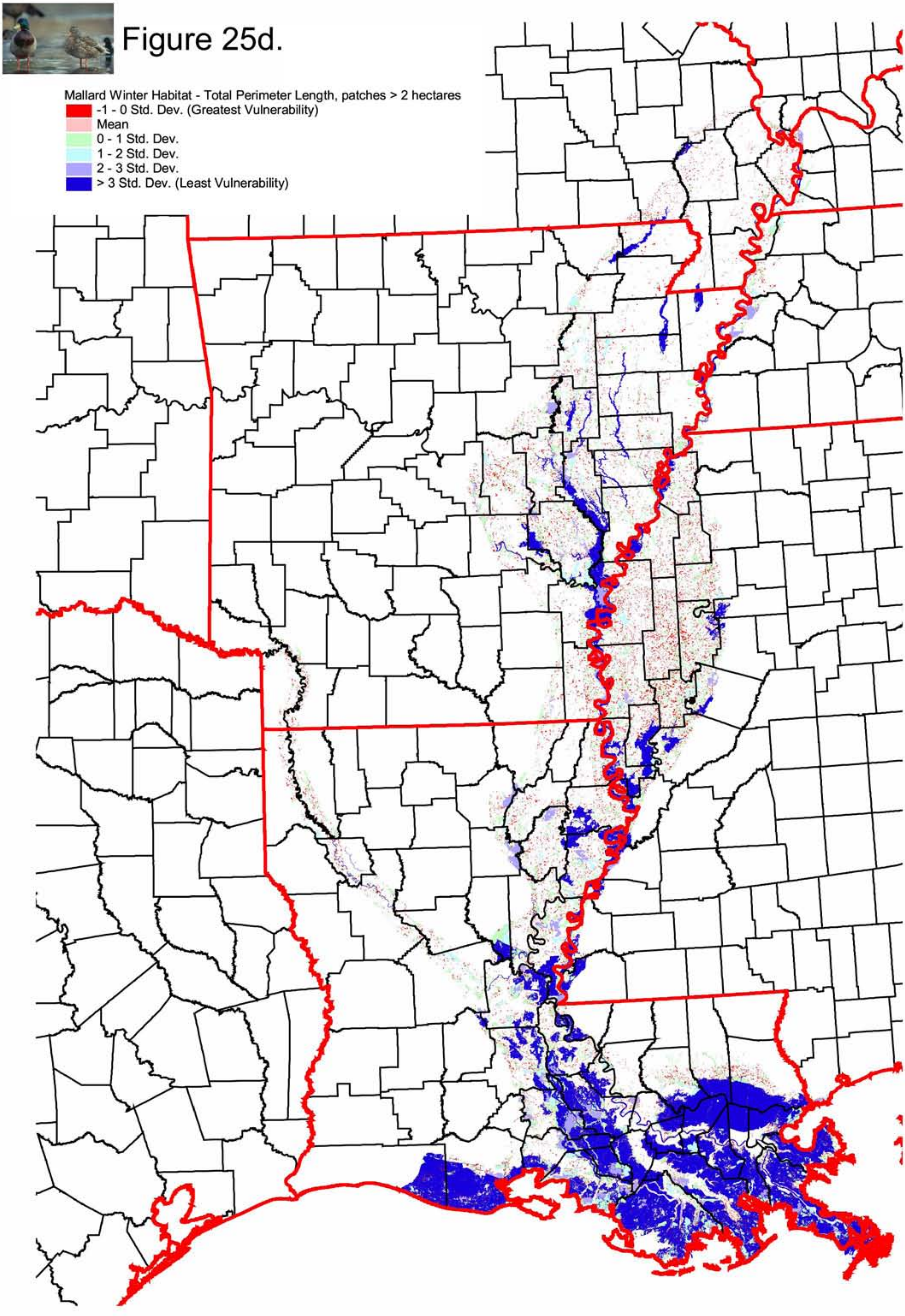
Black Bear Wetland Habitat, Total Area, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25c.


Wetland Plant Habitat, Total Area, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Total Perimeter)

Figure 25d.



Mallard Winter Habitat - Total Perimeter Length, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25e.

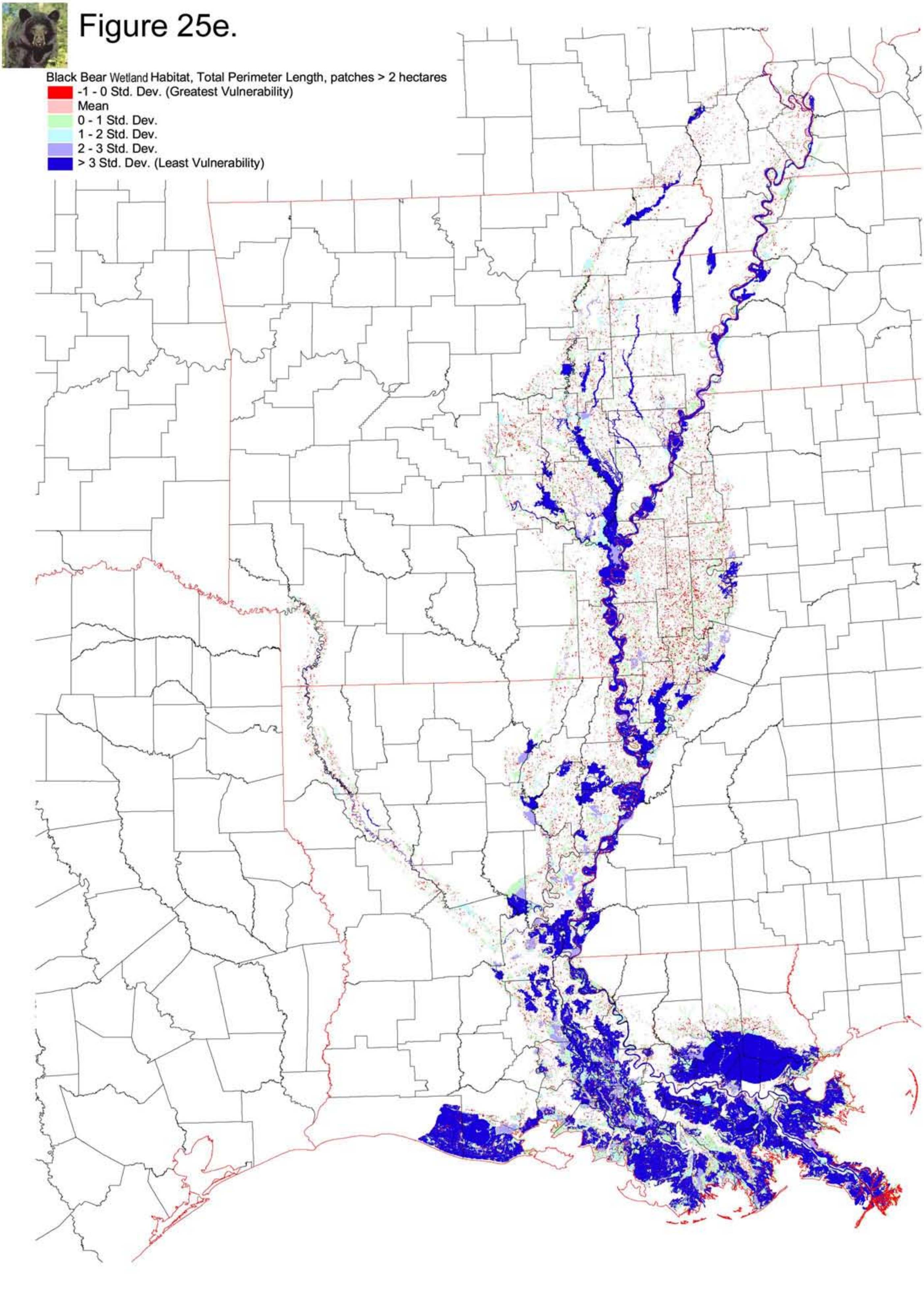
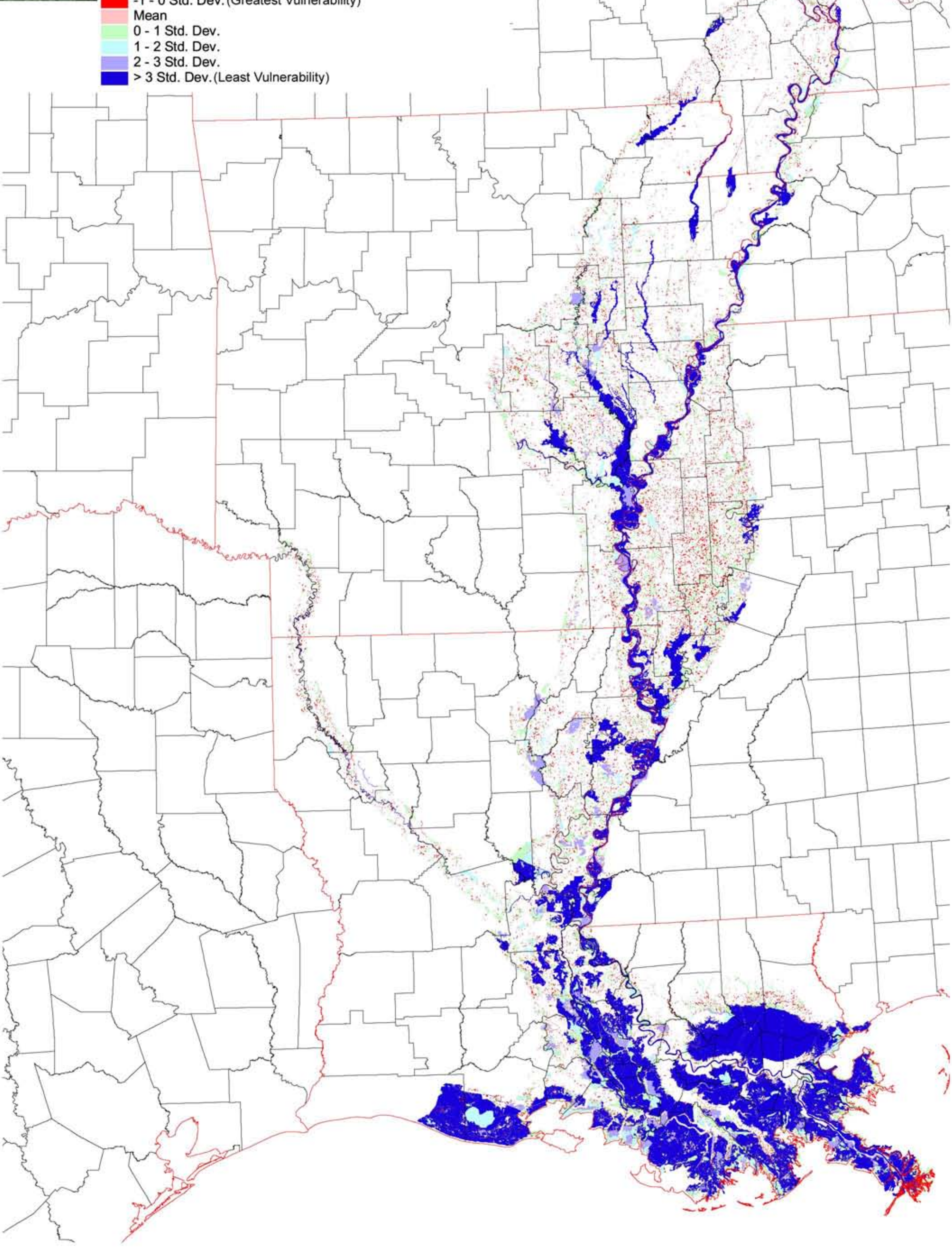
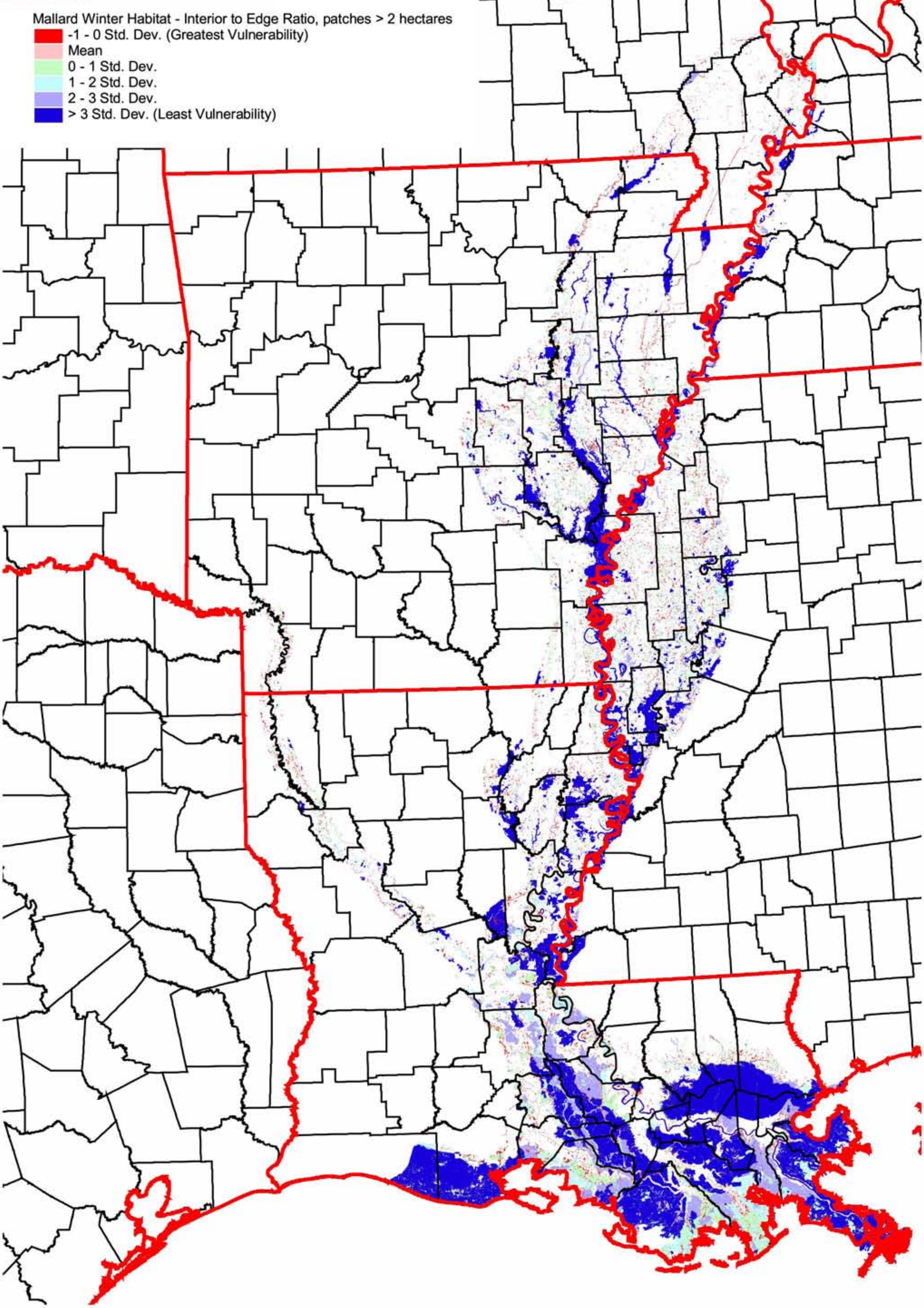

Black Bear Wetland Habitat, Total Perimeter Length, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25f.


Wetland Plant Habitat, Total Perimeter Length, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Interior-to-Edge Ratio)

Figure 25g.



Mallard Winter Habitat - Interior to Edge Ratio, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25h.

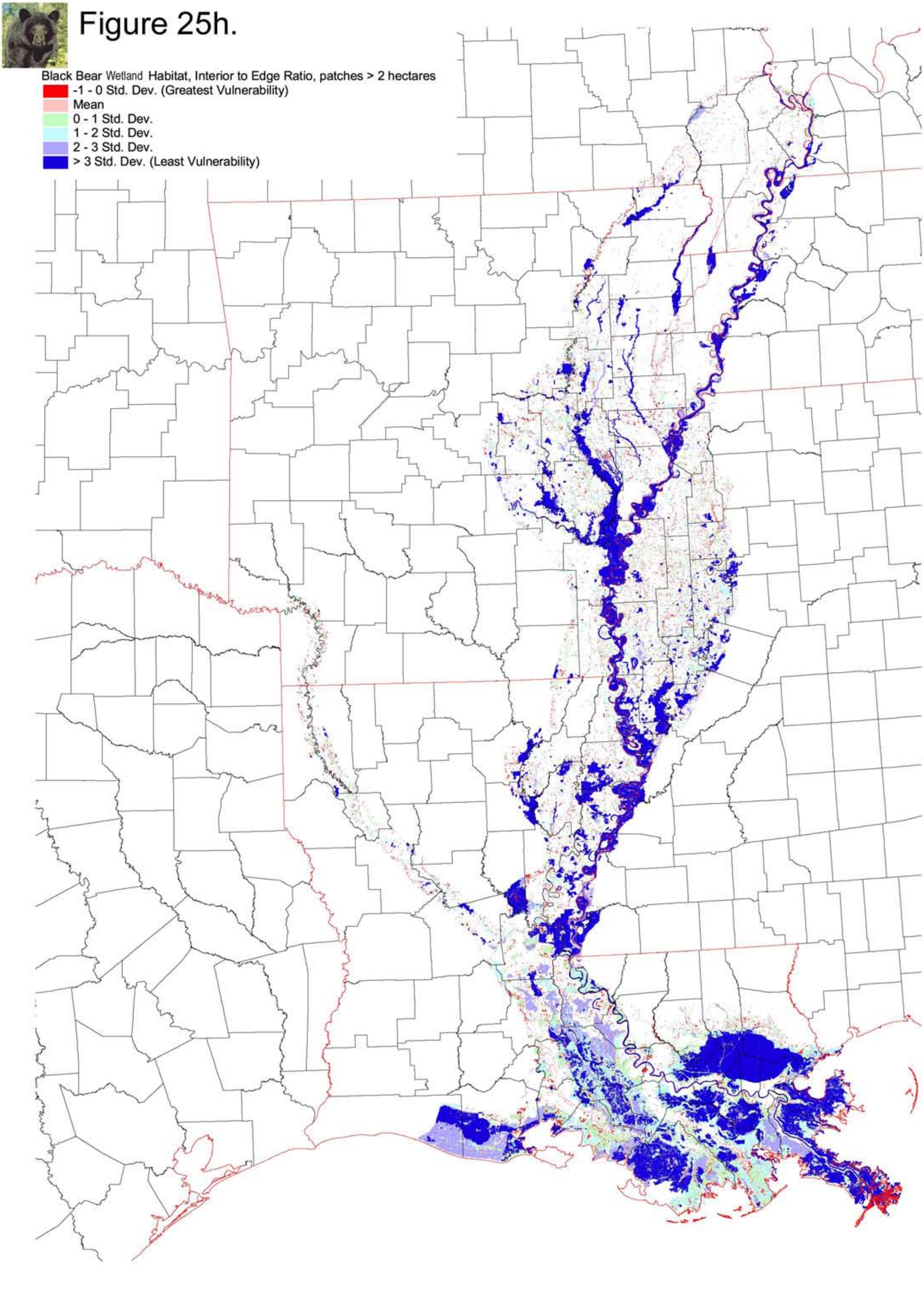
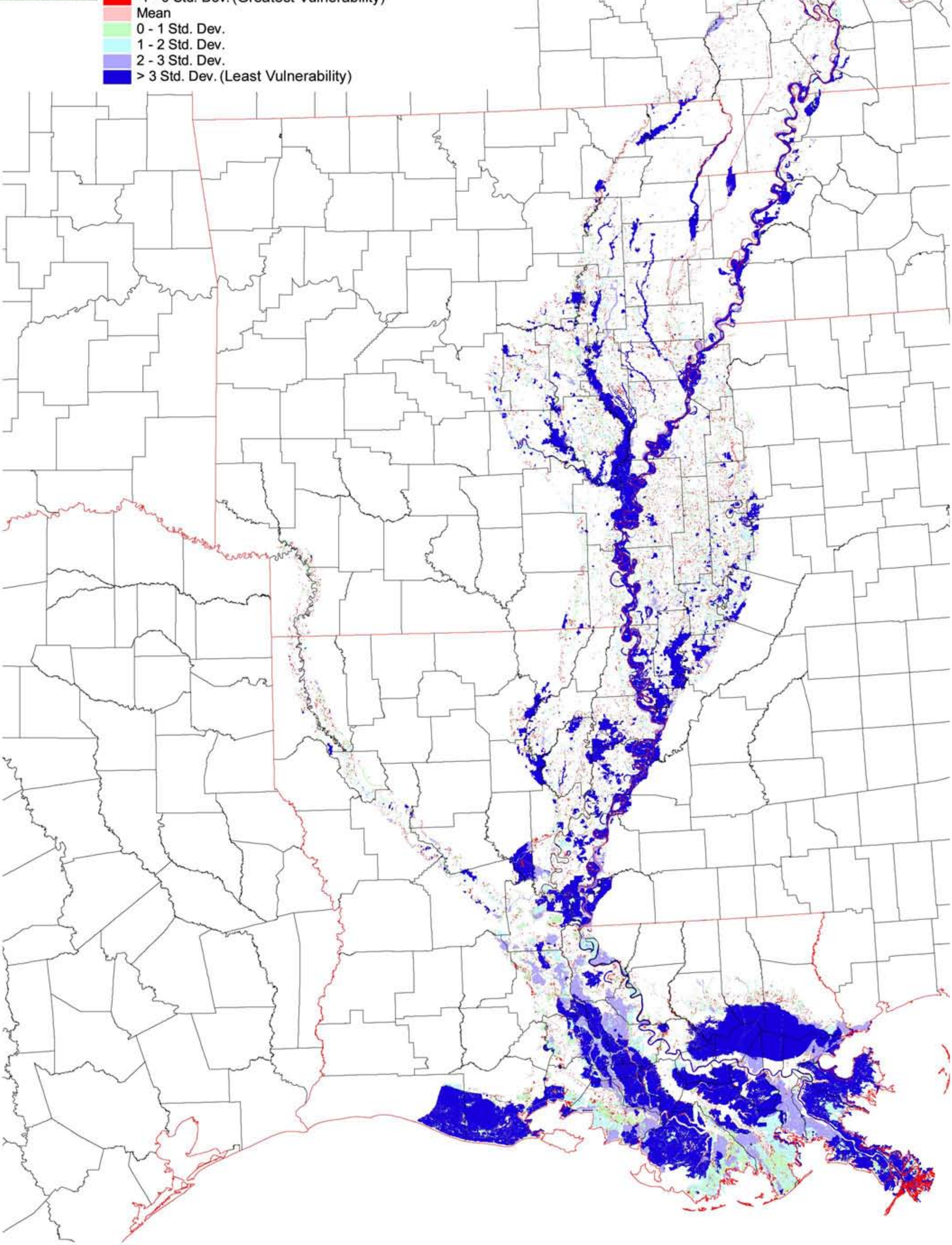

Black Bear Wetland Habitat, Interior to Edge Ratio, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25i.


Wetland Plant Habitat, Interior to Edge Ratio, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Circularity Index)

Figure 25j.

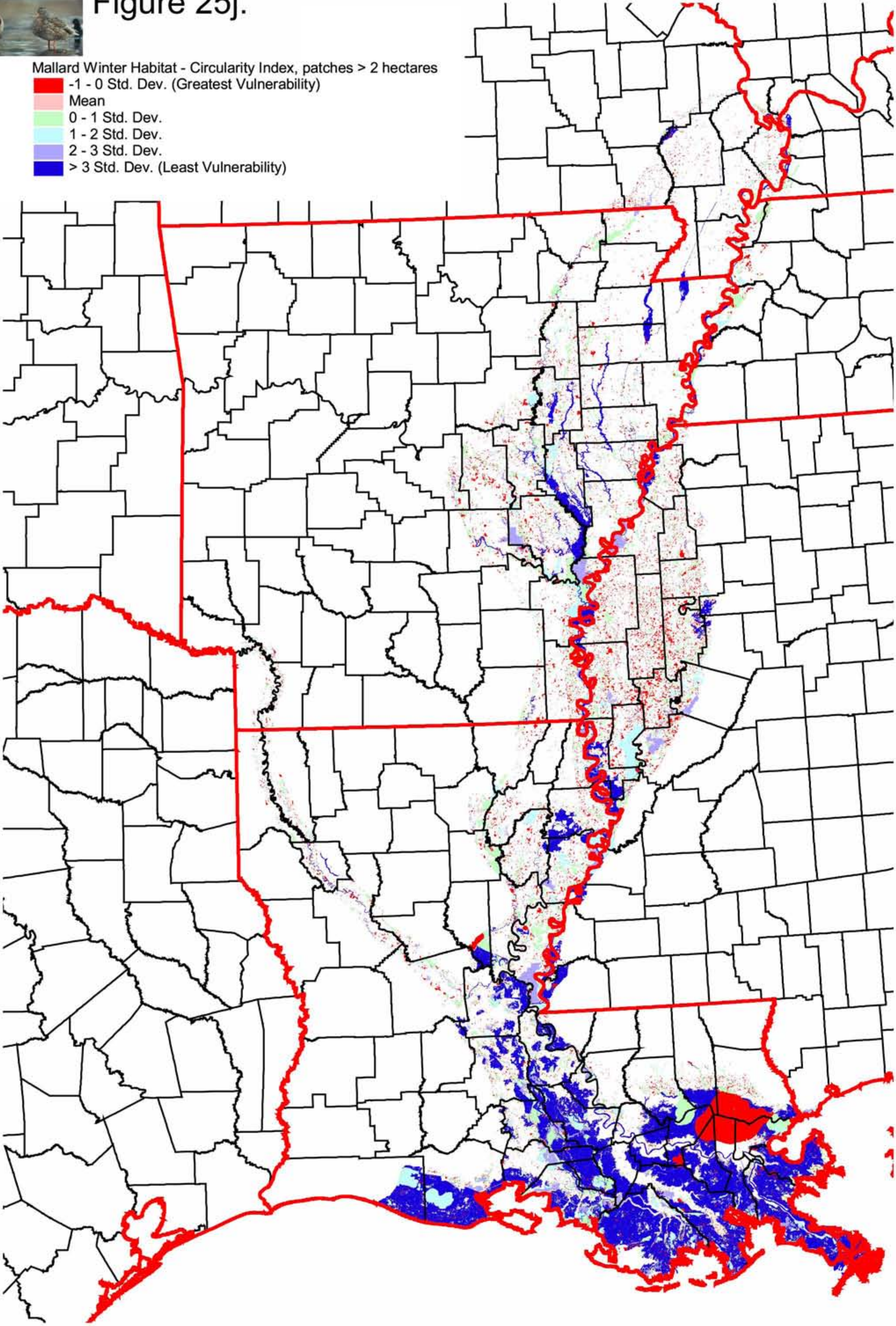

Mallard Winter Habitat - Circularity Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25k.

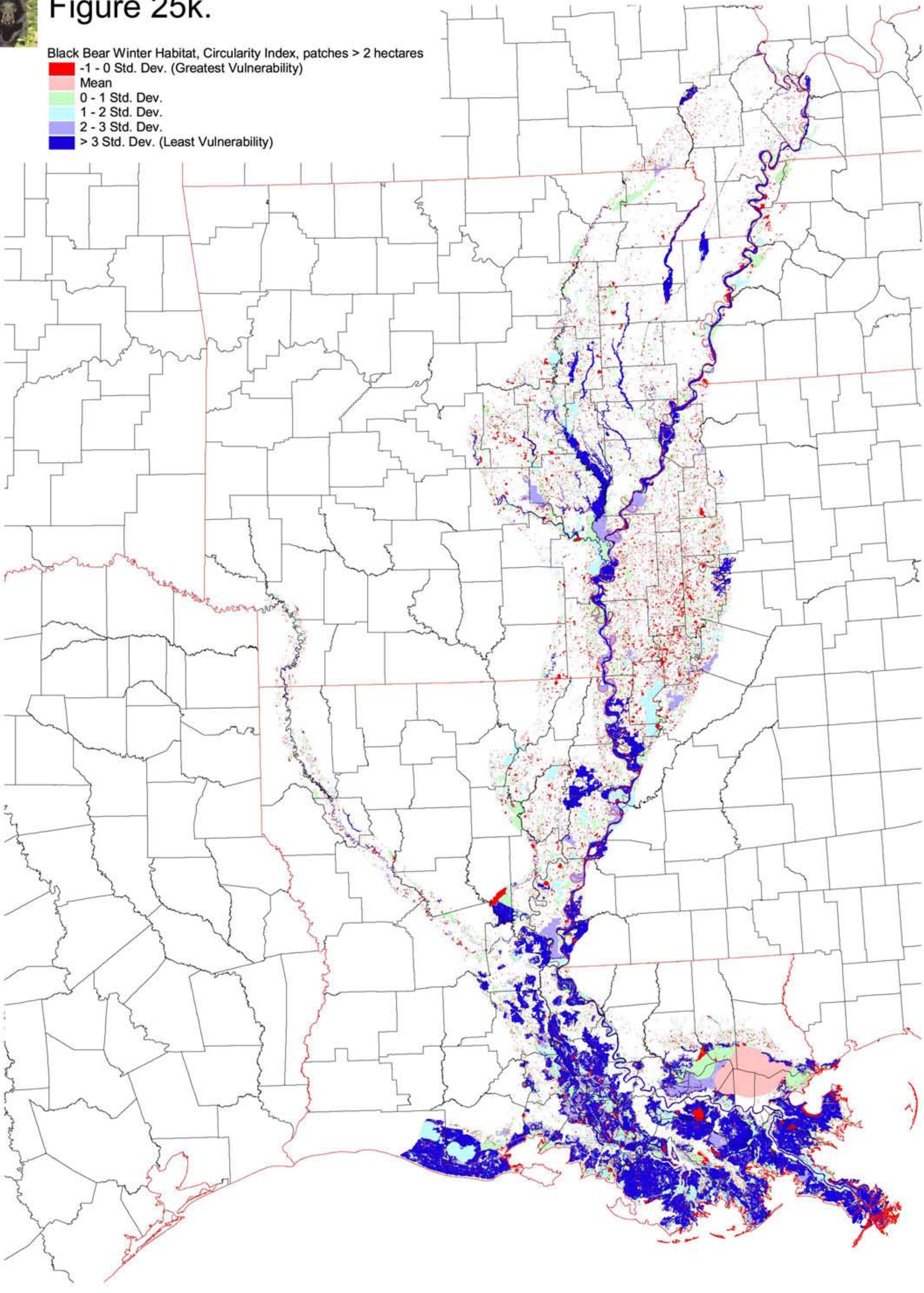
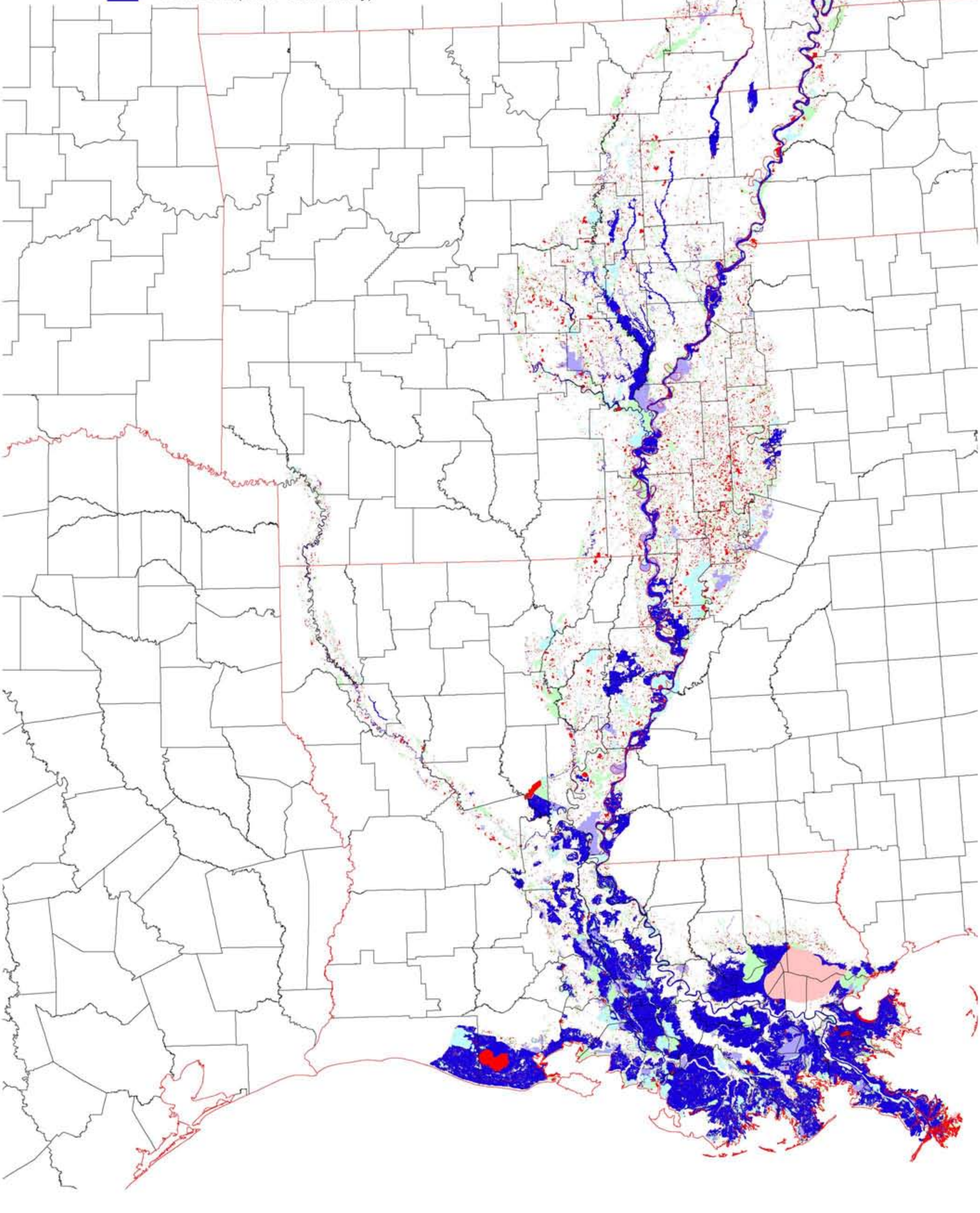

Black Bear Winter Habitat, Circularity Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

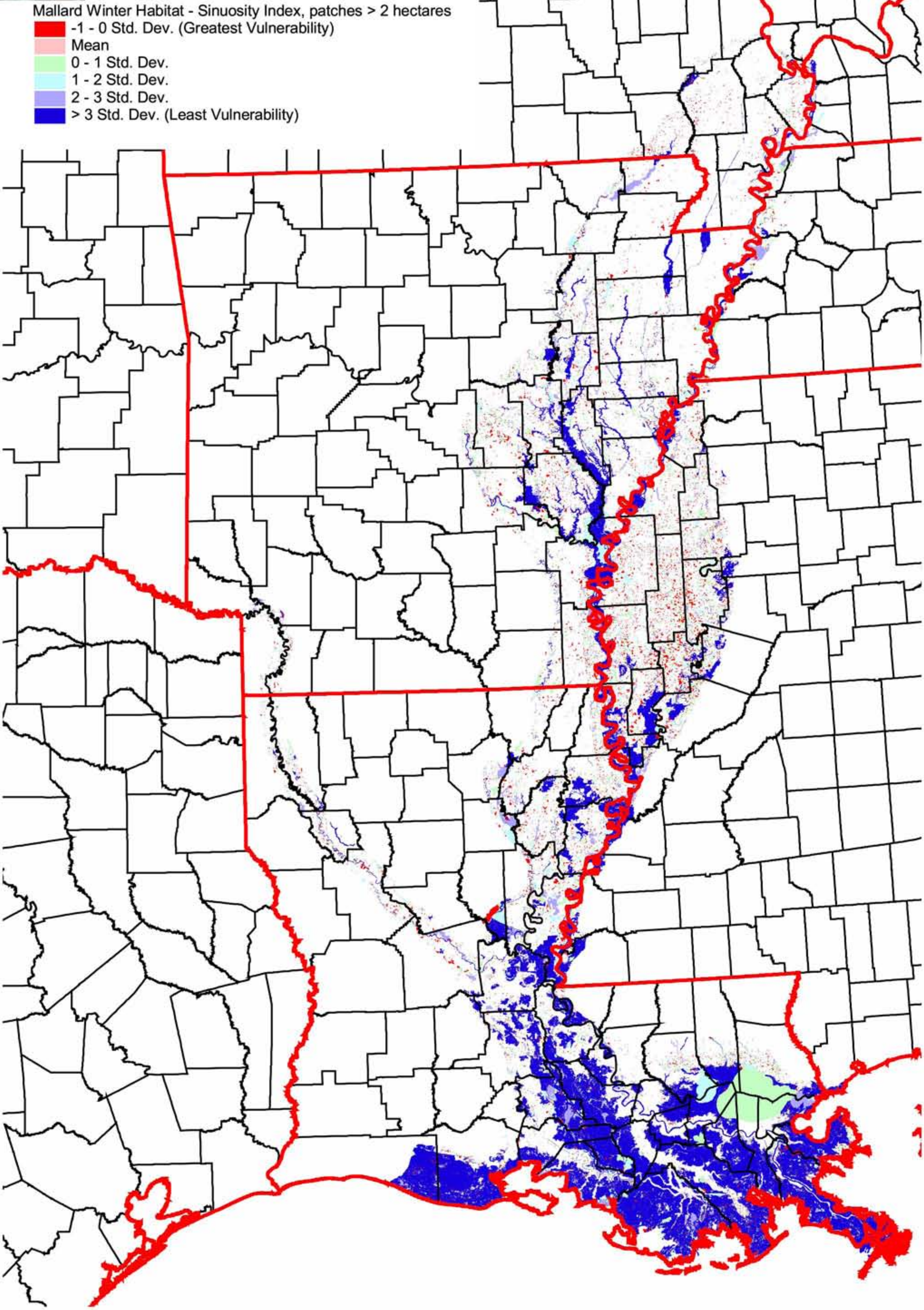
Figure 25l.



Wetland Plant Habitat, Circularity Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

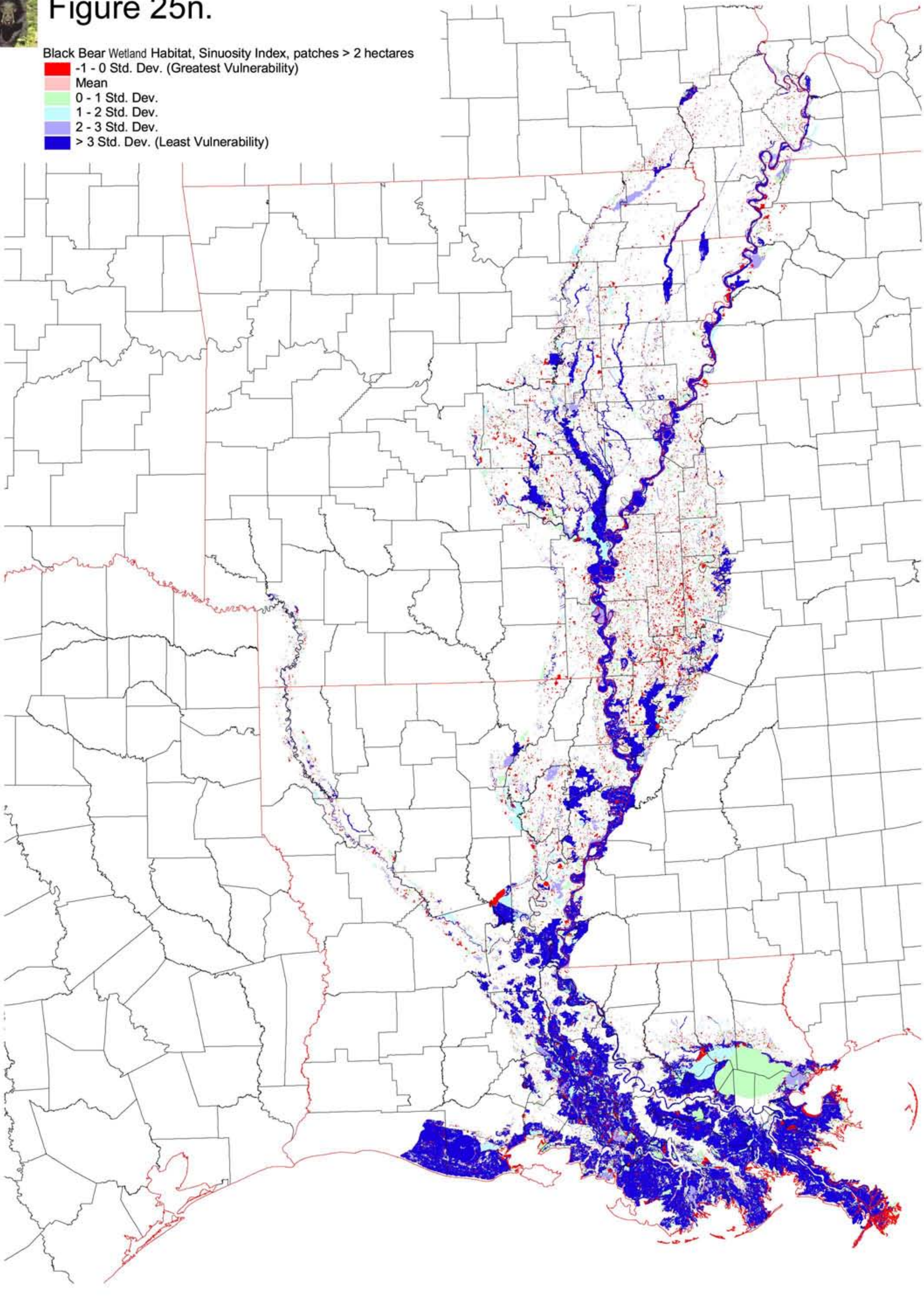
Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Sinuosity Index)

Figure 25m.



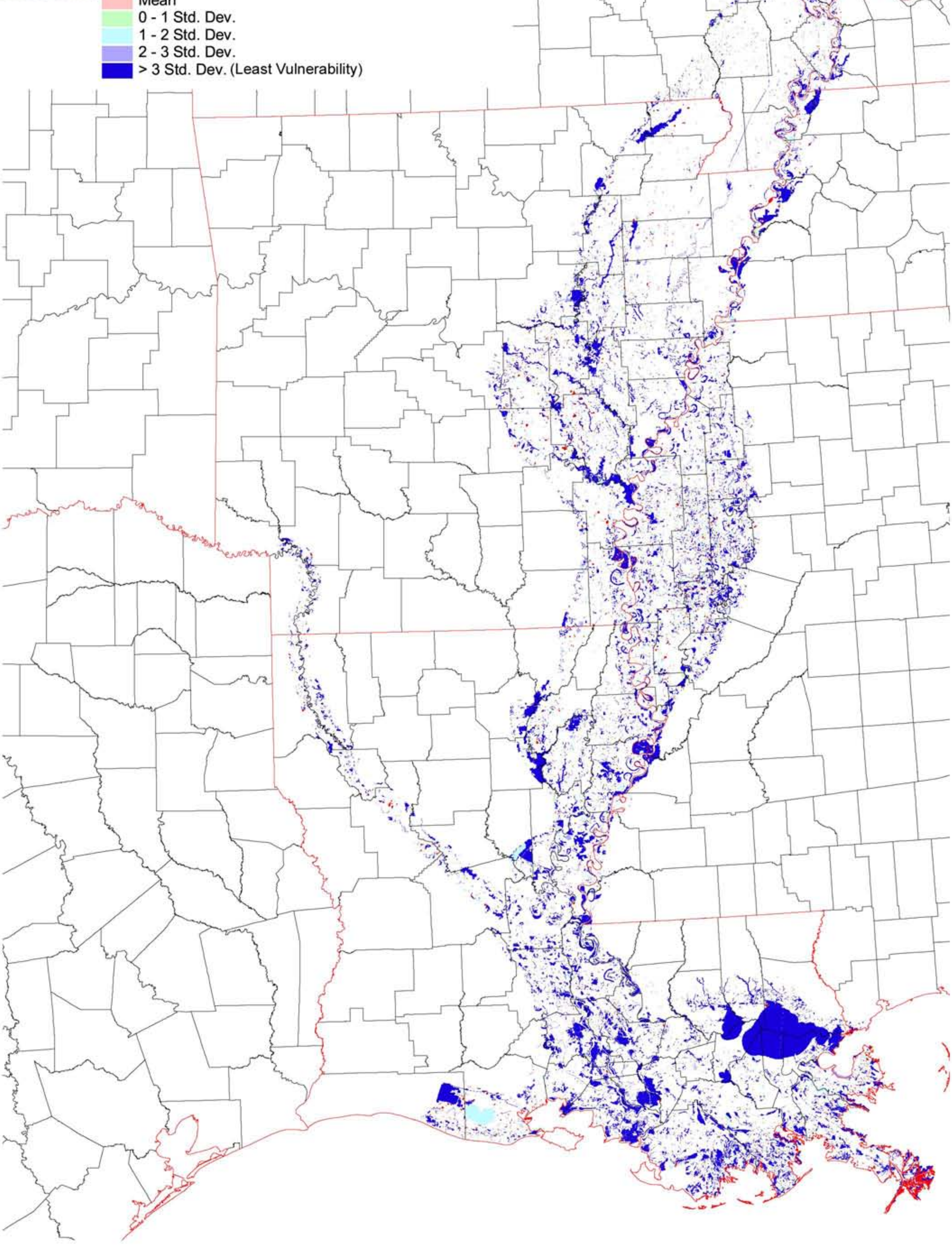
Mallard Winter Habitat - Sinuosity Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25n.



Black Bear Wetland Habitat, Sinuosity Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25o.


Wetland Plant Habitat, Sinuosity Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Unified Patch Index)

Figure 25p.

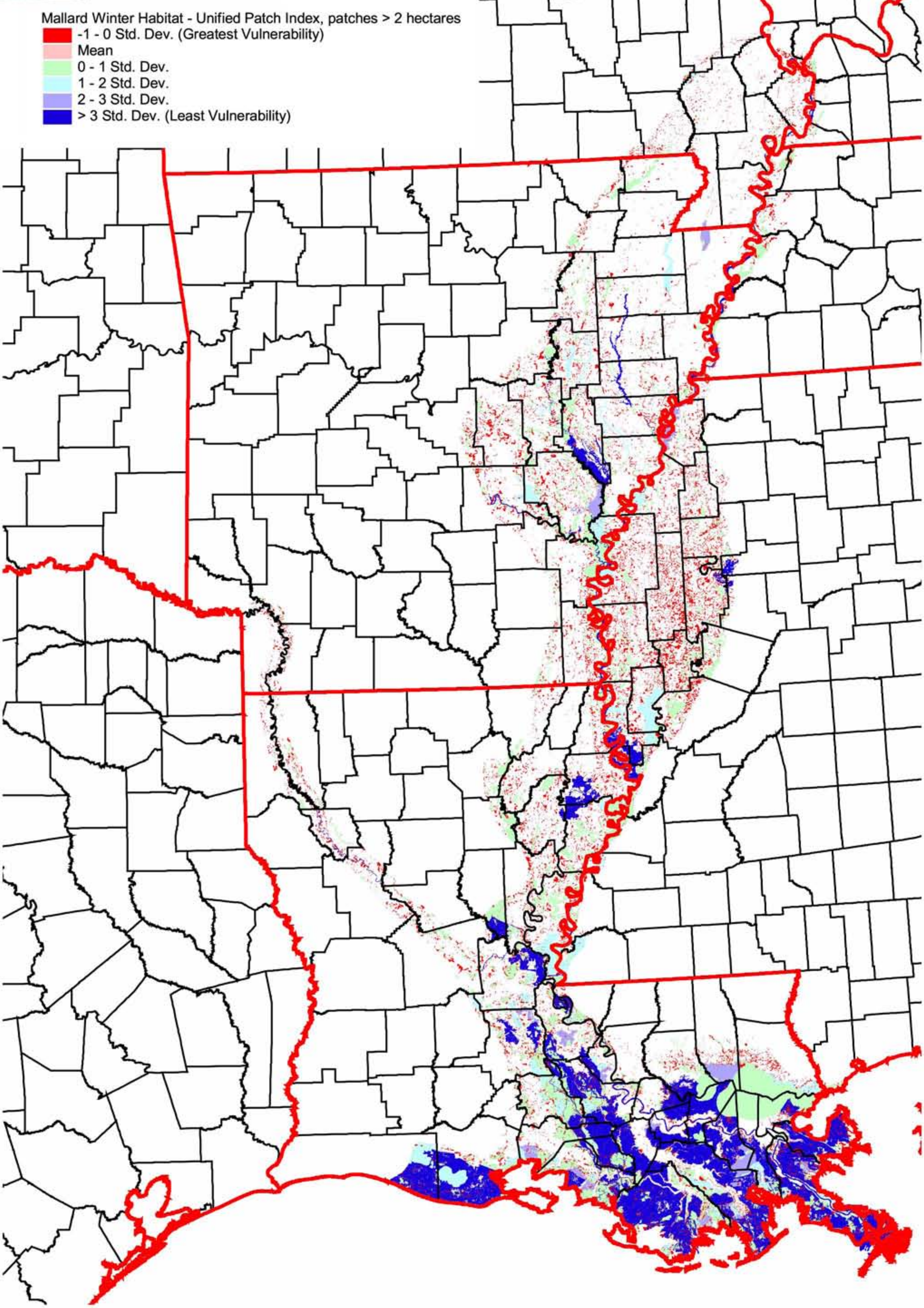

Mallard Winter Habitat - Unified Patch Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 25q.

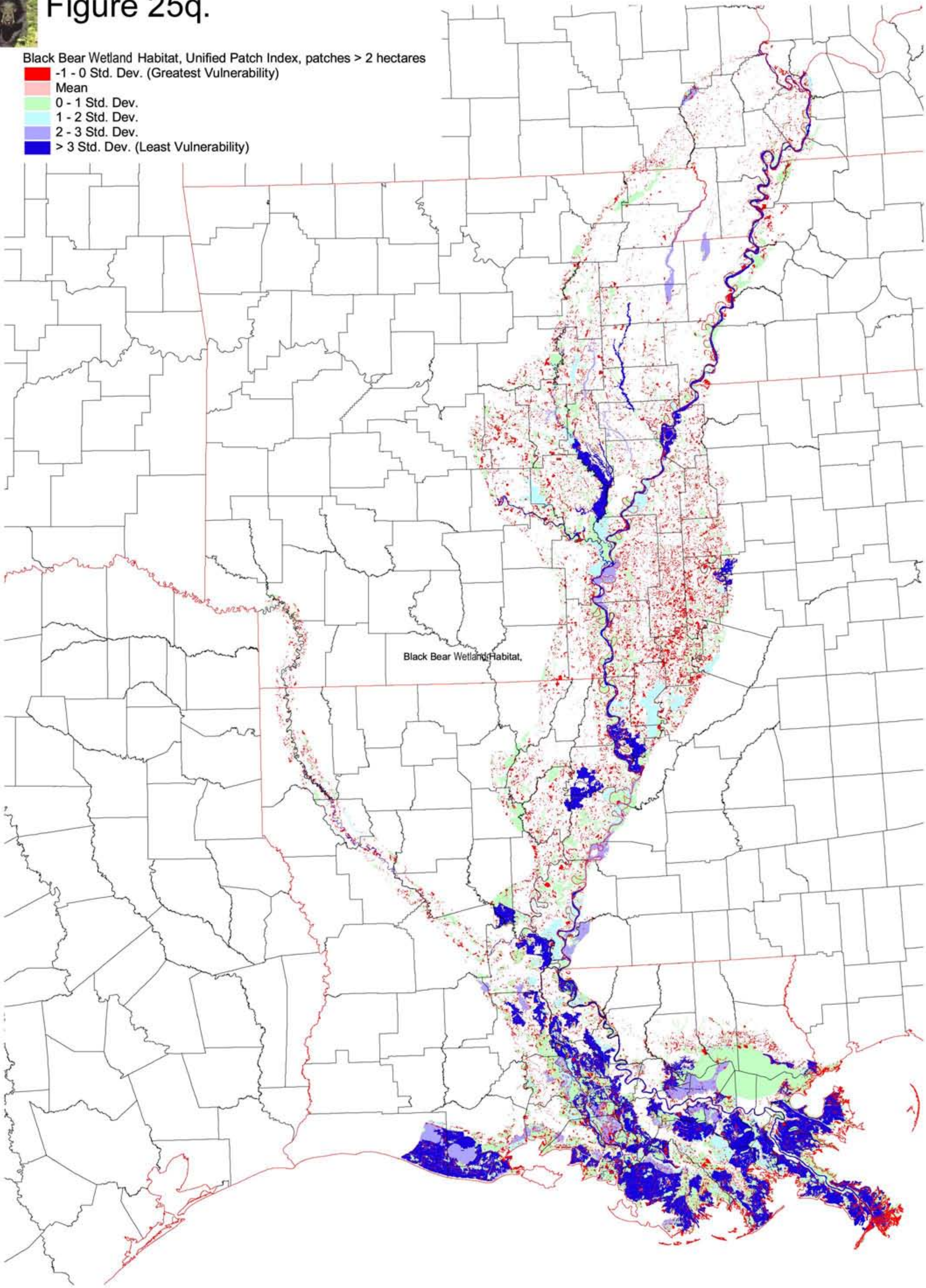
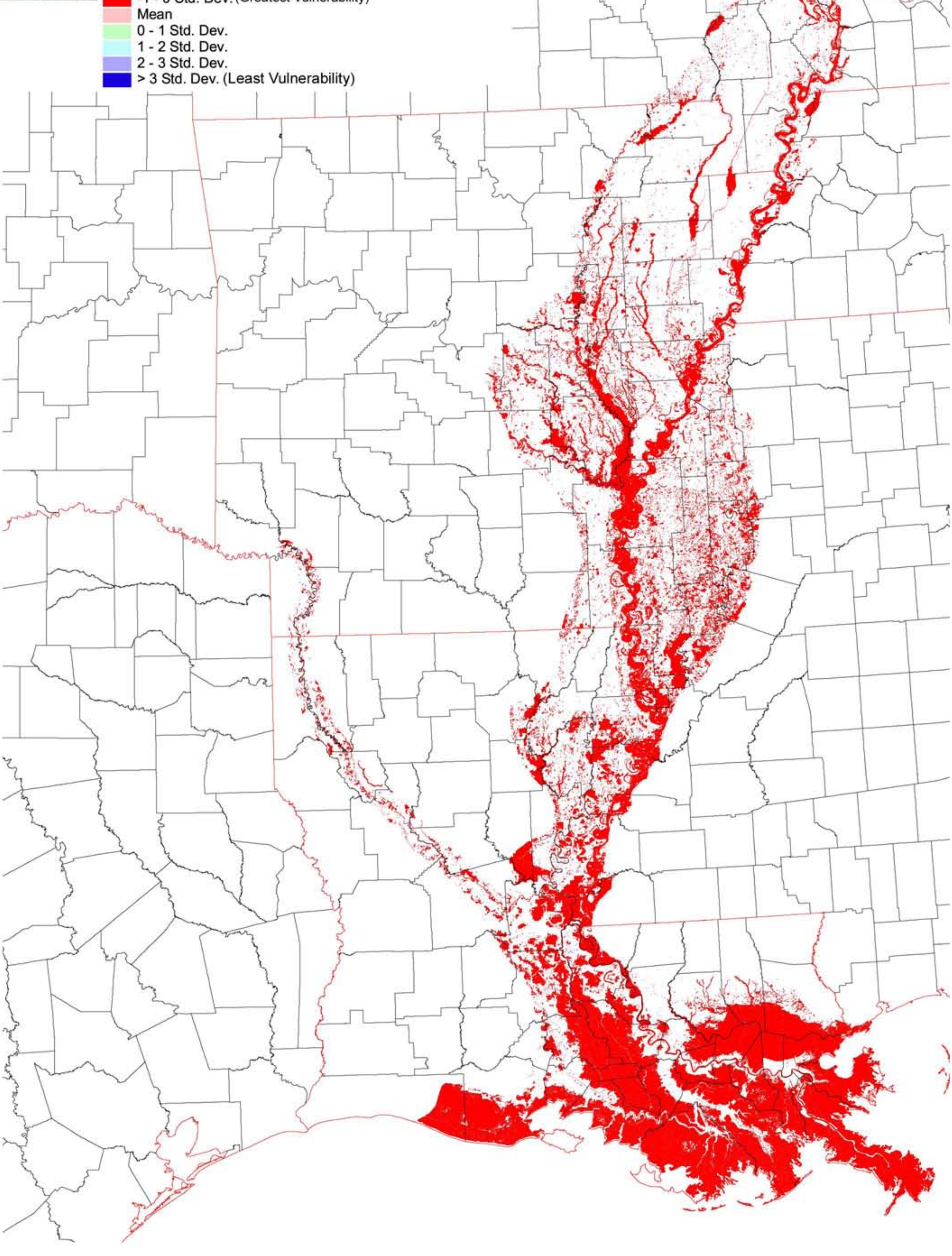

Black Bear Wetland Habitat, Unified Patch Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)
Black Bear Wetland Habitat,

Figure 25r.



Wetland Plant Habitat, Unified Patch Index, patches > 2 hectares
-1 - 0 Std. Dev. (Greatest Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Patch Human-Induced Disturbance)

Figure 26a. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total road length.
Figure 26b. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total road length.
Figure 26c. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total road length.

Figure 26d. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch total road density.
Figure 26e. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch total road density.
Figure 26f. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch total road density.

Figure 26g. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch road index.
Figure 26h. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch road index.
Figure 26i. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch road index.

Figure 26j. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch human population density in 1990.
Figure 26k. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch human population density in 1990.
Figure 26l. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch human population density in 1990.

Figure 26m. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch estimated human population density in 2011.
Figure 26n. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch estimated human population density in 2011.
Figure 26o. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch estimated human population density in 2011.

Figure 26p. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch human population density change from 1990 to 2011.
Figure 26q. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch human population density change from 1990 to 2011.

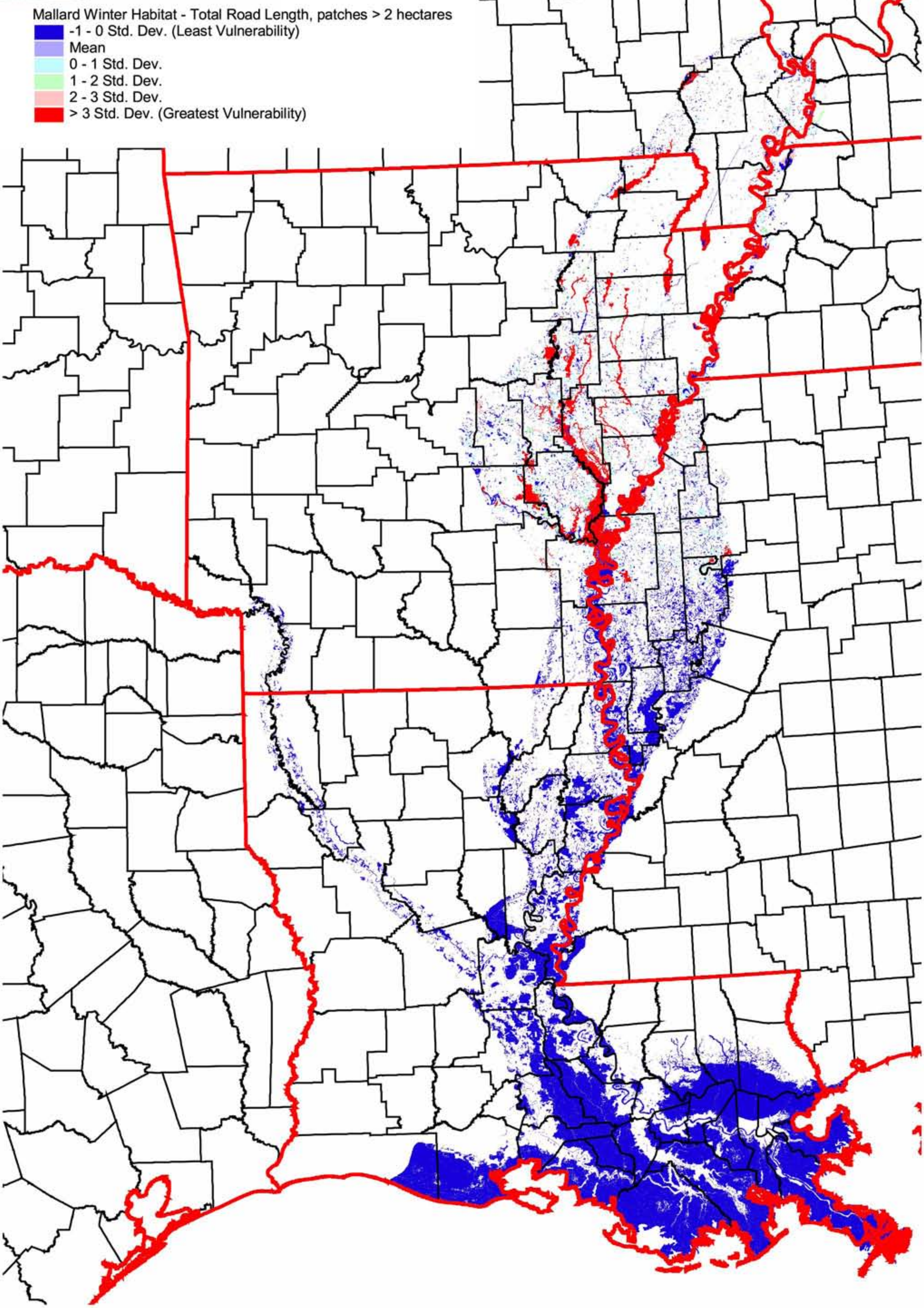
Figure 26r. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch human population density change from 1990 to 2011.

Figure 26s. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch unified human index.
Figure 26t. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch unified human index.
Figure 26u. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch unified human index.

Figure 26v. Mississippi Alluvial Valley Ecoregion (MAVE) mallard duck winter habitat vulnerability (> 2 ha) in terms of habitat patch unified vulnerability index.
Figure 26w. Mississippi Alluvial Valley Ecoregion (MAVE) black bear wetland habitat vulnerability (> 2 ha) in terms of habitat patch unified vulnerability index.
Figure 26x. Mississippi Alluvial Valley Ecoregion (MAVE) wetland plant habitat vulnerability (> 2 ha) in terms of habitat patch unified vulnerability index.

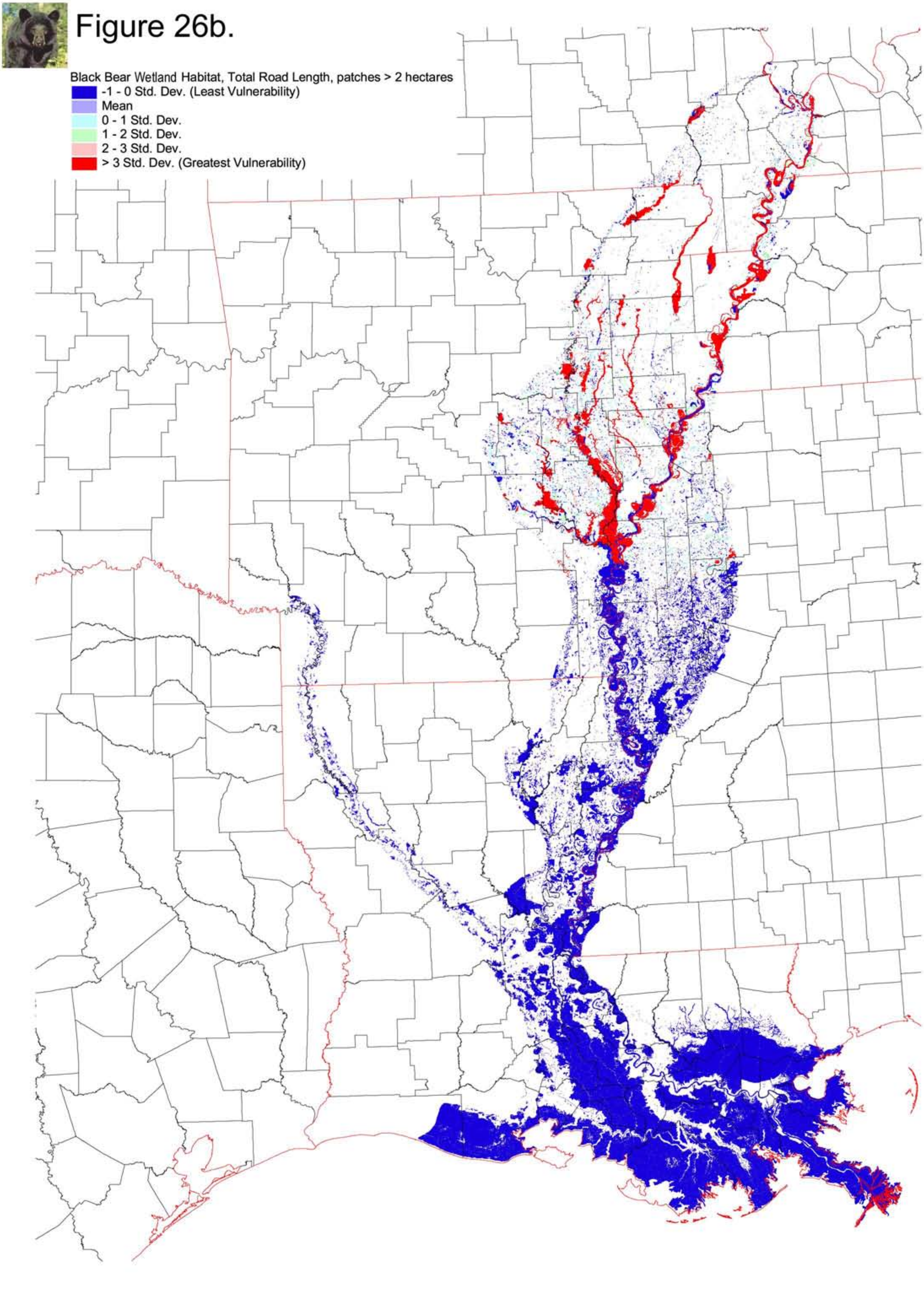
Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Total Road Length)

Figure 26a.



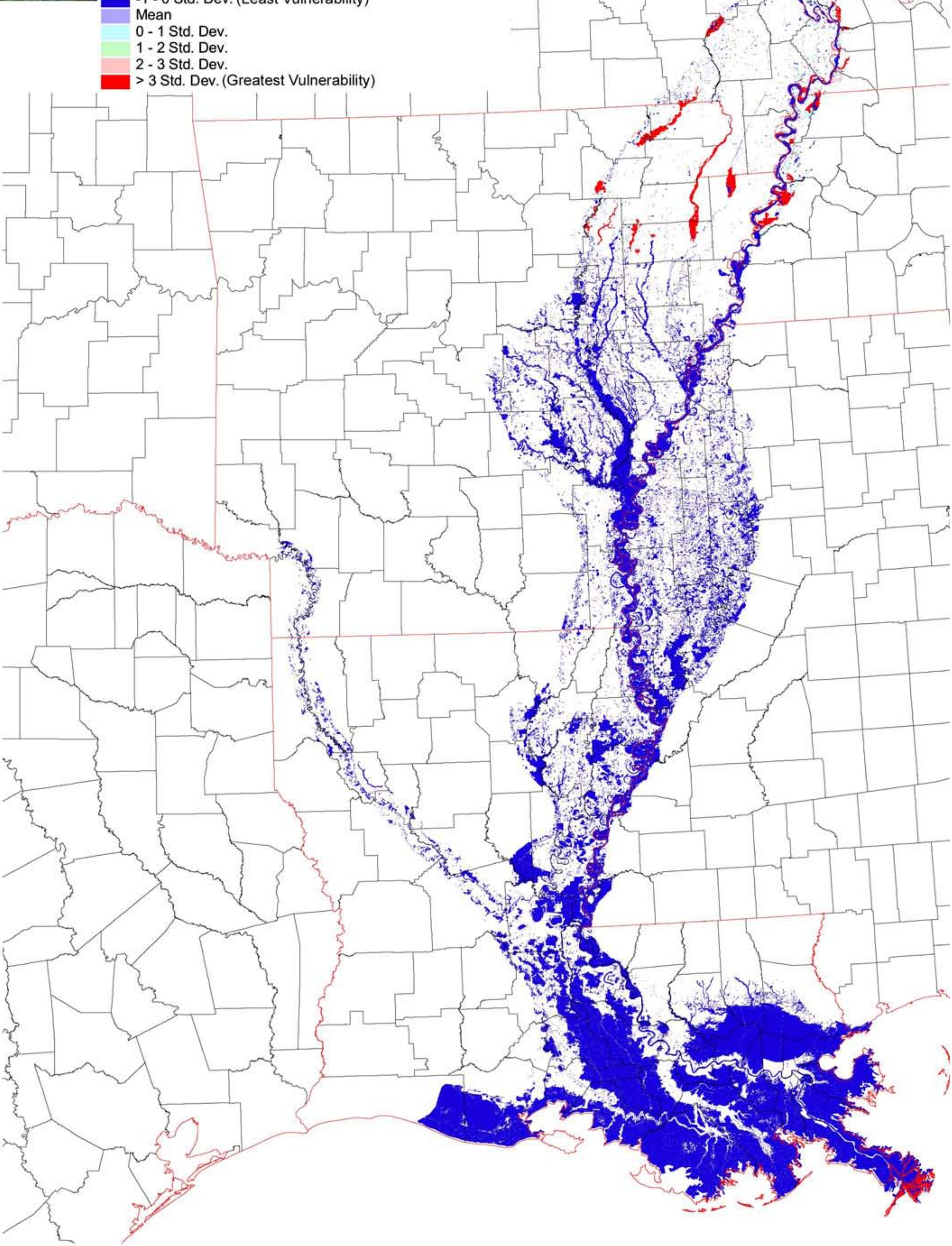
Mallard Winter Habitat - Total Road Length, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26b.



Black Bear Wetland Habitat, Total Road Length, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26c.



Wetland Plant Habitat, Total Road Length, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Total Road Density)

Figure 26d.

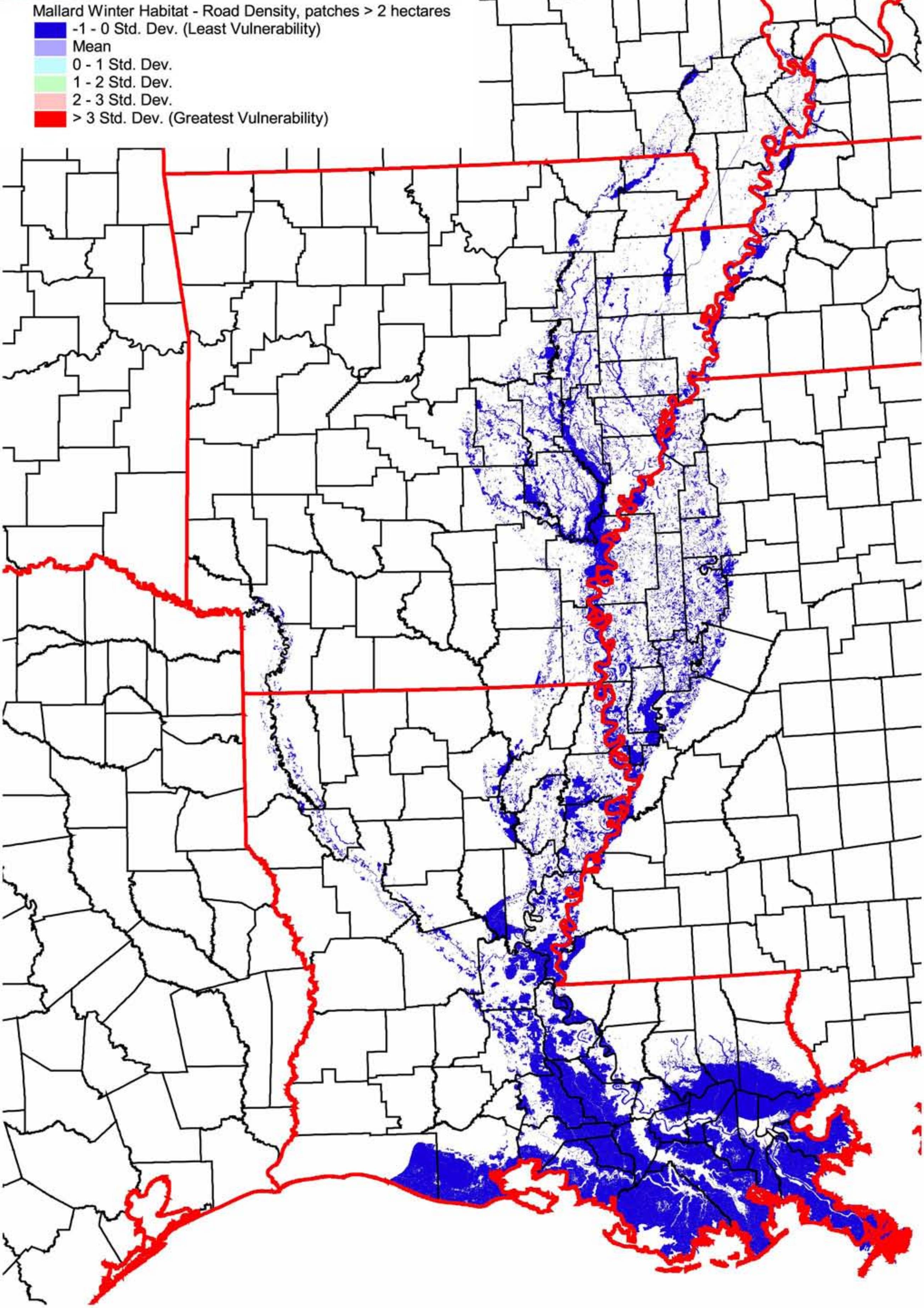

Mallard Winter Habitat - Road Density, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26e.

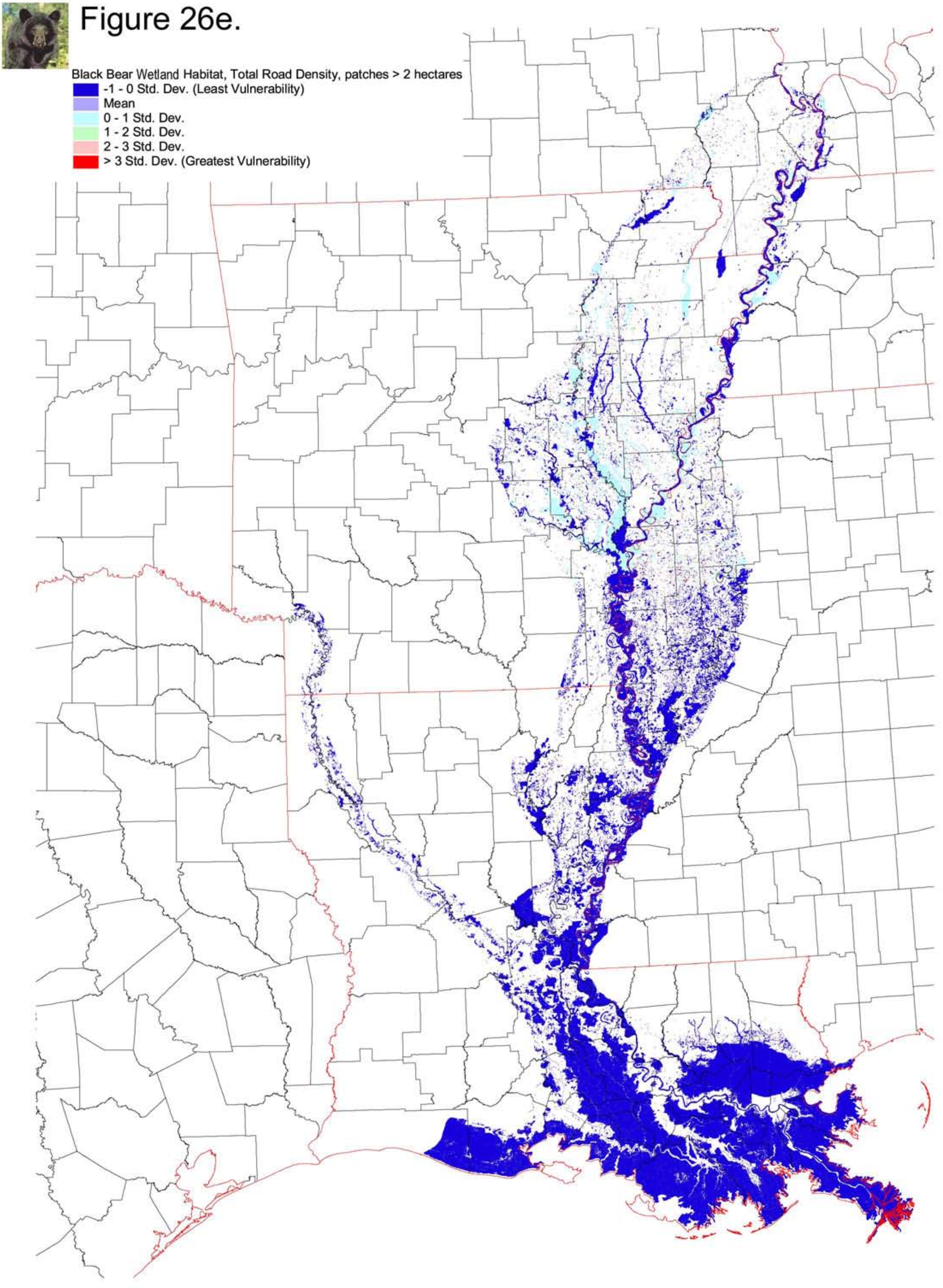
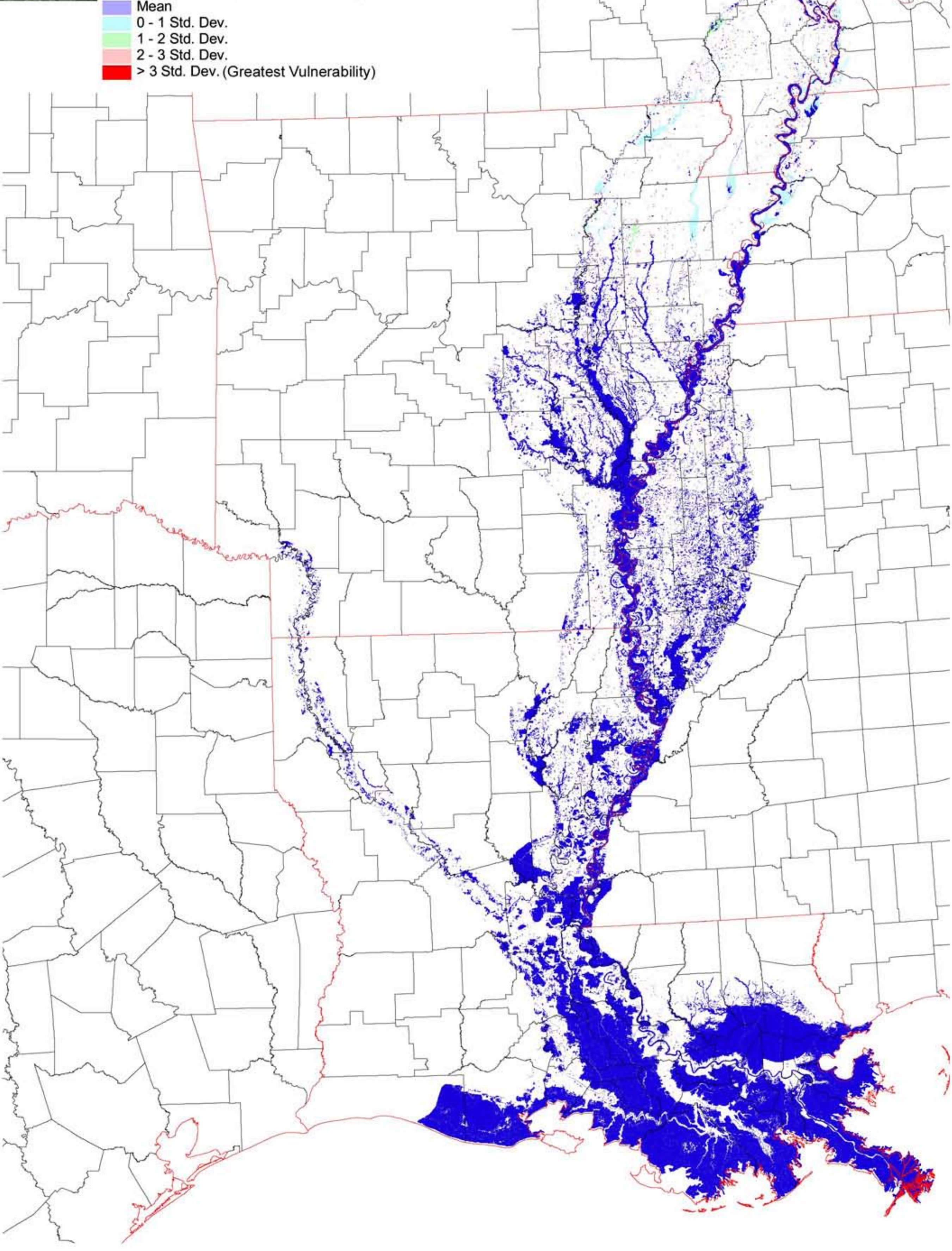

Black Bear Wetland Habitat, Total Road Density, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26f.



Wetland Plant Habitat, Total Road Density, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Road Index)

Figure 26g.

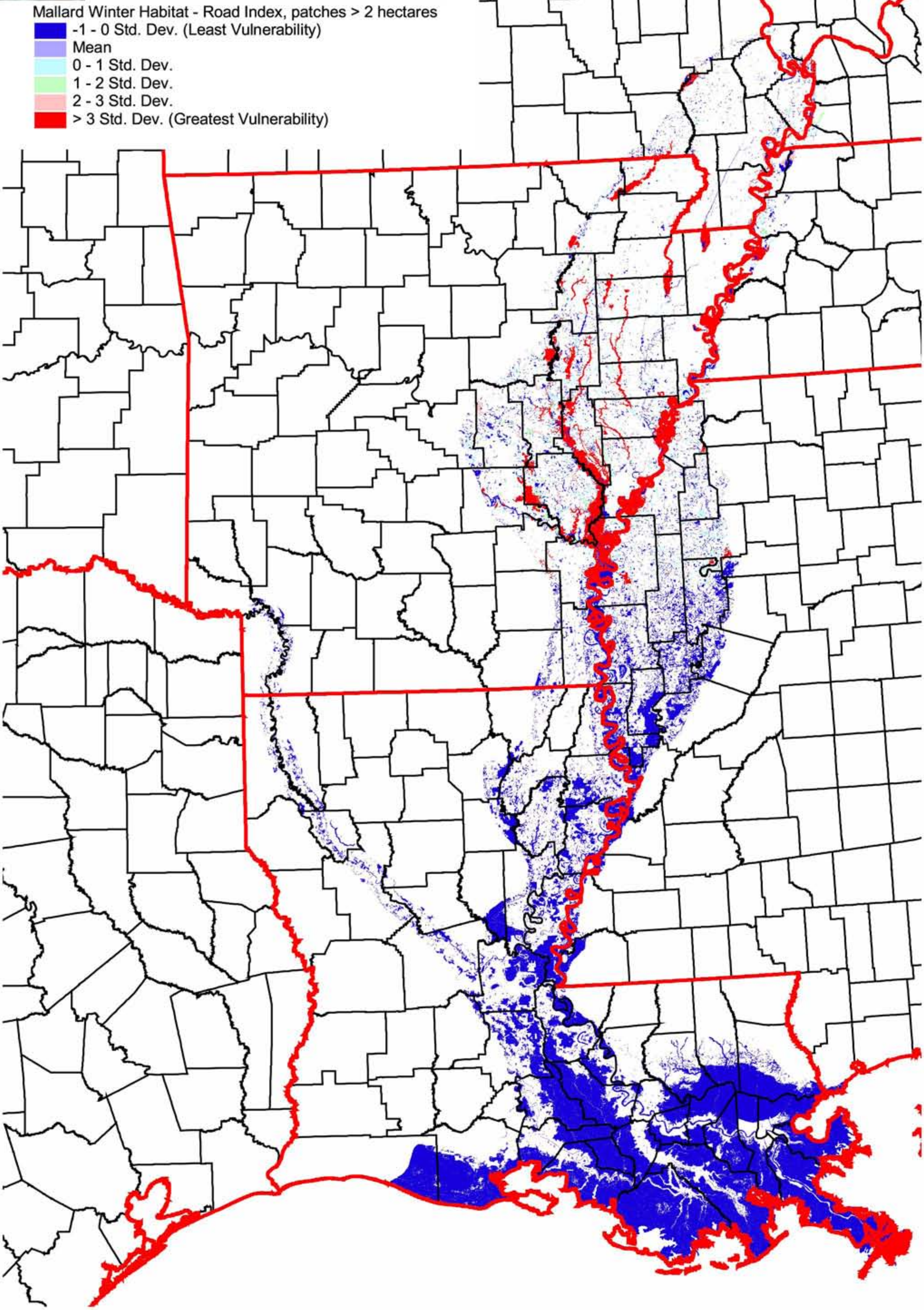
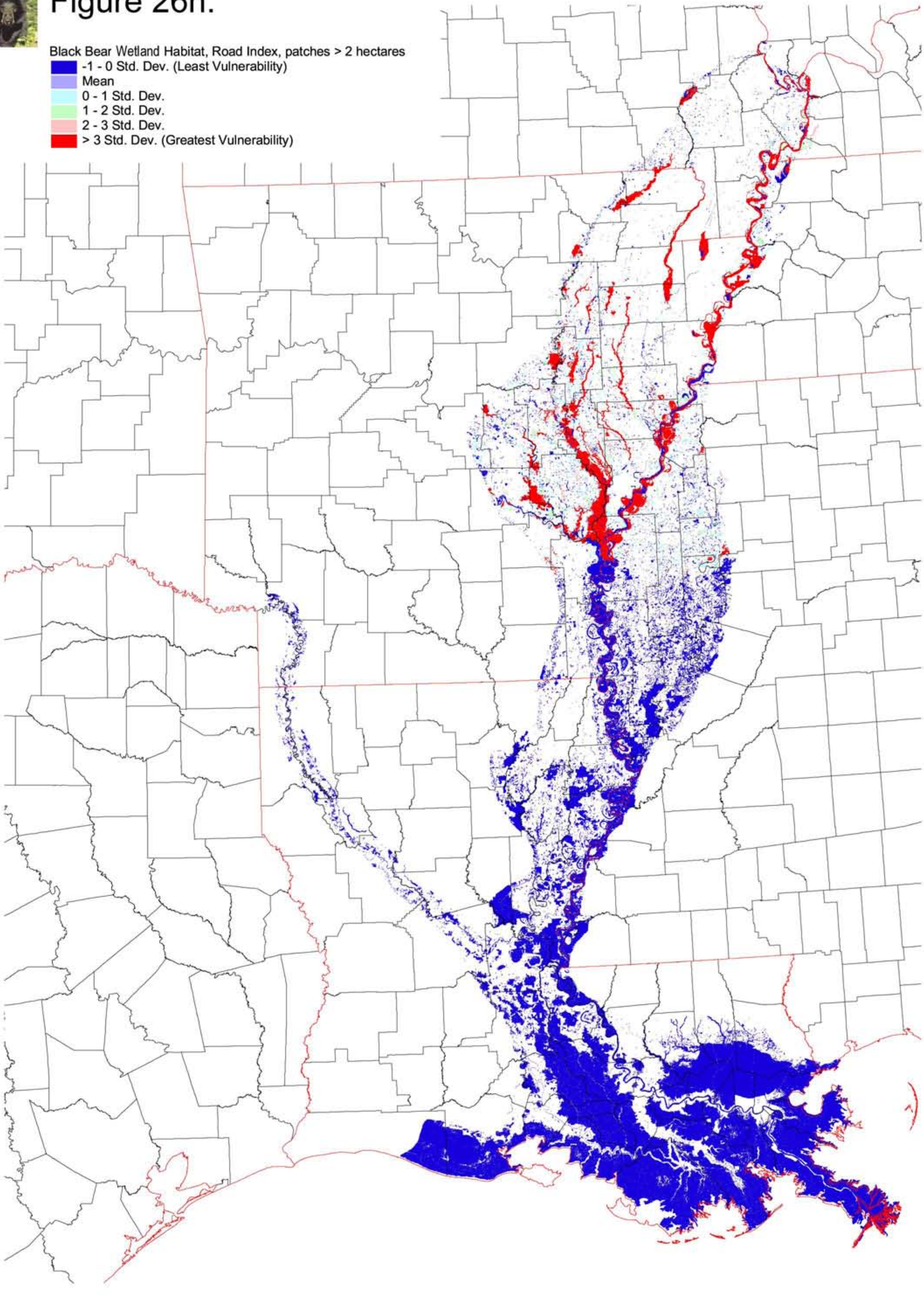
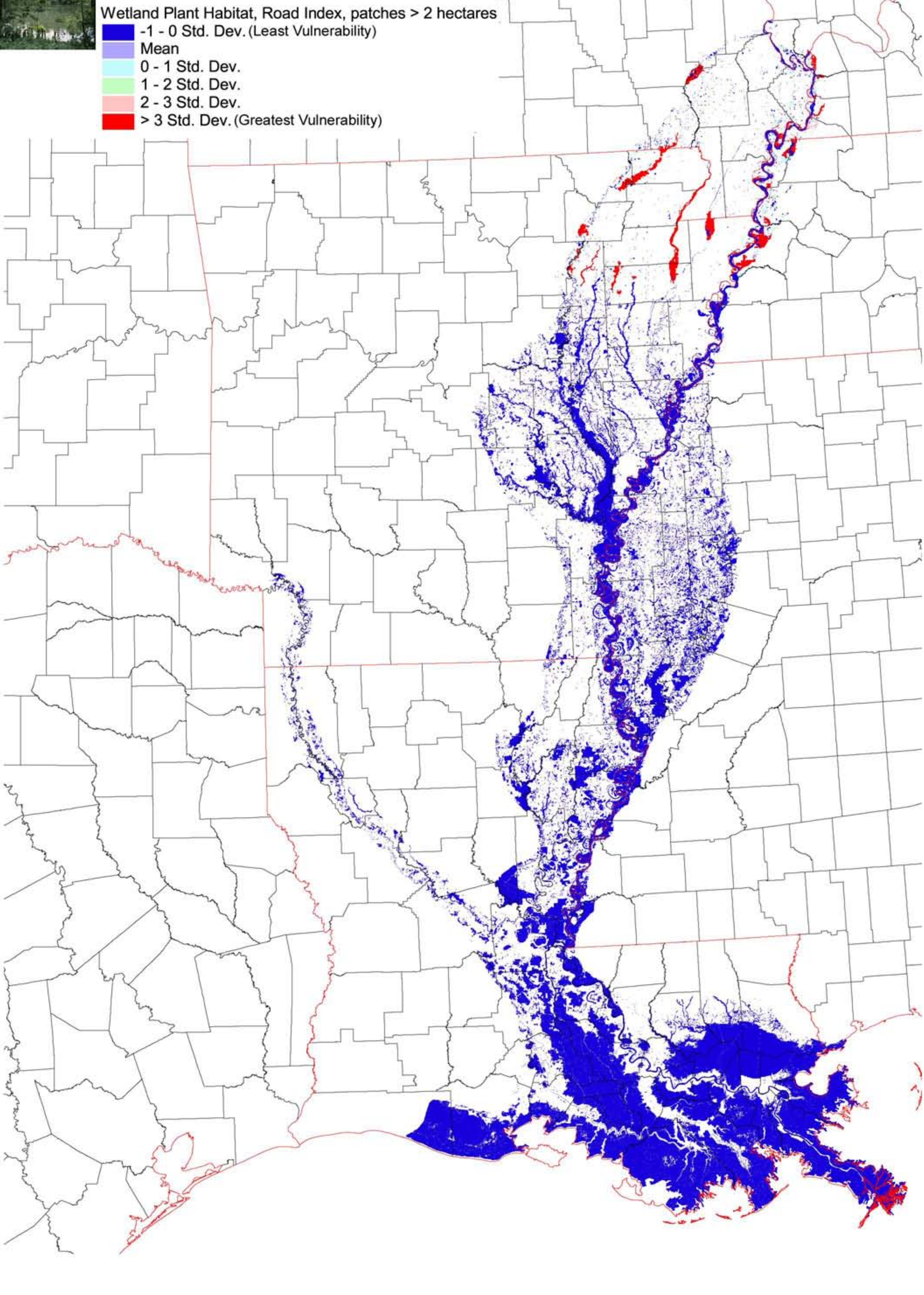

Mallard Winter Habitat - Road Index, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26h.



Black Bear Wetland Habitat, Road Index, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26i.



Wetland Plant Habitat, Road Index, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Human Population Density in 1990)

Figure 26j.

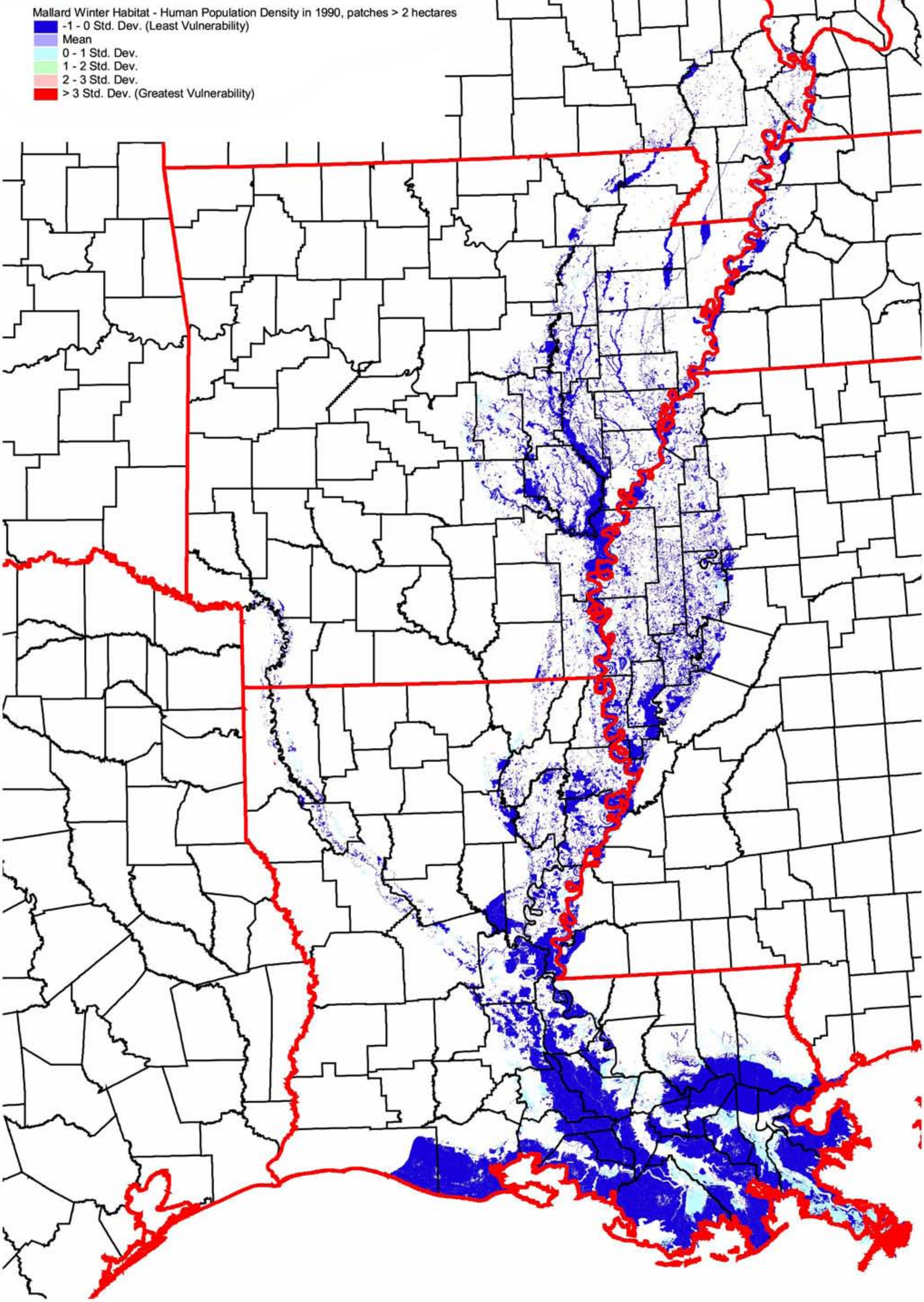

Mallard Winter Habitat - Human Population Density in 1990, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26k.

Black Bear Wetland Habitat, Human Population Density in 1990, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)

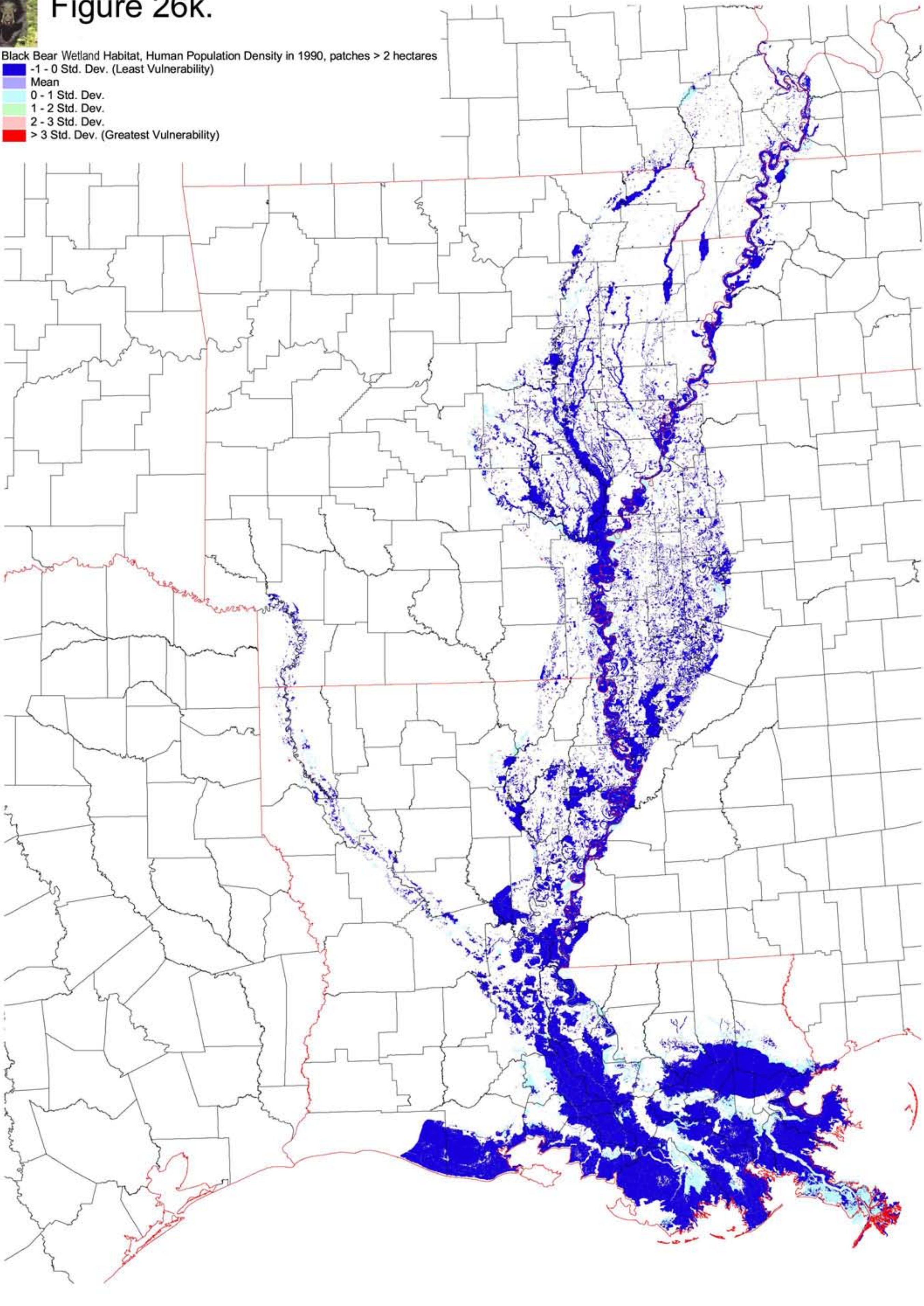
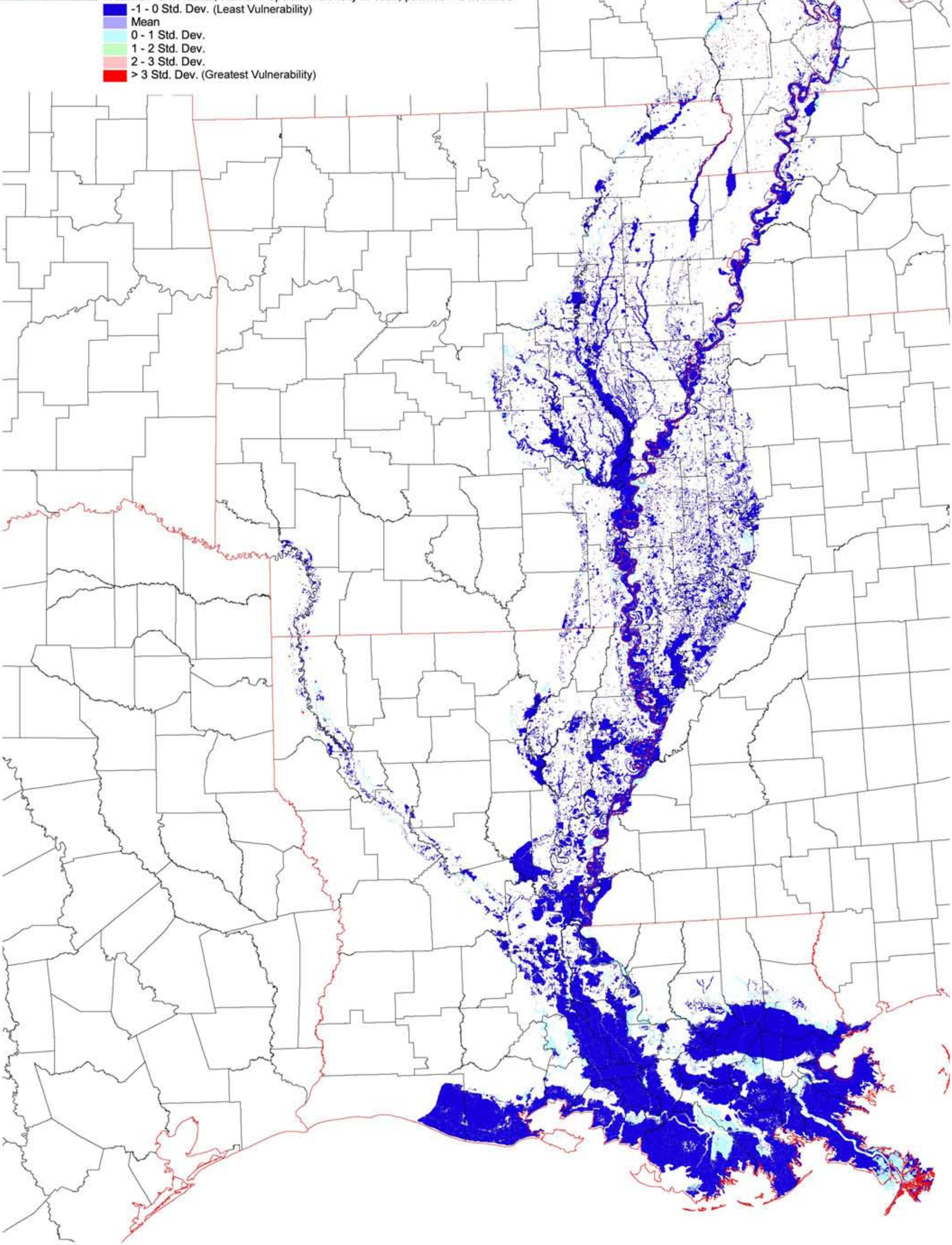


Figure 26l.

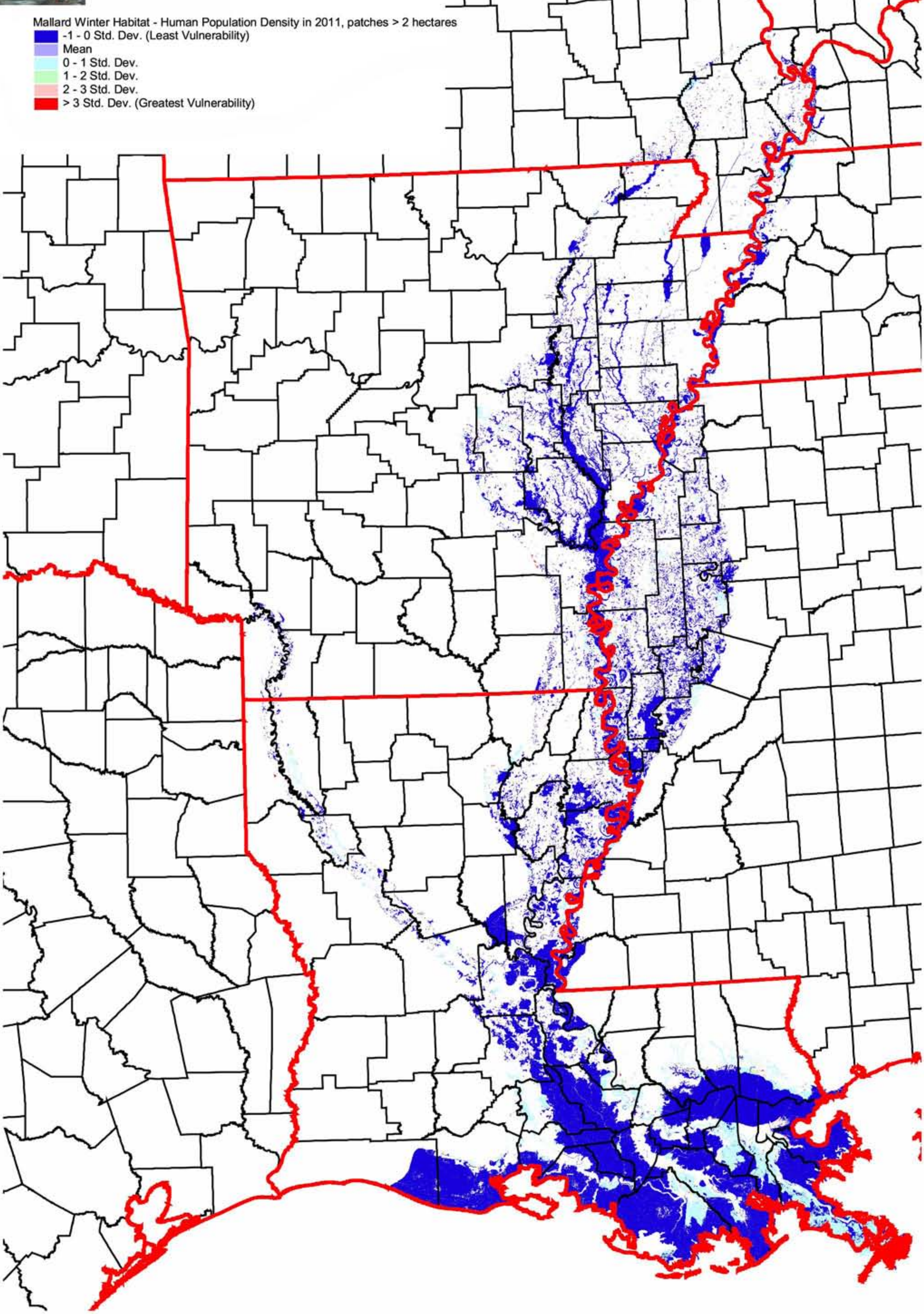
Wetland Plant Habitat, Human Population Density in 1990, patches > 2 hectares

- -1 - 0 Std. Dev. (Least Vulnerability)
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Greatest Vulnerability)



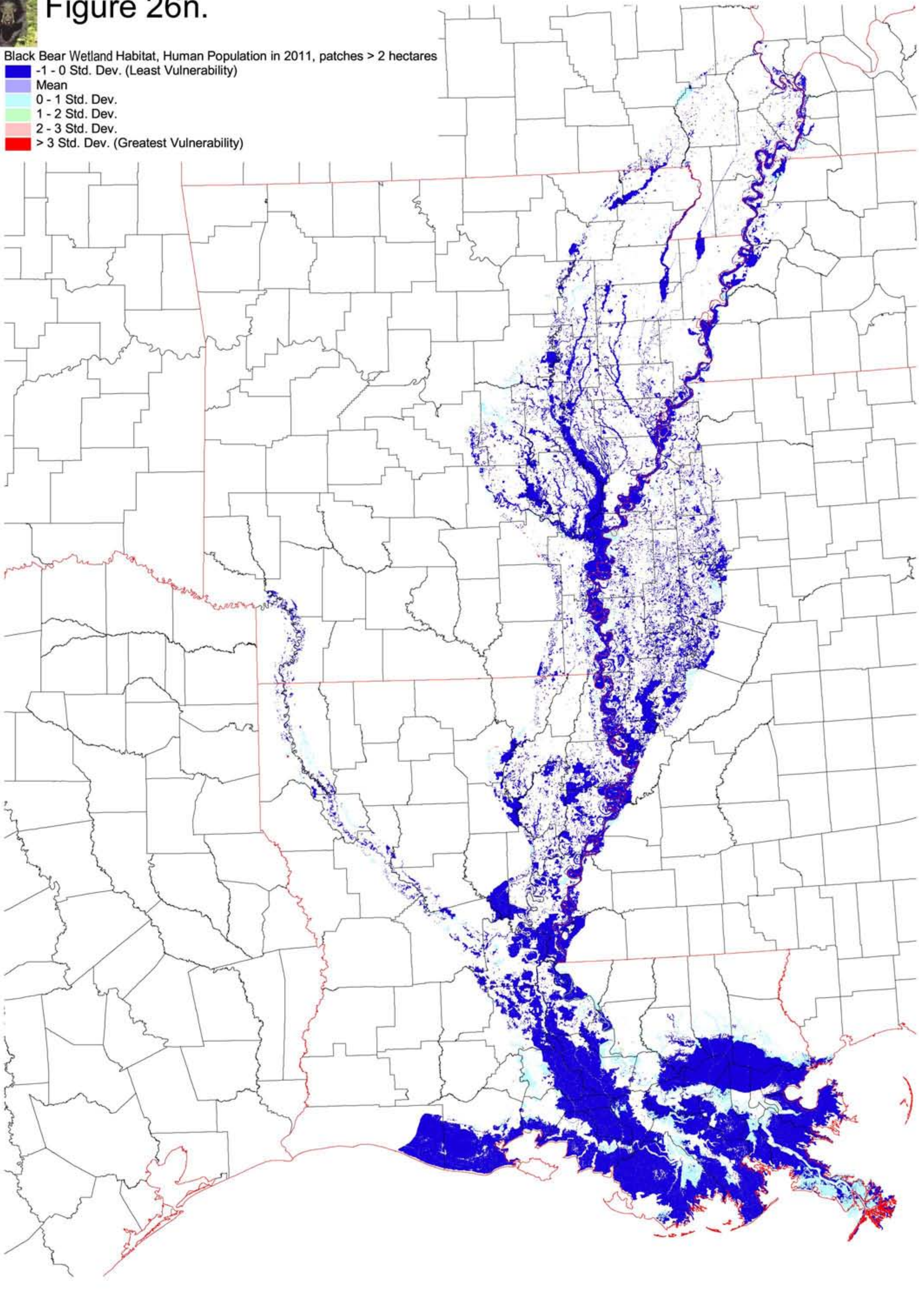
Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Estimated Human Population Density in 2011)

Figure 26m.



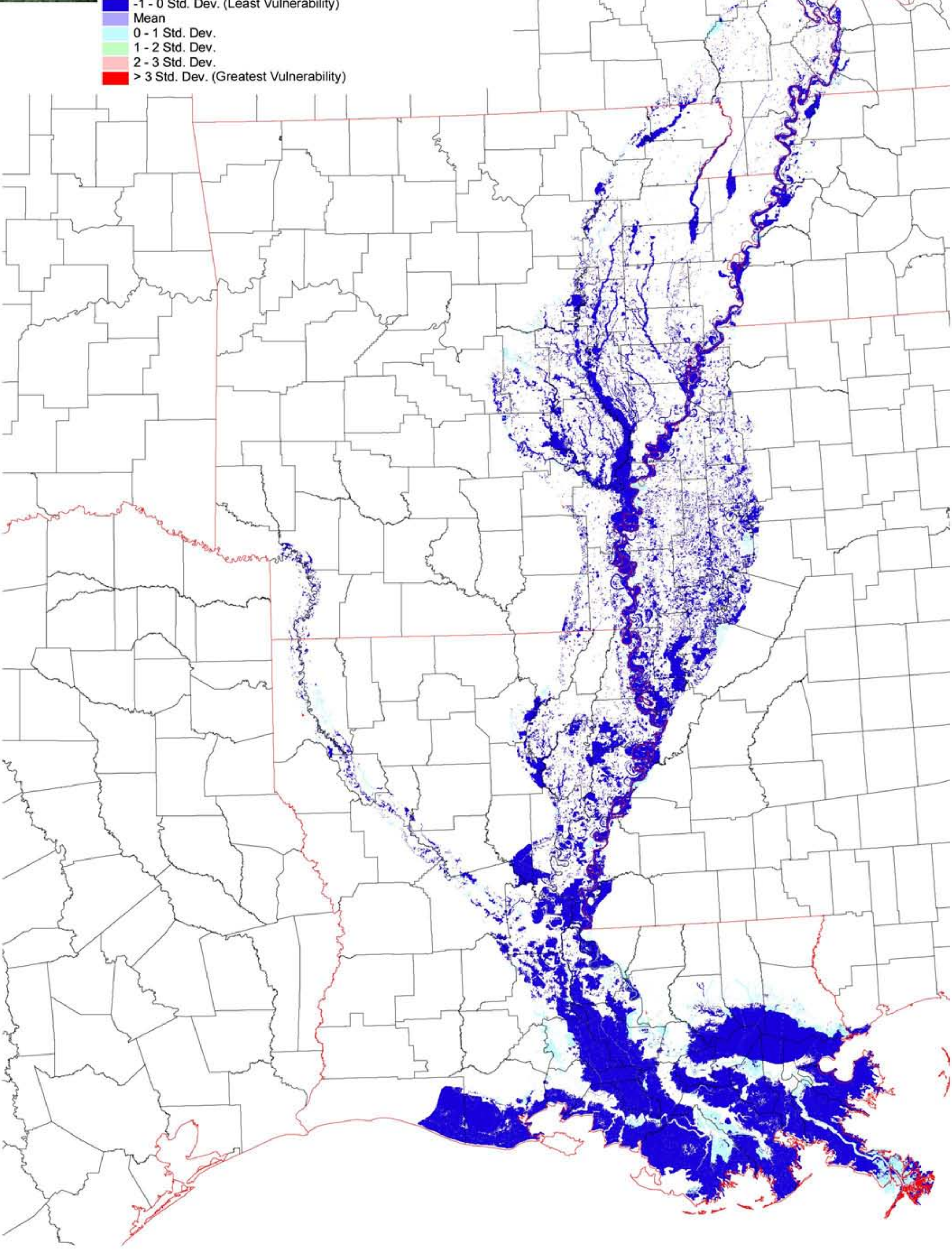
Mallard Winter Habitat - Human Population Density in 2011, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26n.



Black Bear Wetland Habitat, Human Population in 2011, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26o.



Wetland Plant Habitat, Human Population in 2011, patches > 2 hectares
-1 - 0 Std. Dev. (Least Vulnerability)
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Estimated Human Population Density Change from 1990 to 2011)

Figure 26p.

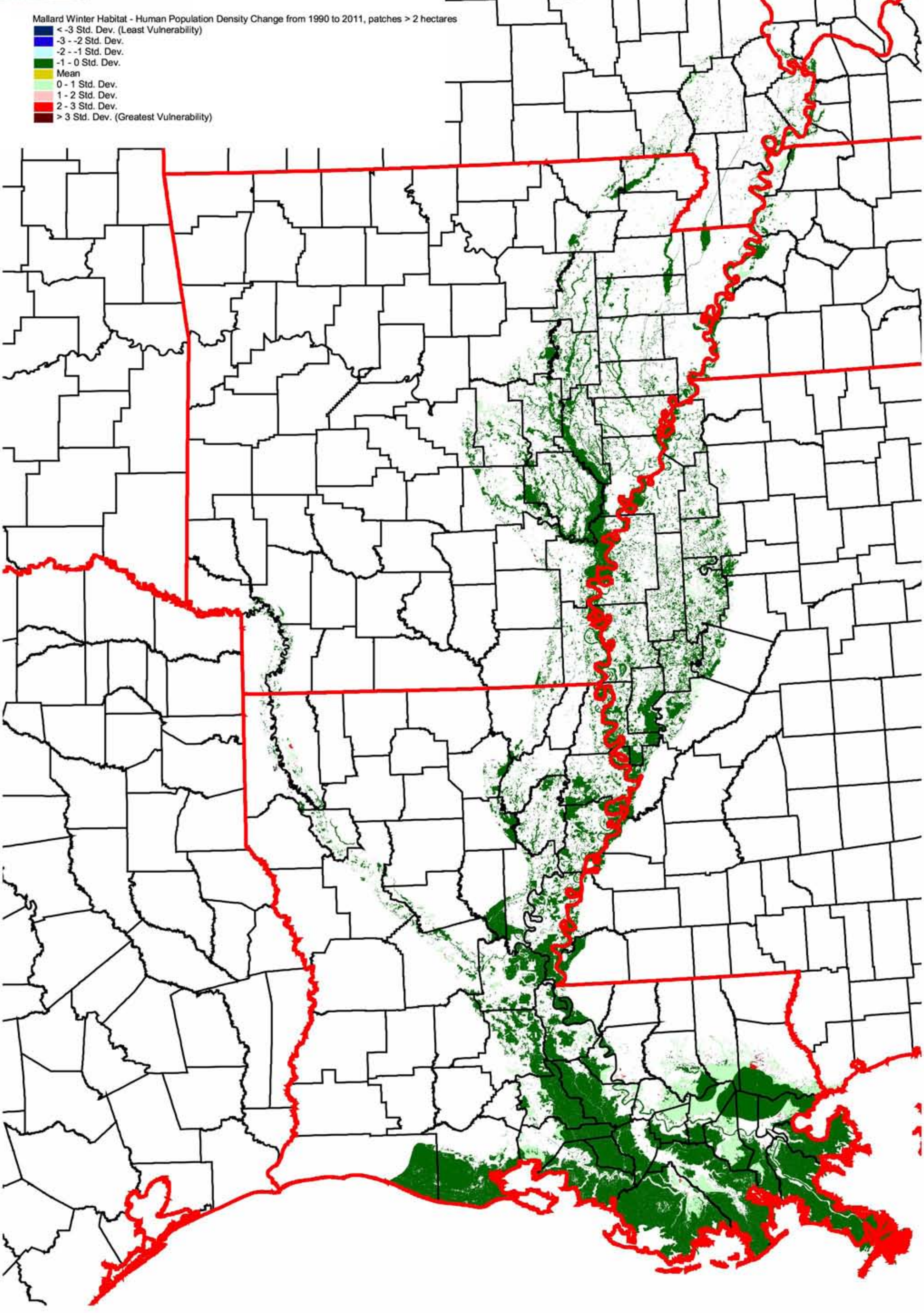
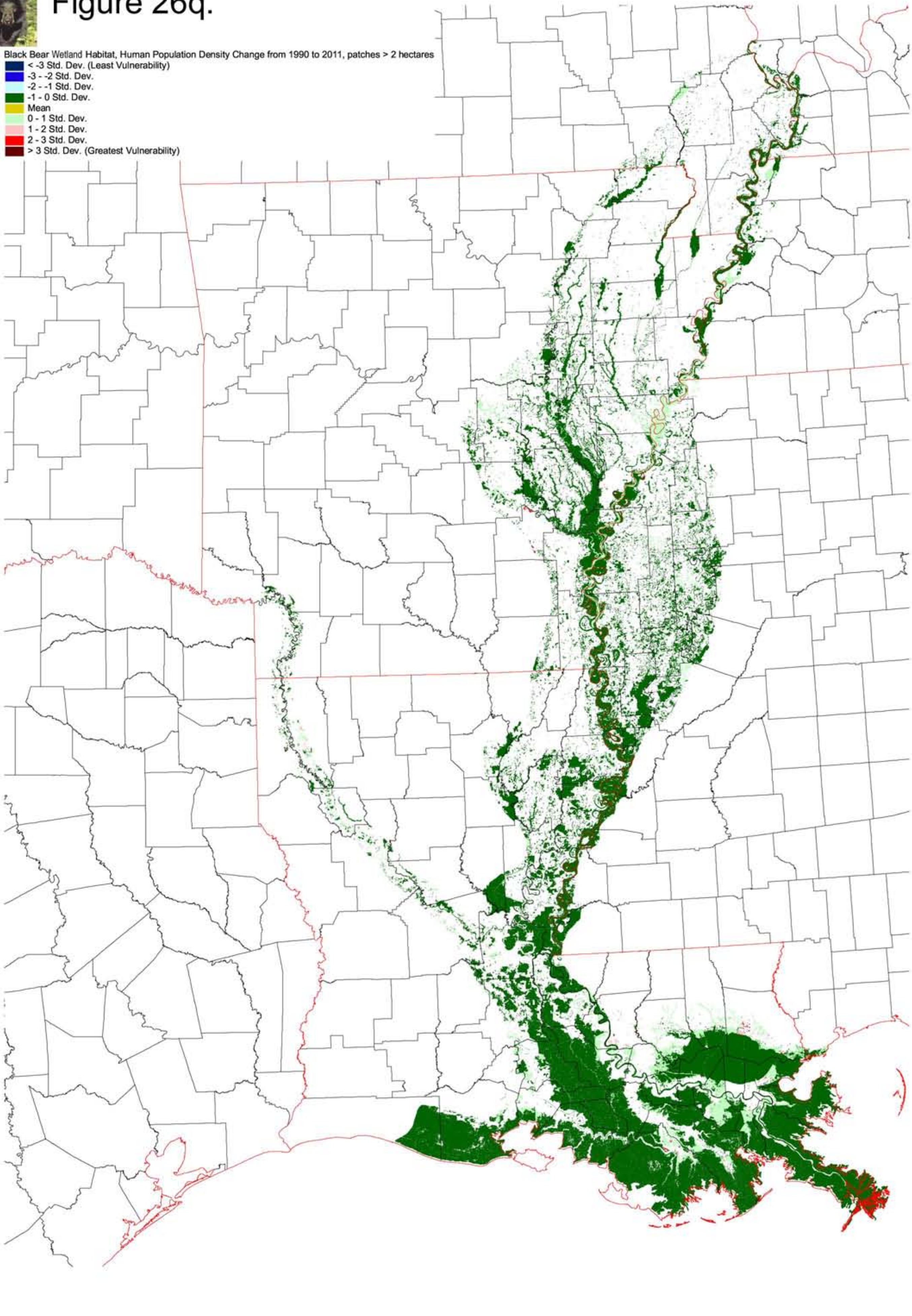
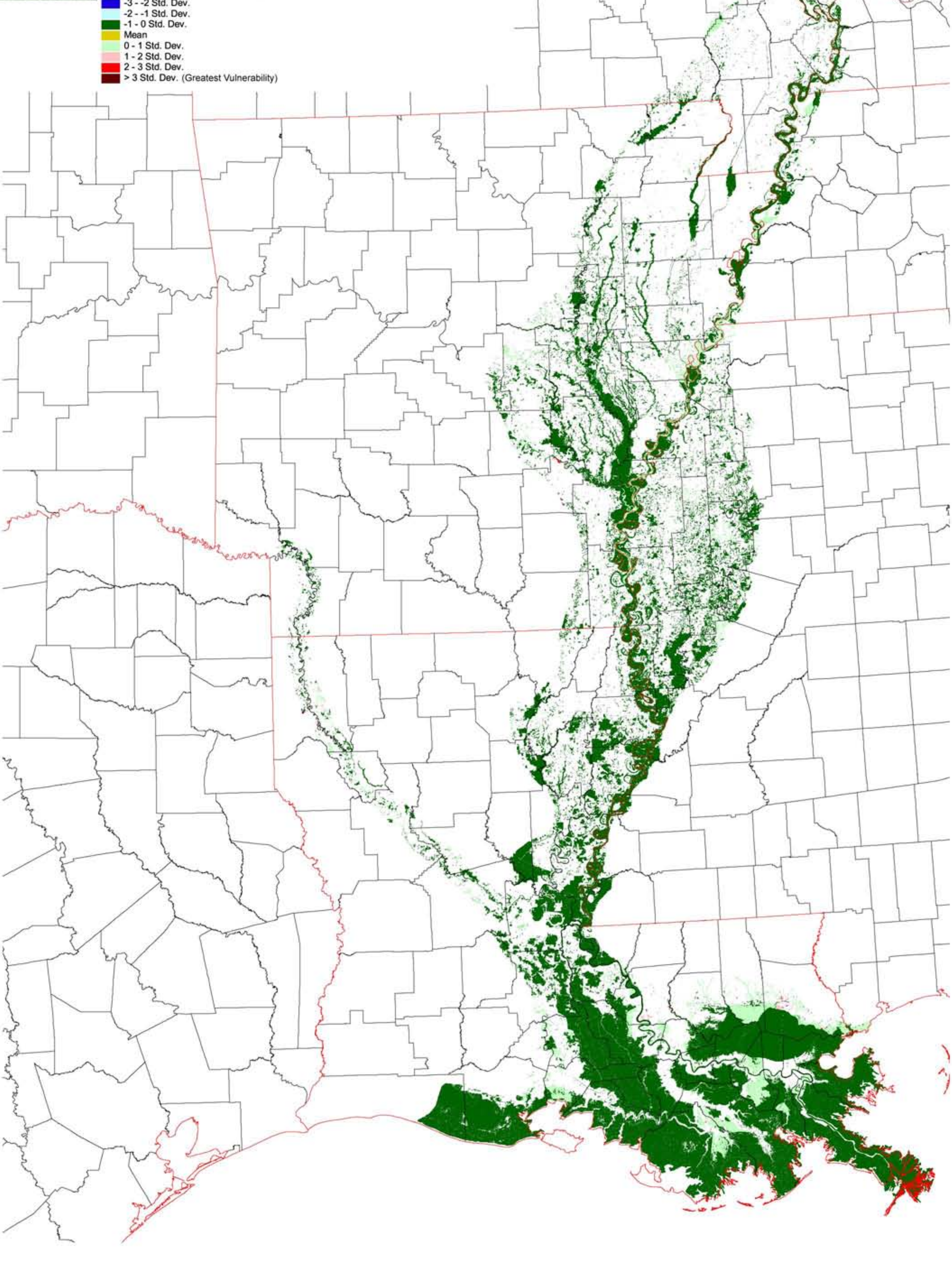

Mallard Winter Habitat - Human Population Density Change from 1990 to 2011, patches > 2 hectares
< -3 Std. Dev. (Least Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26q.



Black Bear Wetland Habitat, Human Population Density Change from 1990 to 2011, patches > 2 hectares
< -3 Std. Dev. (Least Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26r.


Wetland Plant Habitat, Human Population Density Change from 1990 to 2011, patches > 2 hectares
< -3 Std. Dev. (Least Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Unified Human Index)

Figure 26s.

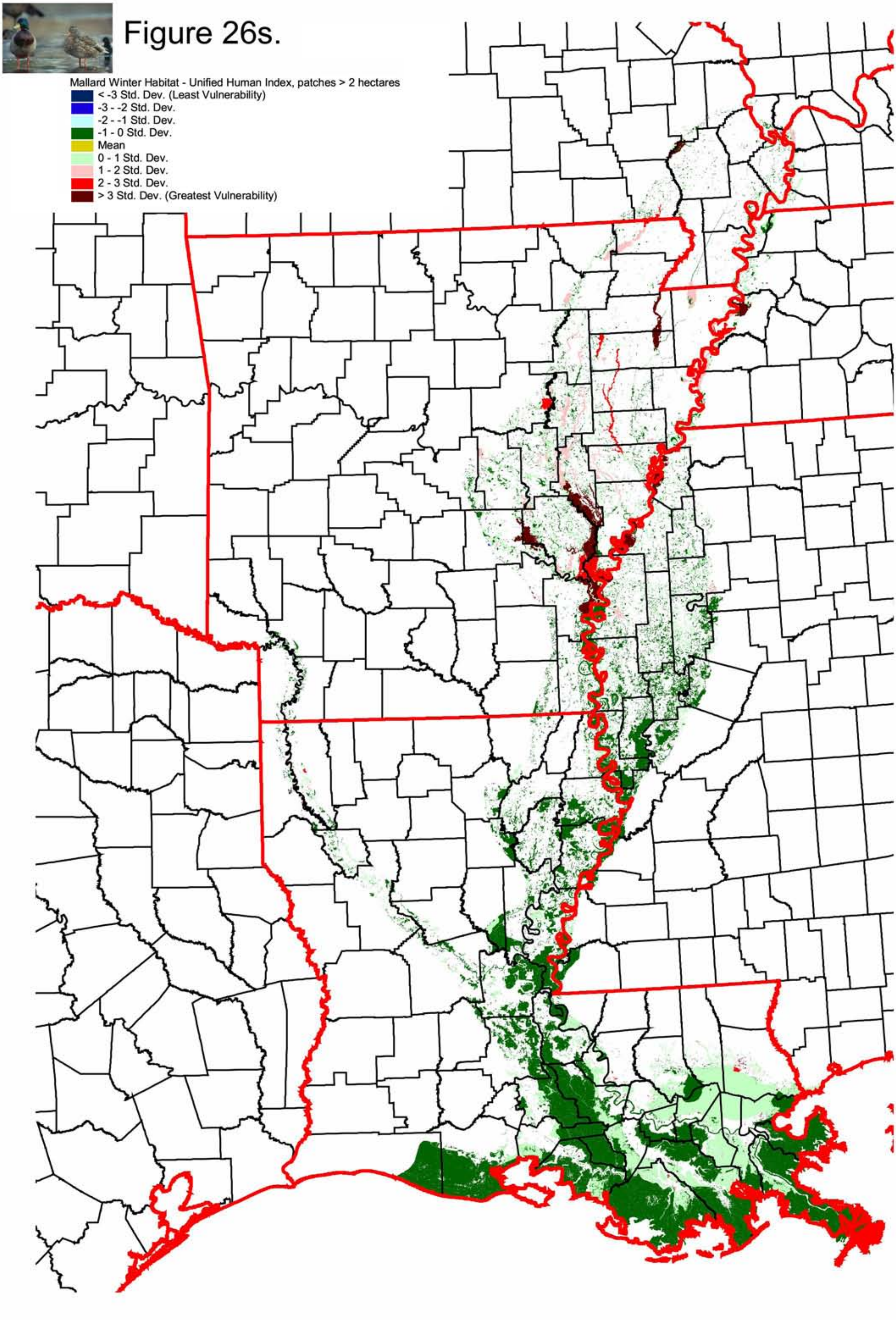

Mallard Winter Habitat - Unified Human Index, patches > 2 hectares
< -3 Std. Dev. (Least Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26t.

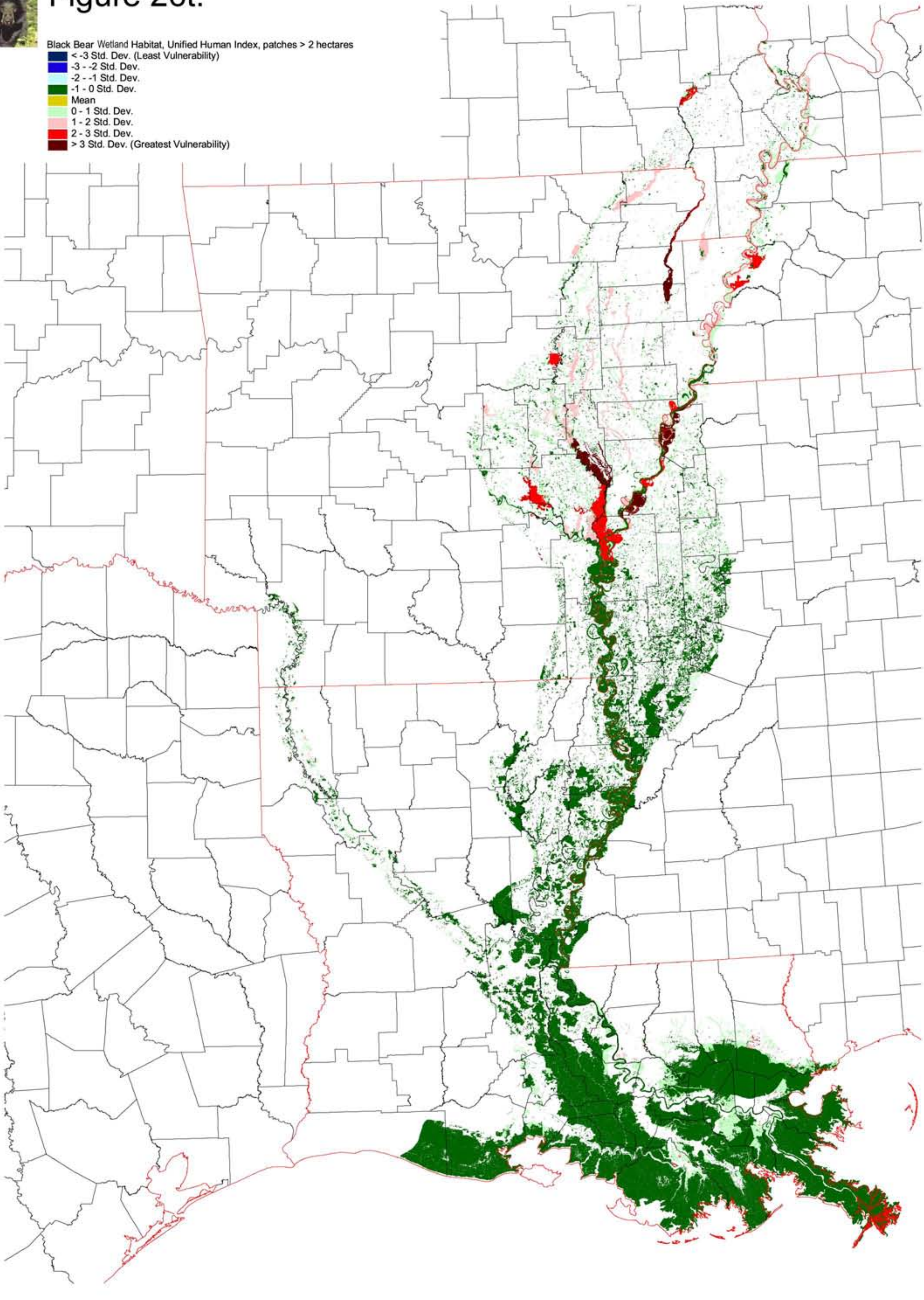
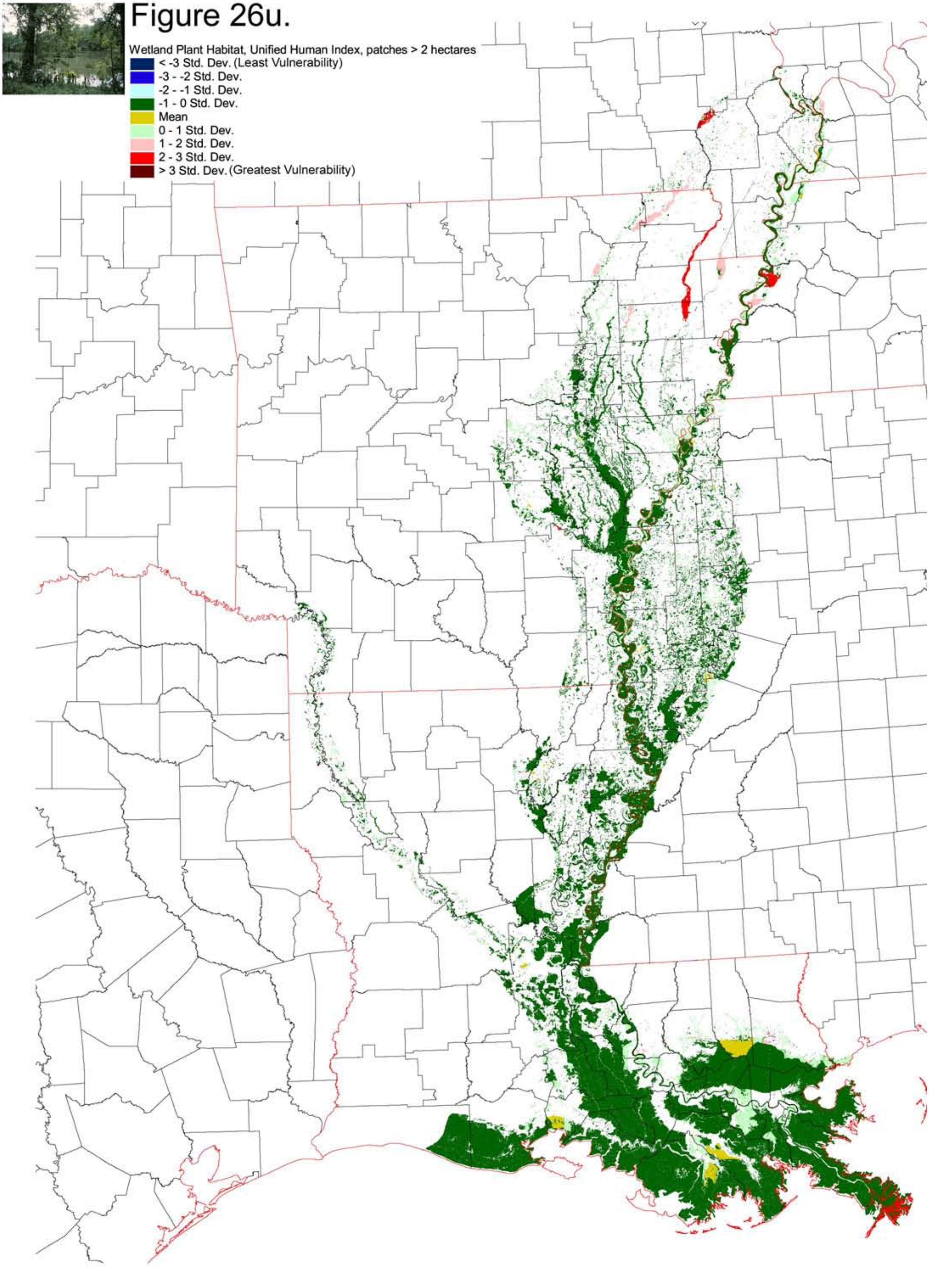
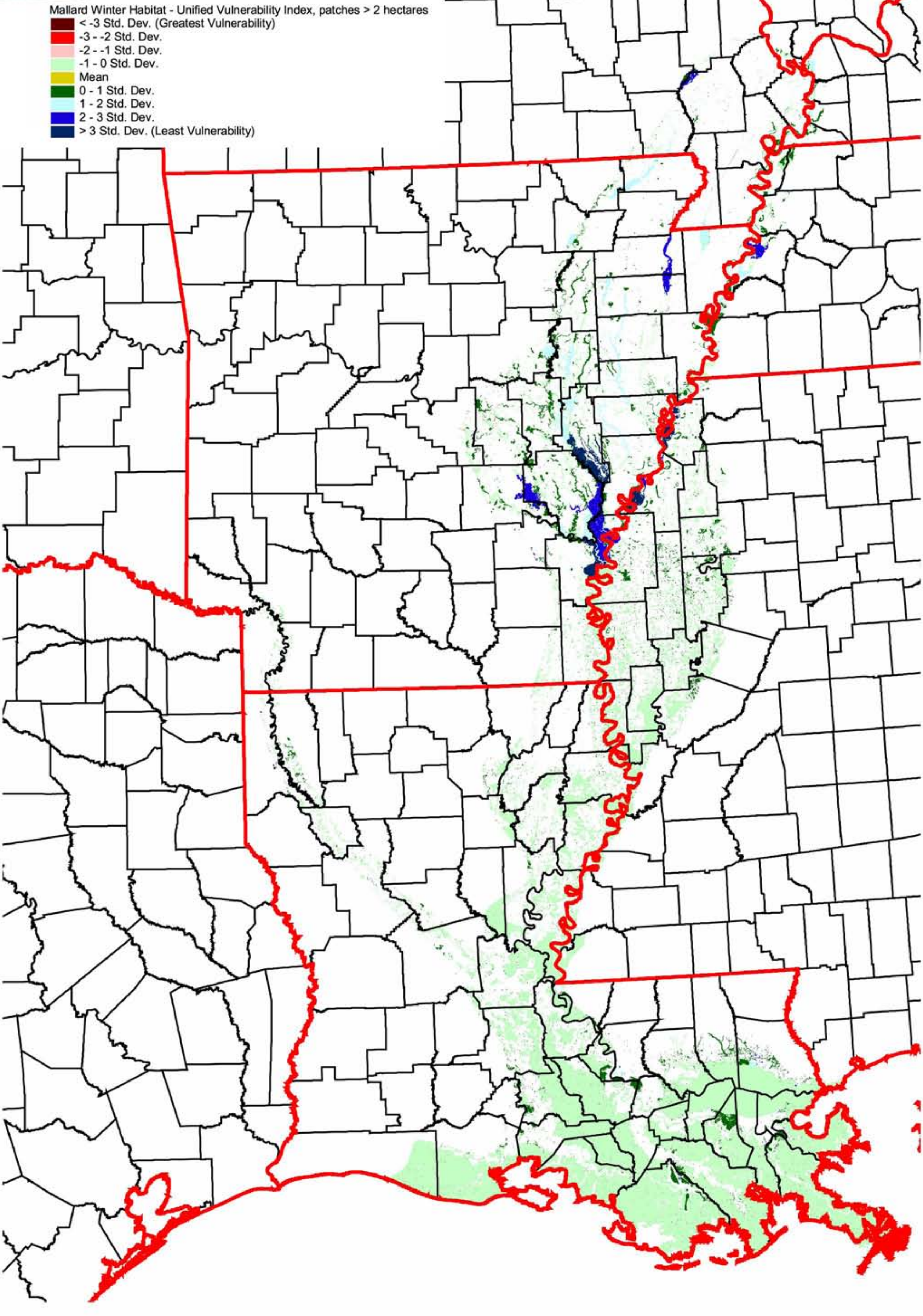

Black Bear Wetland Habitat, Unified Human Index, patches > 2 hectares
< -3 Std. Dev. (Least Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

Figure 26u.


Wetland Plant Habitat, Unified Human Index, patches > 2 hectares
< -3 Std. Dev. (Least Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Greatest Vulnerability)

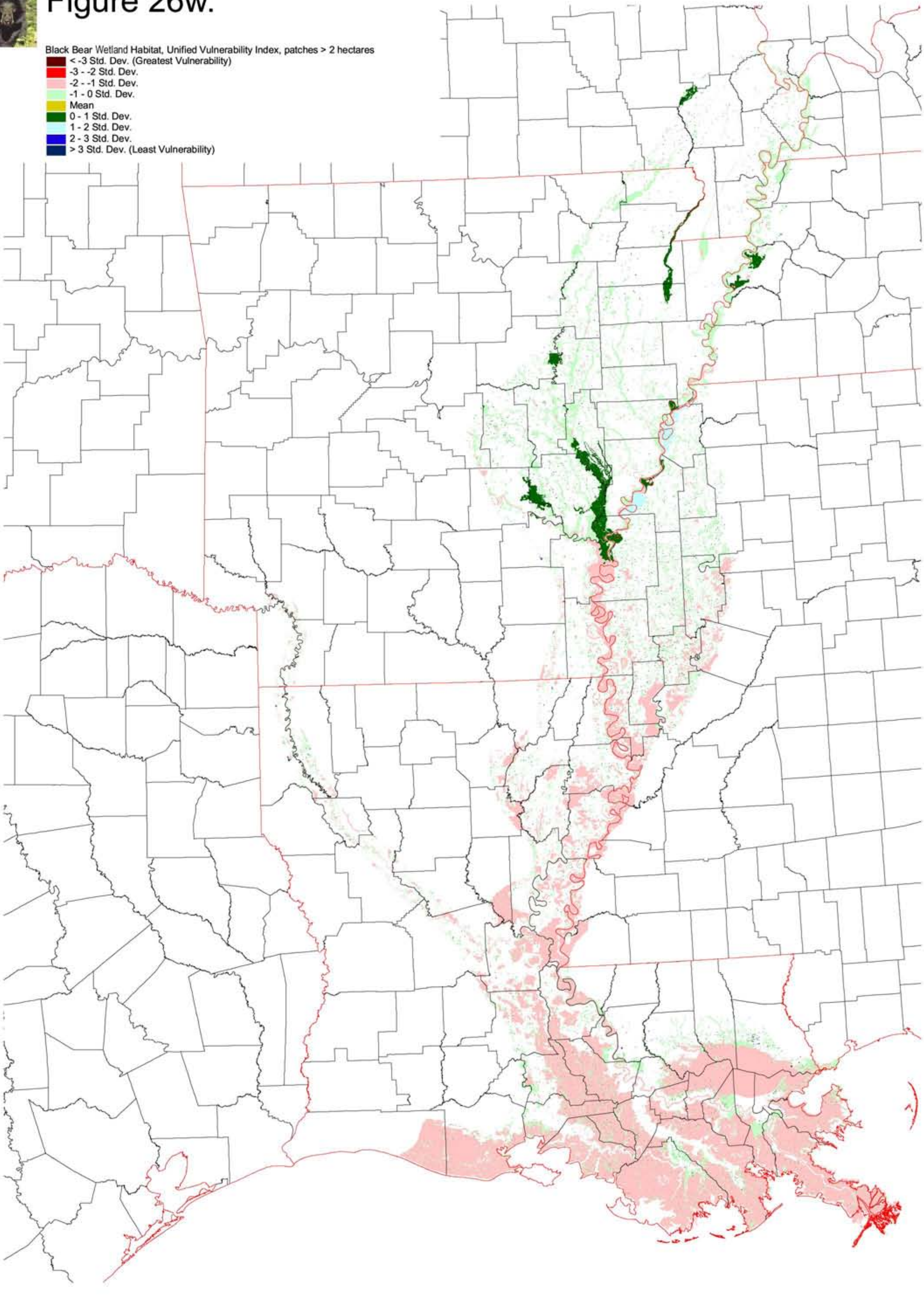
Mississippi Alluvial Valley Ecoregion Wetland Habitat Vulnerability Models (Unified Vulnerability Index)

Figure 26v.



Mallard Winter Habitat - Unified Vulnerability Index, patches > 2 hectares
< -3 Std. Dev. (Greatest Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 26w.

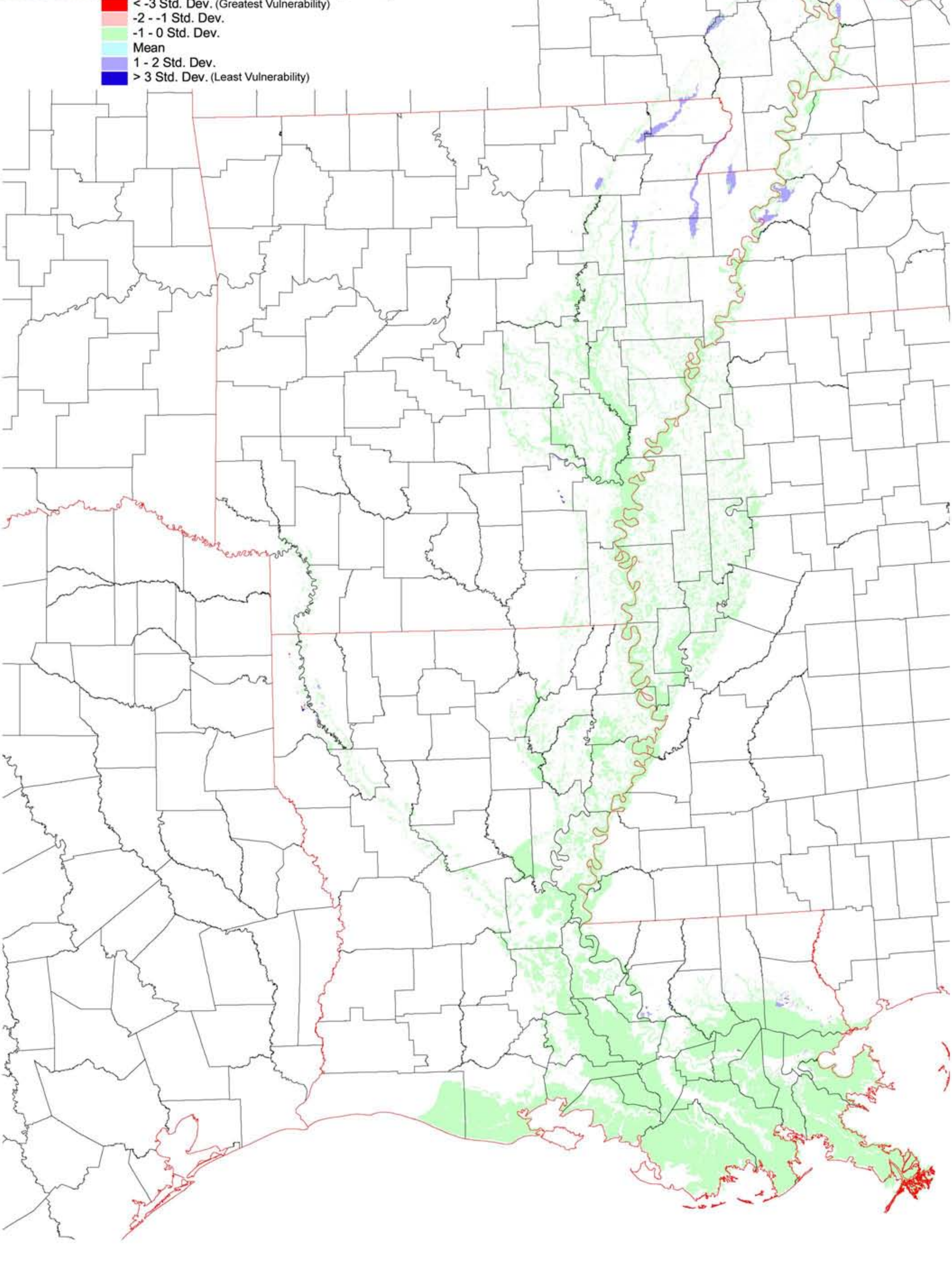


Black Bear Wetland Habitat, Unified Vulnerability Index, patches > 2 hectares
< -3 Std. Dev. (Greatest Vulnerability)
-3 - -2 Std. Dev.
-2 - -1 Std. Dev.
-1 - 0 Std. Dev.
Mean
0 - 1 Std. Dev.
1 - 2 Std. Dev.
2 - 3 Std. Dev.
> 3 Std. Dev. (Least Vulnerability)

Figure 26x.

Wetland Plant Habitat, Unified Vulnerability Index, patches > 2 hectares

- < -3 Std. Dev. (Greatest Vulnerability)
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 1 - 2 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)



White River Watershed Water Quality Vulnerability Models and Figures

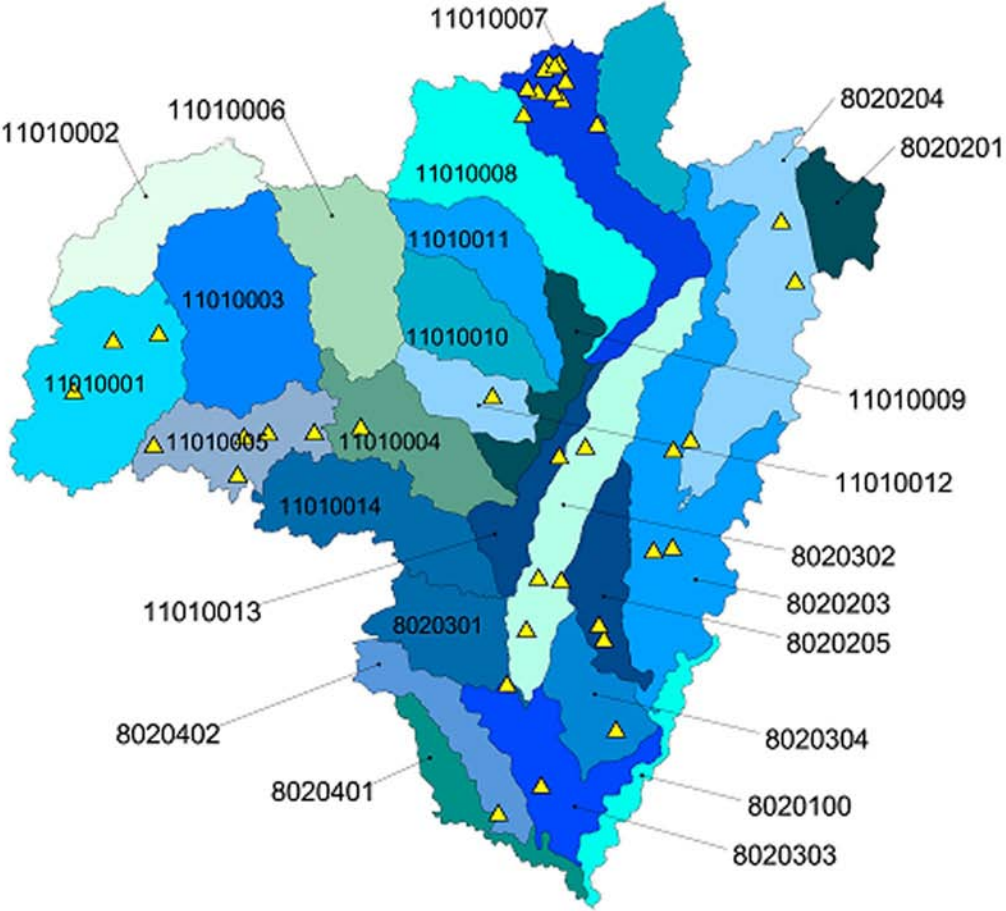


Figure 27. Twenty-five 8-digit hydrologic unit code (HUC) subwatersheds in the White River Watershed. Yellow triangle indicates a National Water Quality Assessment (NAWQA) Program field sampling location, sampled during the 1990s (N = 35).

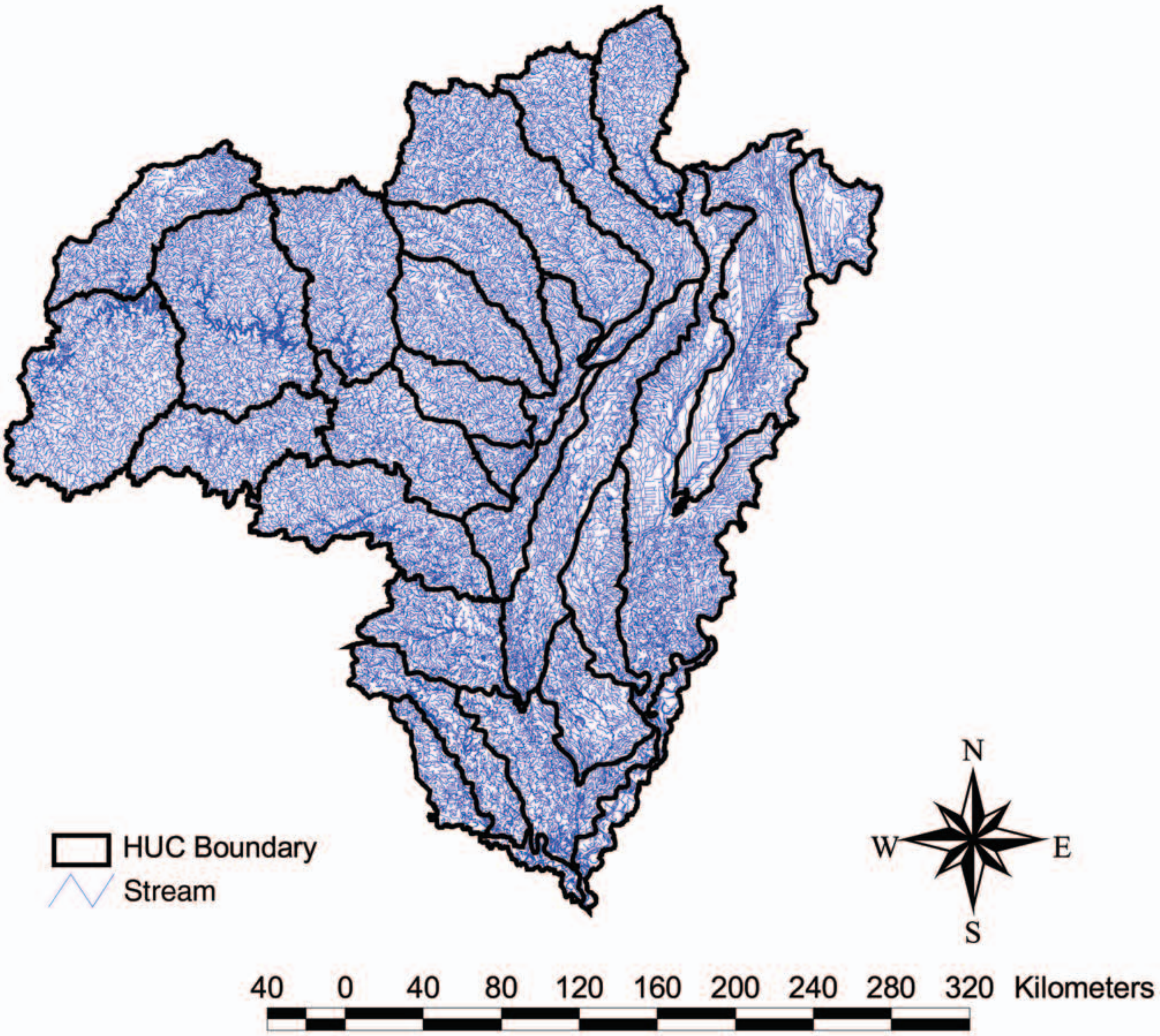


Figure 28. Location of surface water in the White River Watershed. Surface water locational data was used to calculate the percent of streams in proximity to roads.

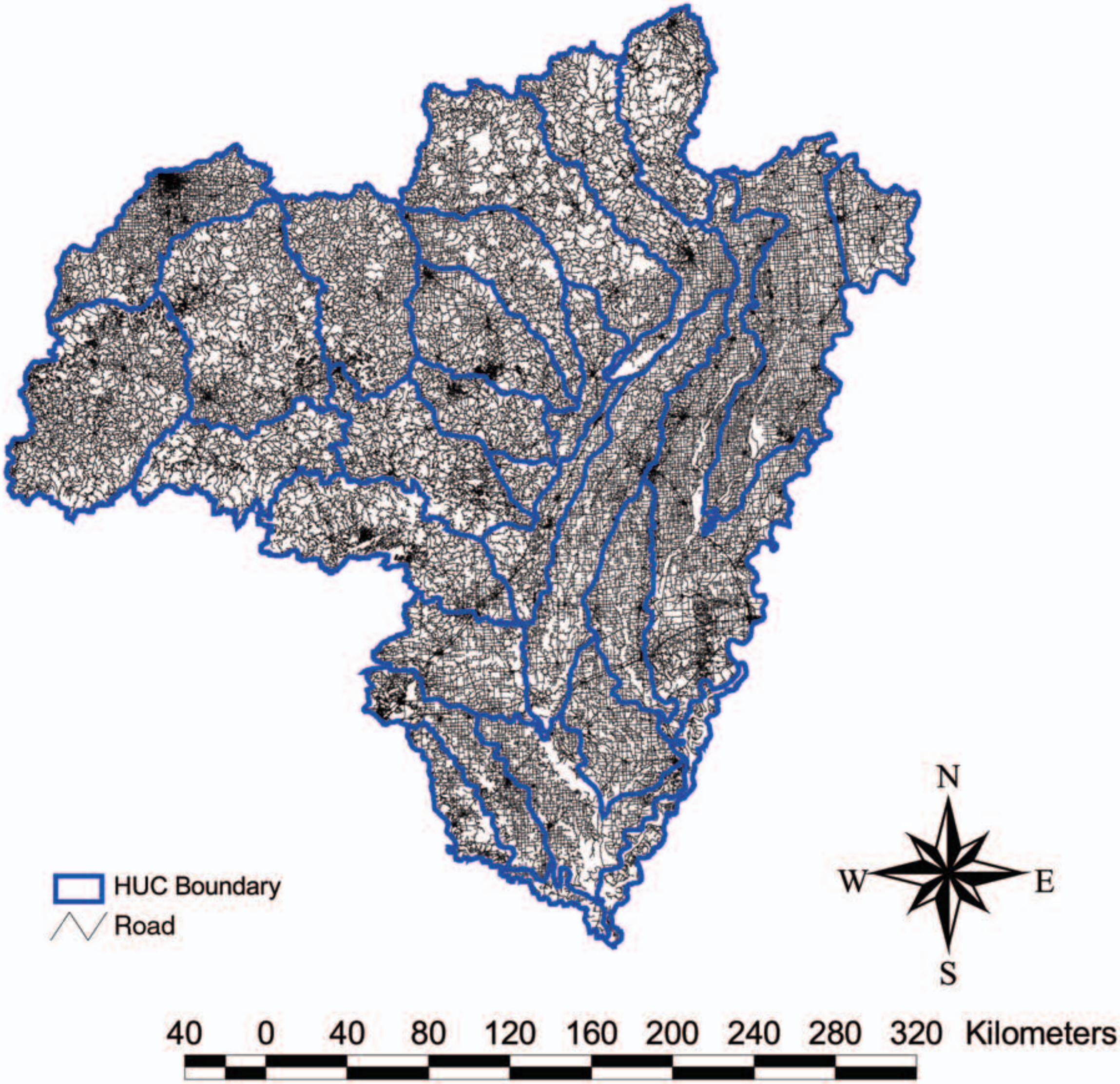


Figure 29. Road network in the White River Watershed. Data used to calculate the percent of streams in proximity to roads.

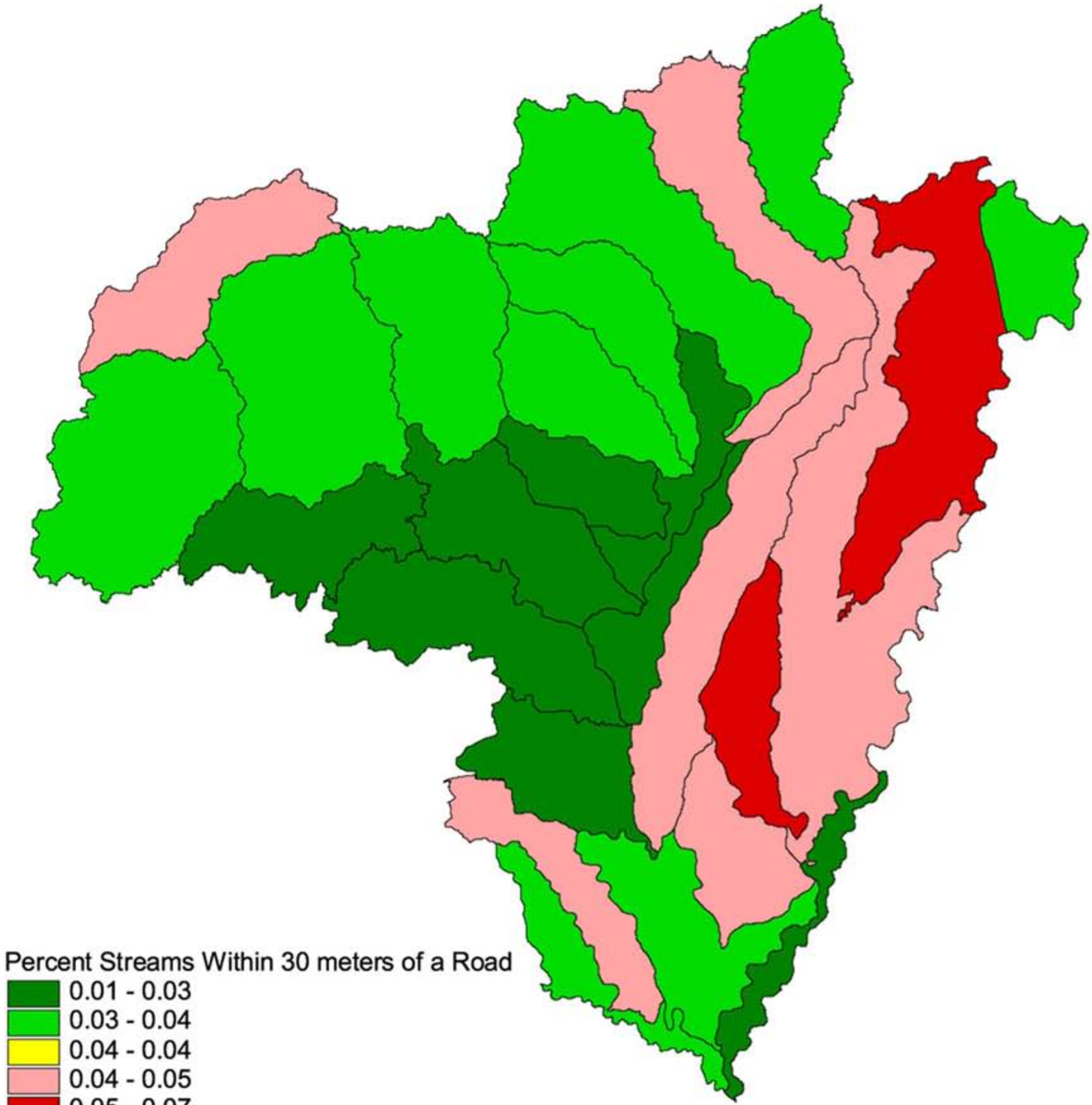


Figure 30. White River Watershed percent of streams within 30 meters of a road.

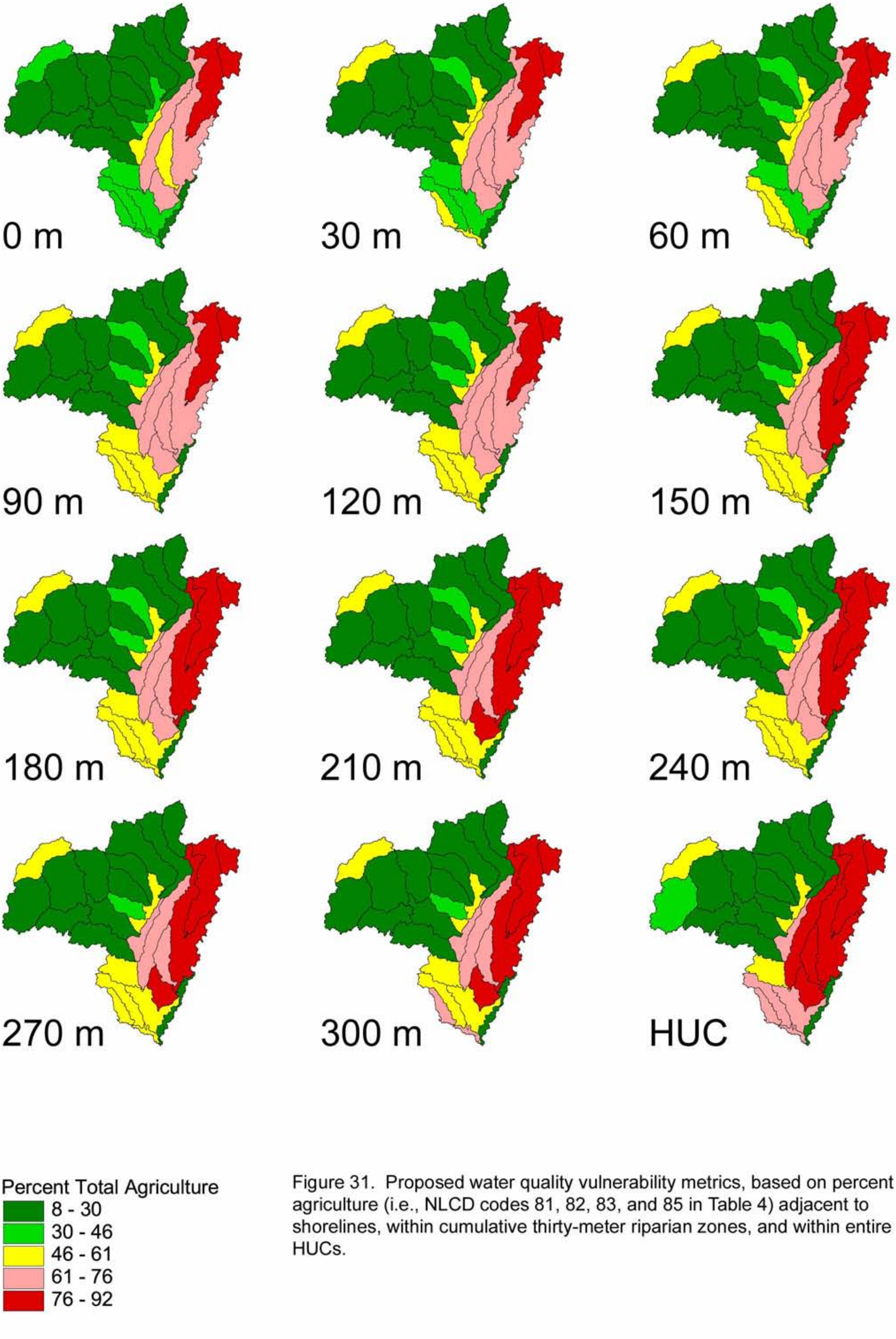


Figure 31. Proposed water quality vulnerability metrics, based on percent agriculture (i.e., NLCD codes 81, 82, 83, and 85 in Table 4) adjacent to shorelines, within cumulative thirty-meter riparian zones, and within entire HUCs.

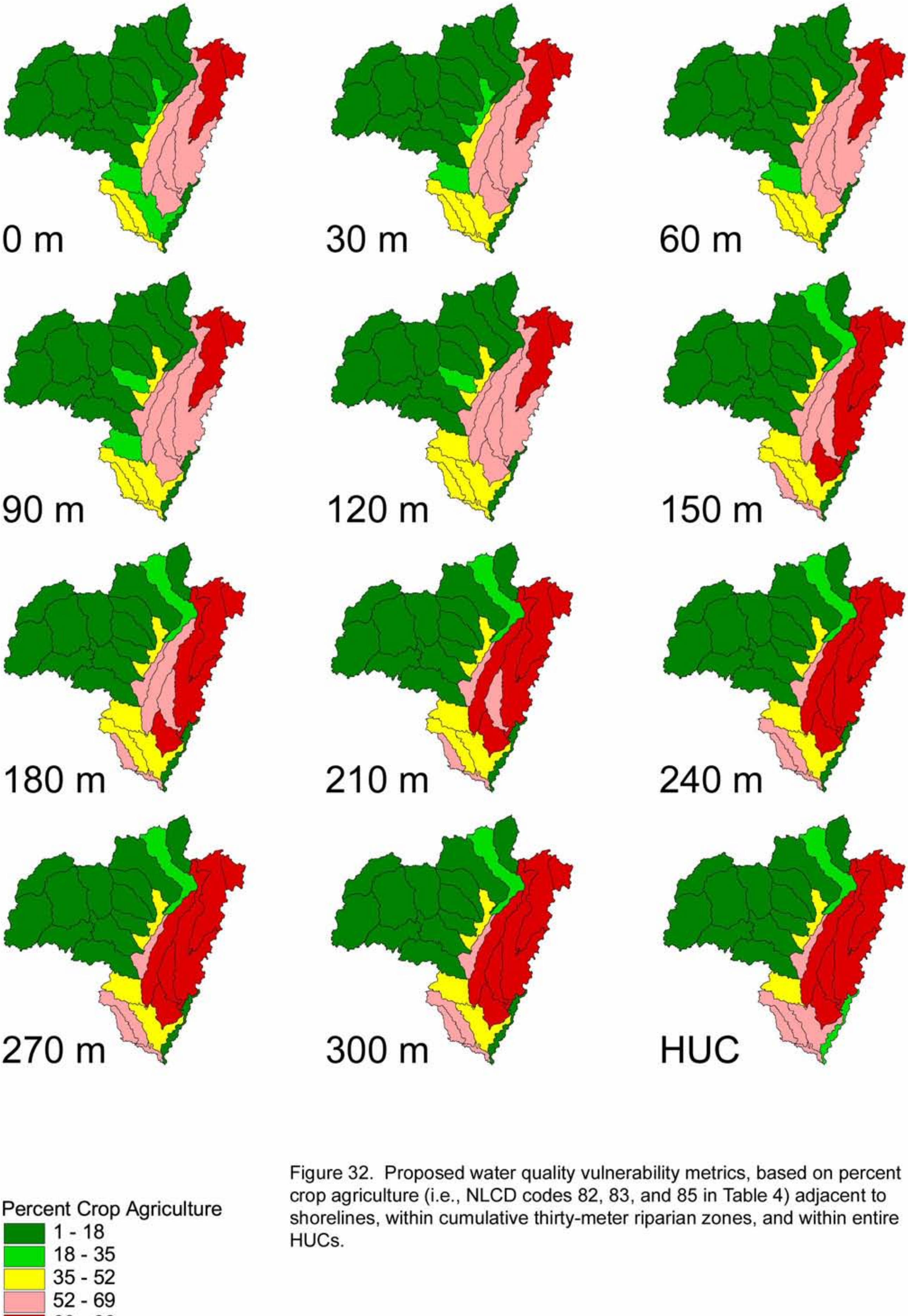


Figure 32. Proposed water quality vulnerability metrics, based on percent crop agriculture (i.e., NLCD codes 82, 83, and 85 in Table 4) adjacent to shorelines, within cumulative thirty-meter riparian zones, and within entire HUCs.

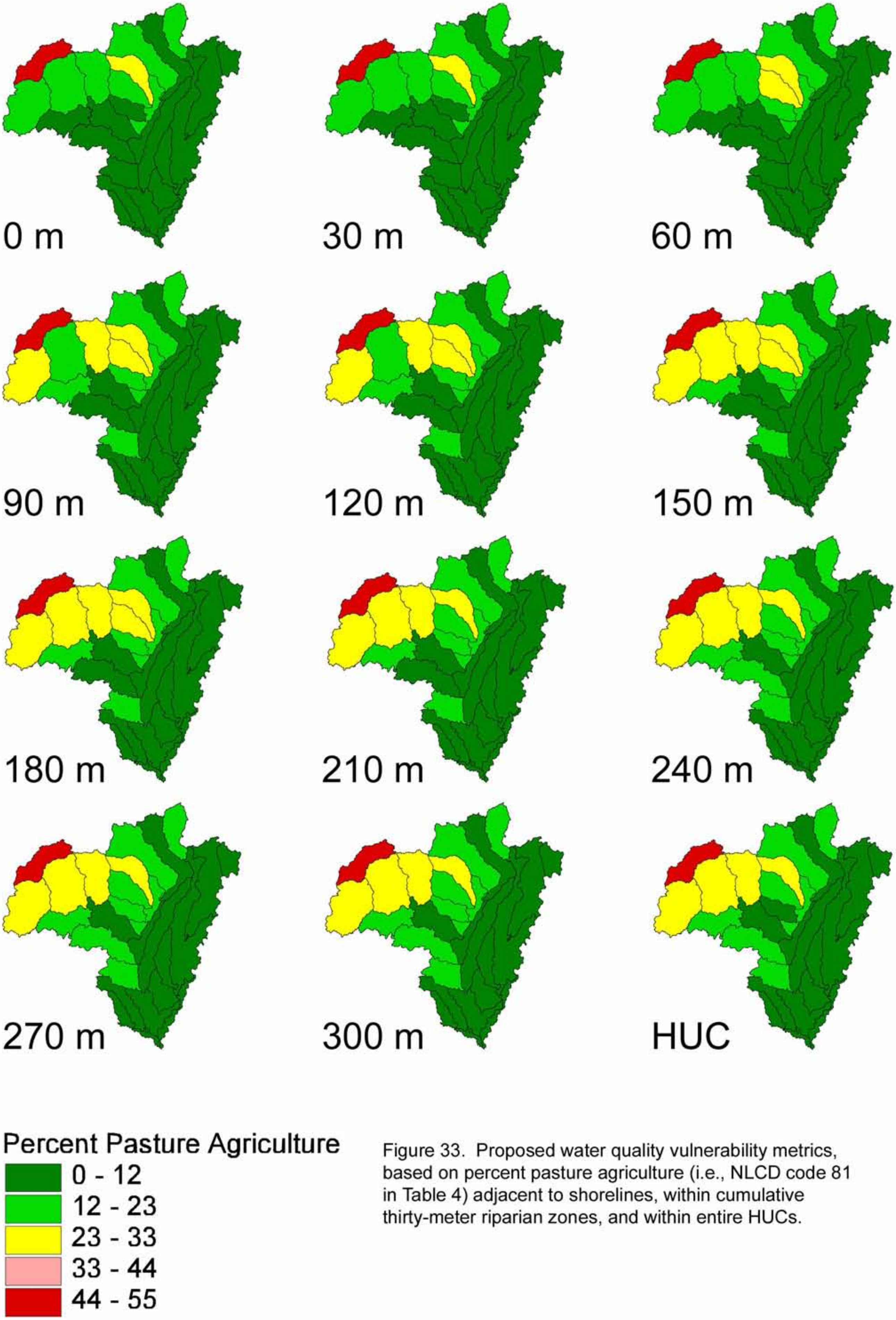


Figure 33. Proposed water quality vulnerability metrics, based on percent pasture agriculture (i.e., NLCD code 81 in Table 4) adjacent to shorelines, within cumulative thirty-meter riparian zones, and within entire HUCs.

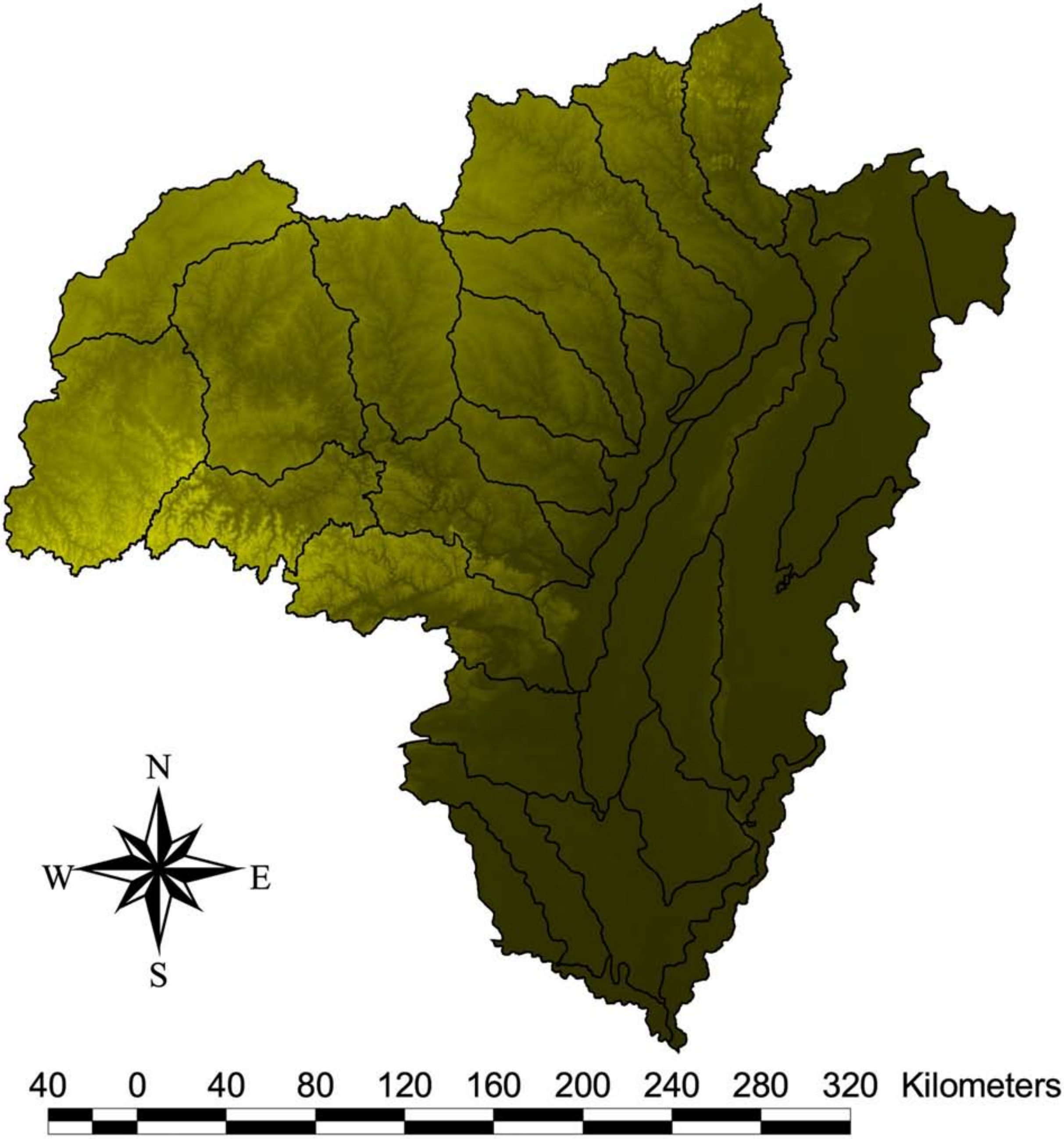


Figure 34. Hillshaded digital elevation model (DEM) of the White River Watershed, depicting areas from lower elevation (darker) to higher elevation (lighter). This DEM was used to calculate percent of total agrculture on slopes greater than three percent.

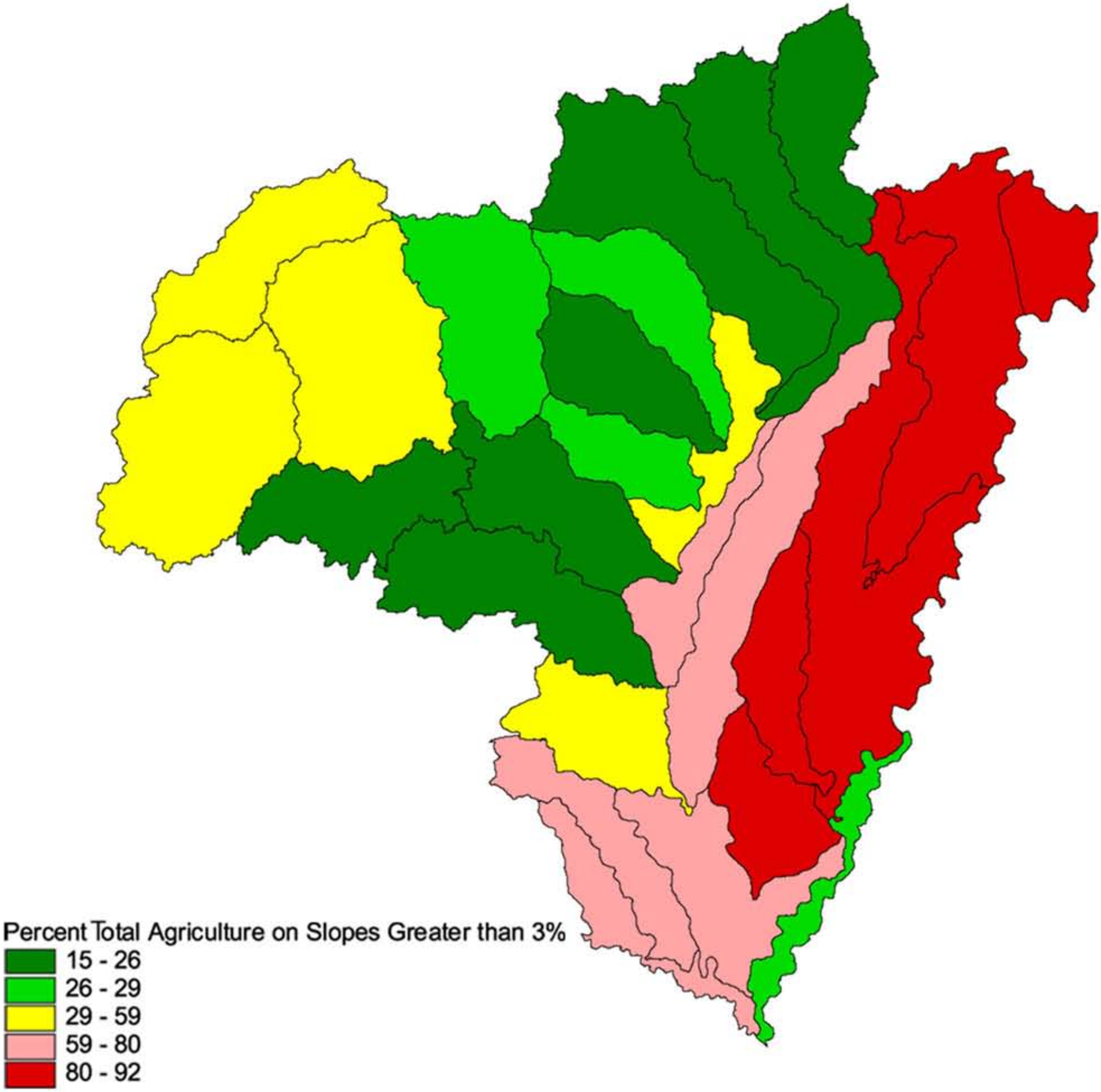
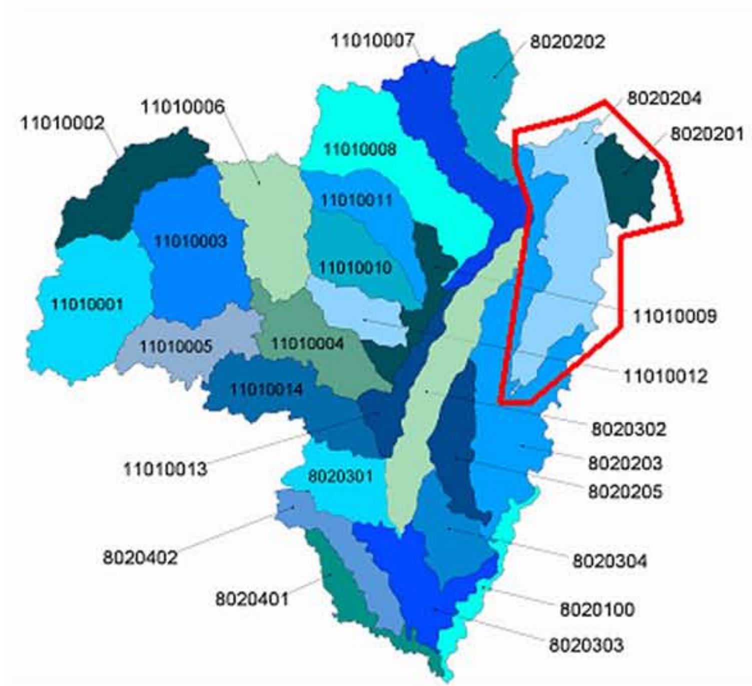


Figure 35. White River Watershed percent total agriculture on slopes greater than three percent.



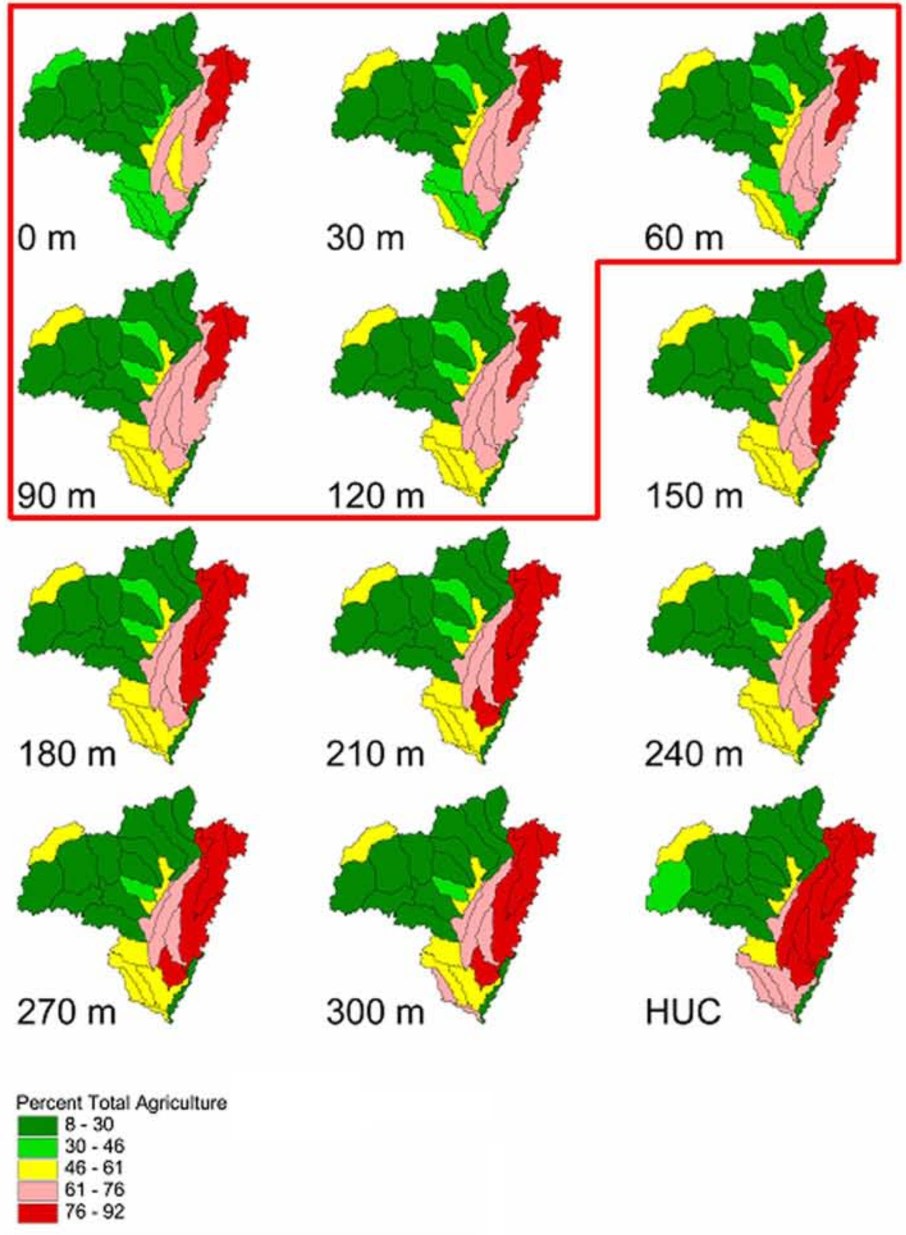


Figure 36. Spatial analysis of twenty-five 8-digit hydrologic unit code (HUC) subwatersheds in the White River Watershed. There is a relatively greater risk of surface water quality impairment in 2 HUCs (outlined in red above and at right) as a result of the presence of agriculture within the cumulative 120 meter riparian zones.

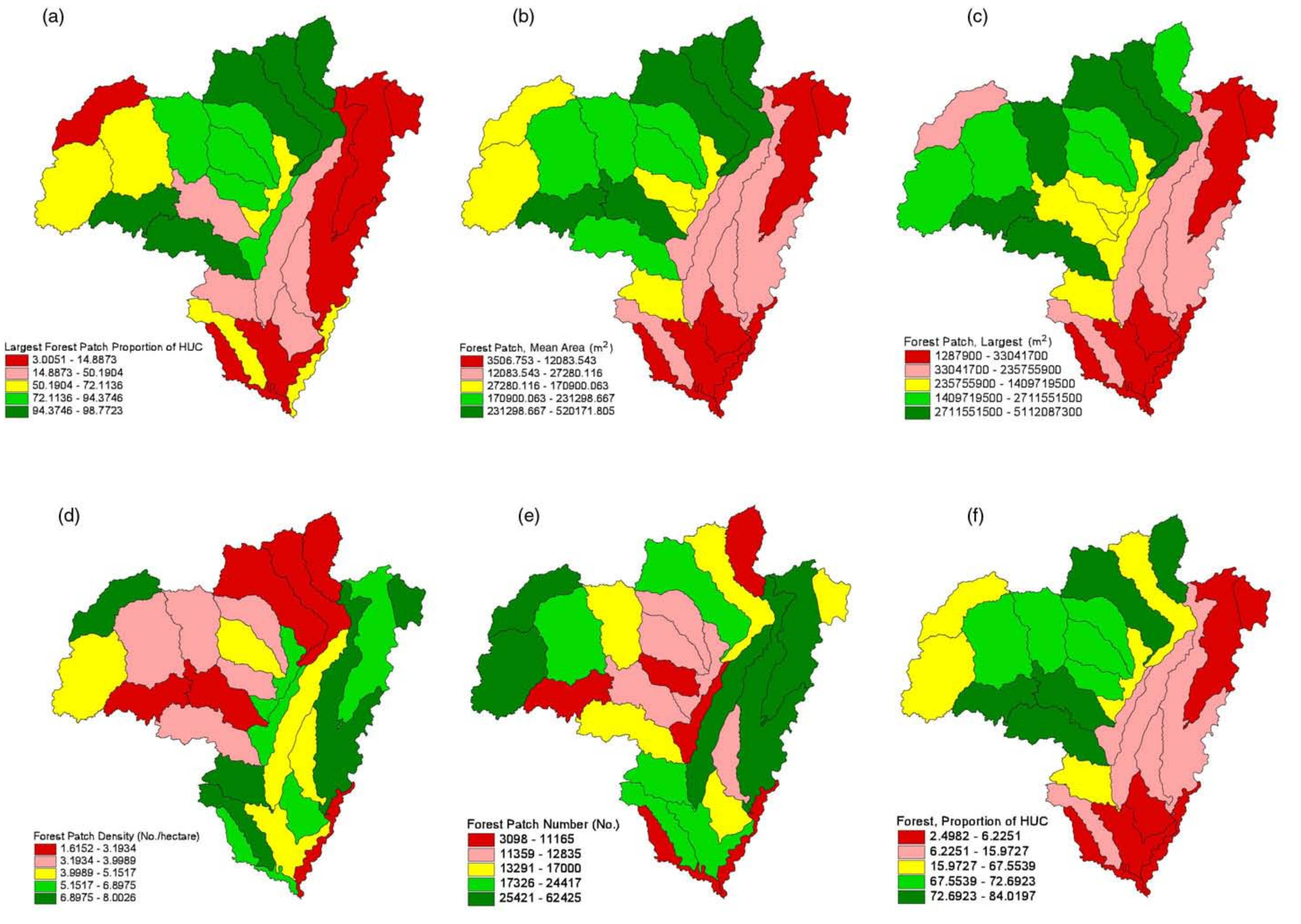


Figure 37. Proposed water quality vulnerability metrics, based on (a) largest forest patch proportion of HUC, (b) mean area of forest patch, (c) largest forest patch area, (d) forest patch density, (e) forest patch number, and (f) percent of HUC that is forest (by area). Forest cover based on NLCD codes 41, 42, and 43 (Table 4).

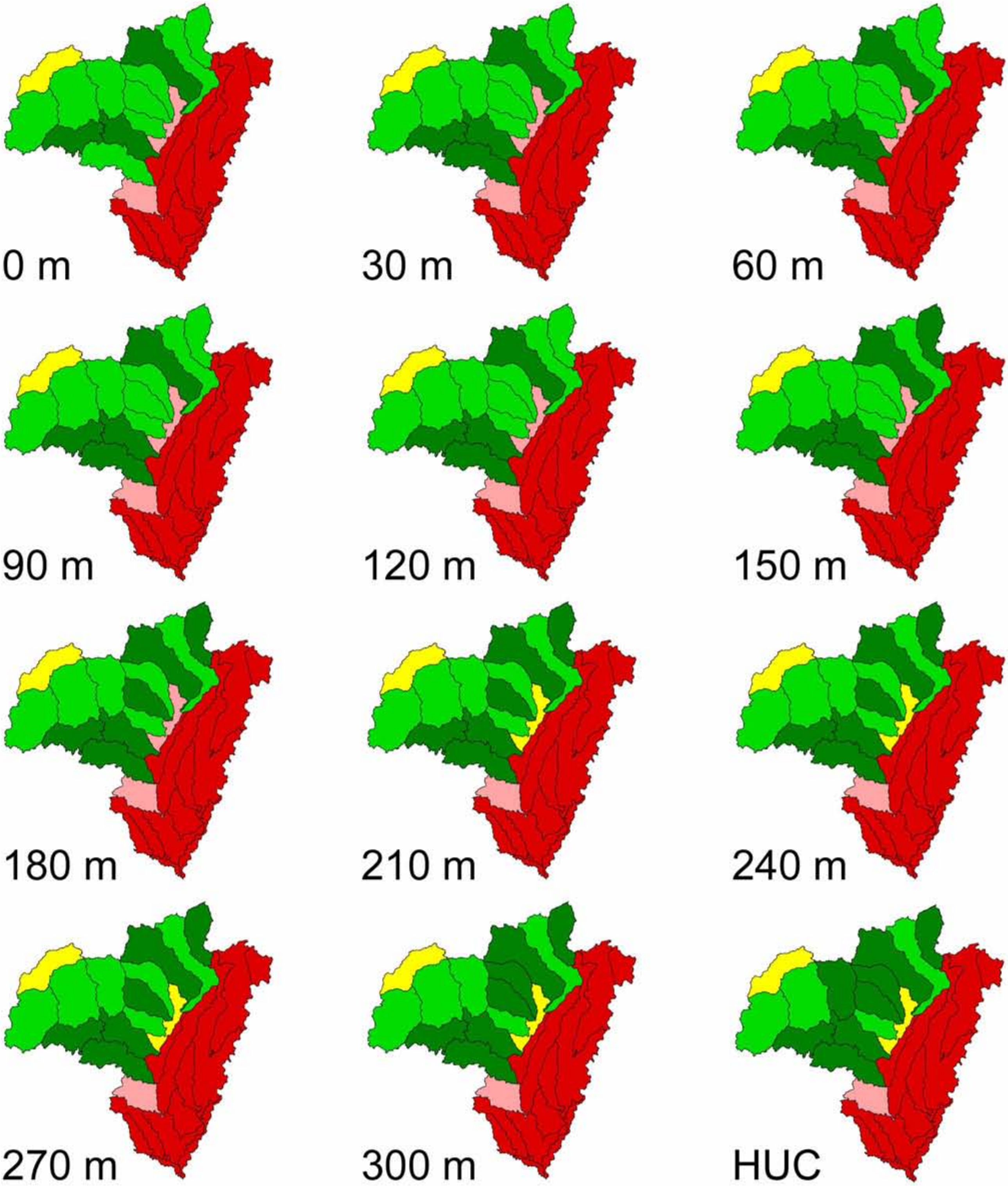


Figure 38. Proposed water quality vulnerability metrics, based on percent forest (i.e., NLCD codes 41, 42, and 43 in Table 4) adjacent to shorelines, within cumulative thirty-meter riparian zones, and within entire HUCs.

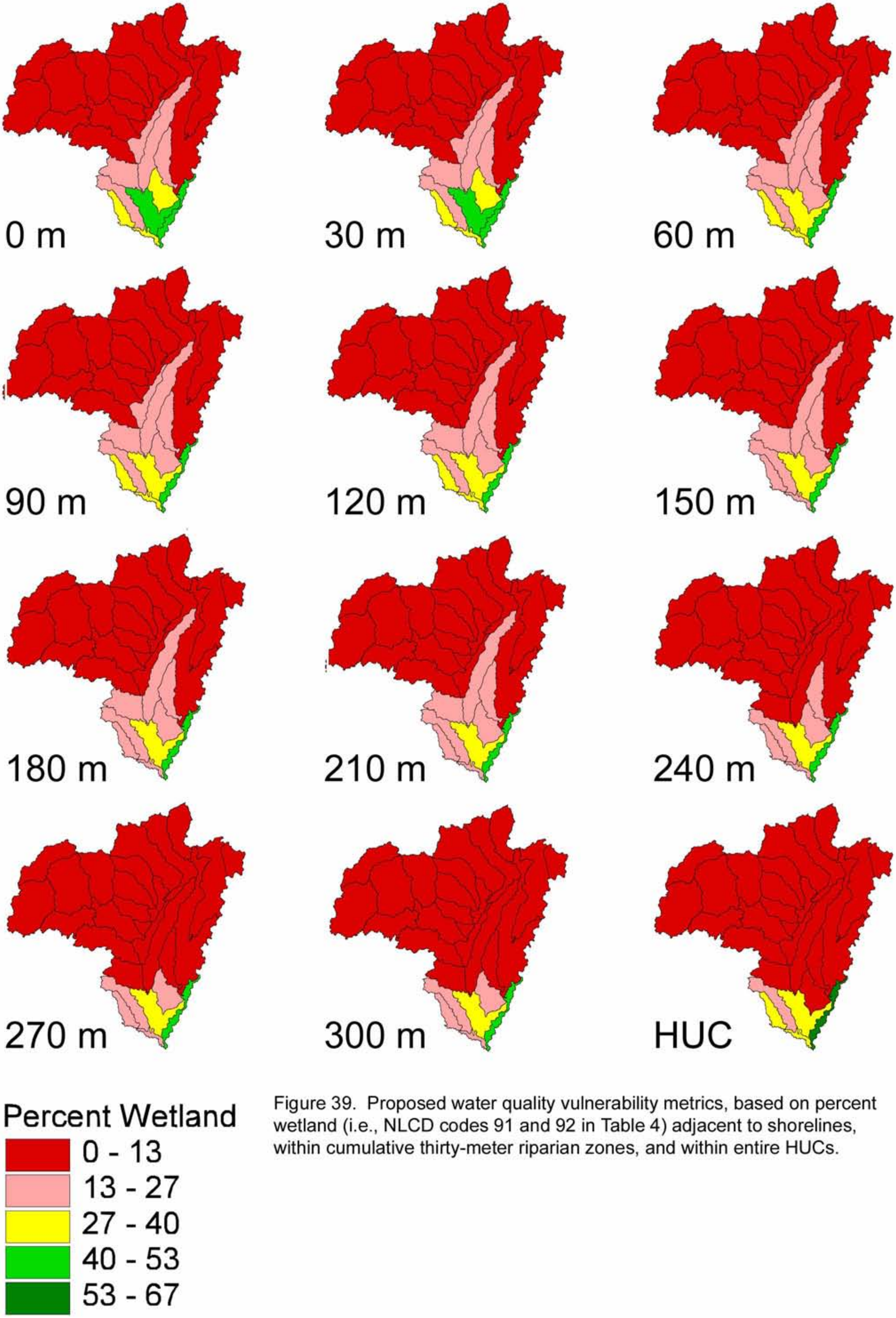


Figure 39. Proposed water quality vulnerability metrics, based on percent wetland (i.e., NLCD codes 91 and 92 in Table 4) adjacent to shorelines, within cumulative thirty-meter riparian zones, and within entire HUCs.

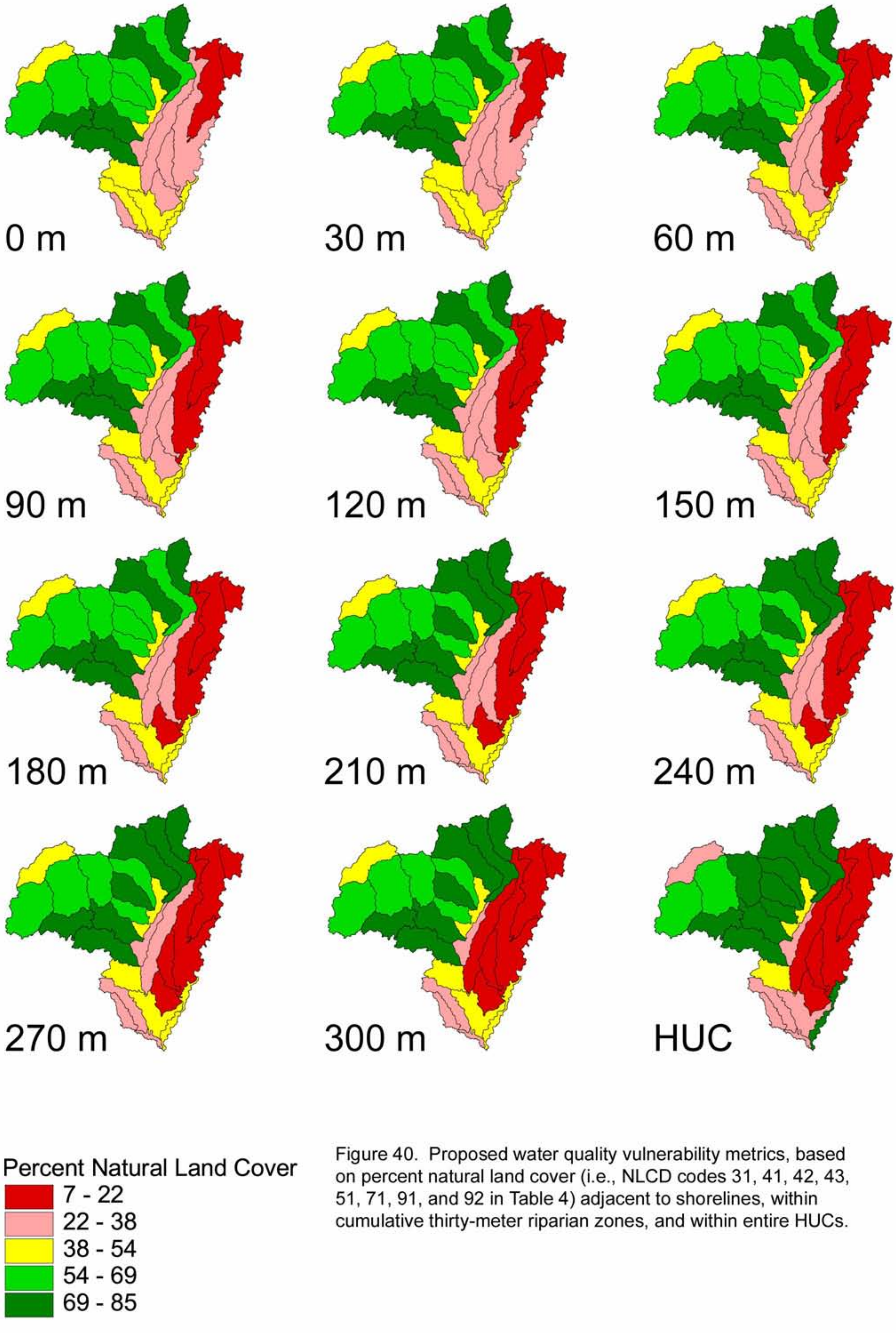
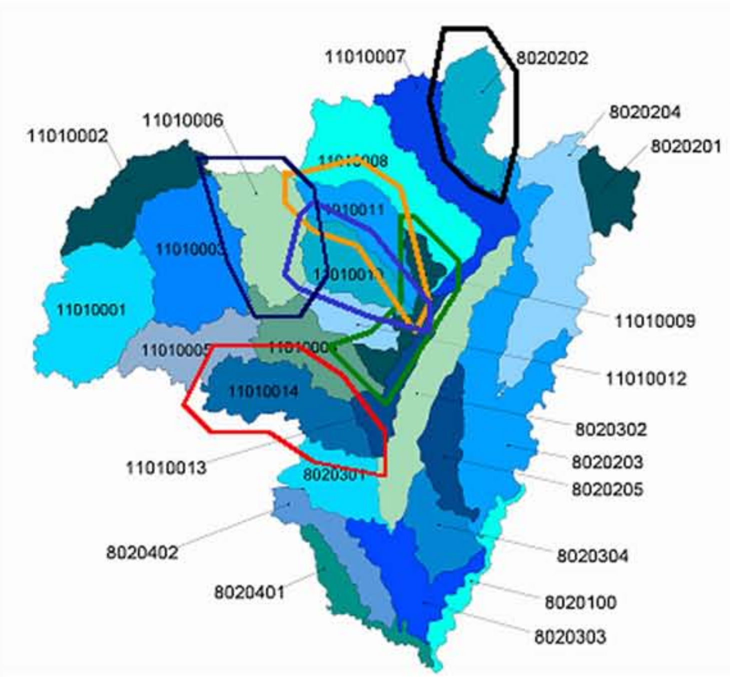


Figure 40. Proposed water quality vulnerability metrics, based on percent natural land cover (i.e., NLCD codes 31, 41, 42, 43, 51, 71, 91, and 92 in Table 4) adjacent to shorelines, within cumulative thirty-meter riparian zones, and within entire HUCs.



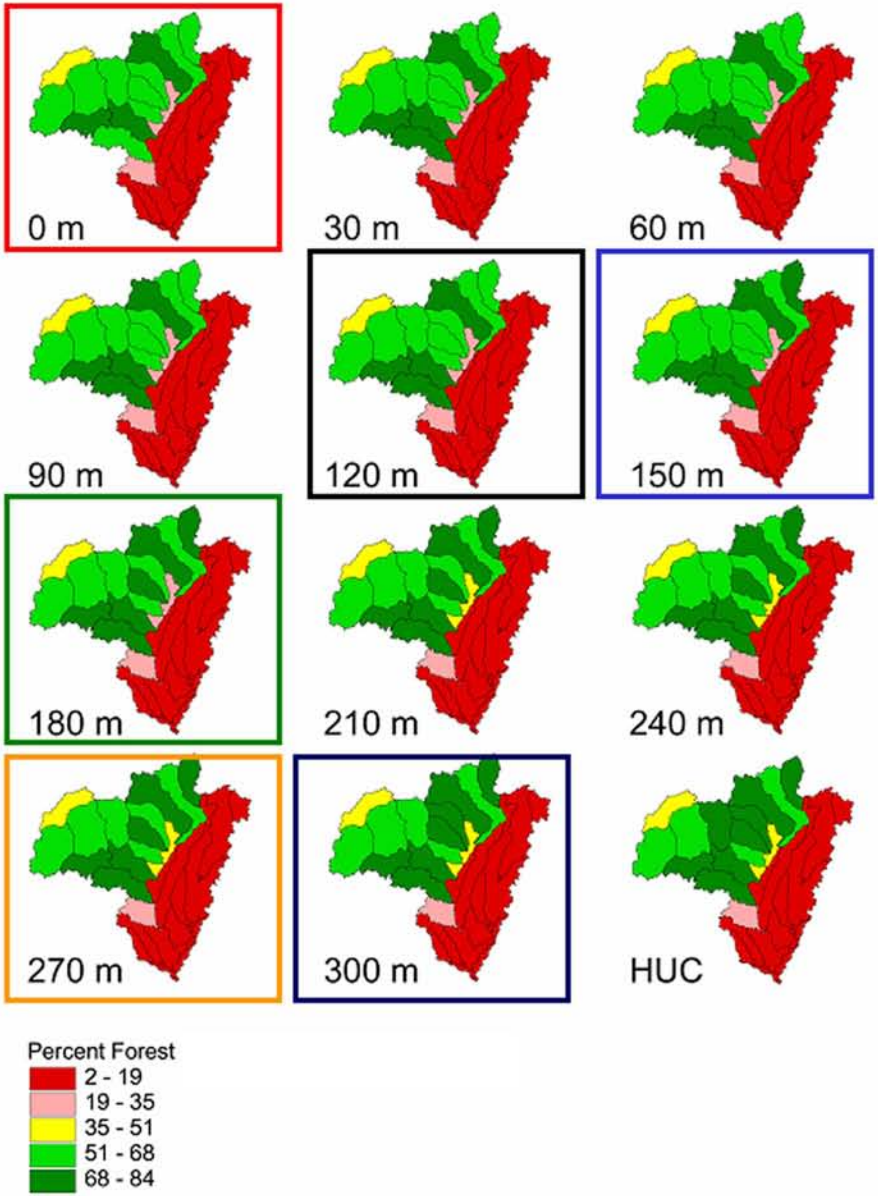


Figure 41. Spatial analysis of twenty-five 8-digit hydrologic unit code (HUC) subwatersheds in the White River Watershed. There is a relatively greater risk of surface water quality impairment in 6 HUCs (outlined above and at right) as a result of forest loss in riparian zones of various widths.

Lower White River Region Federal Wildlife Refuge Analyses

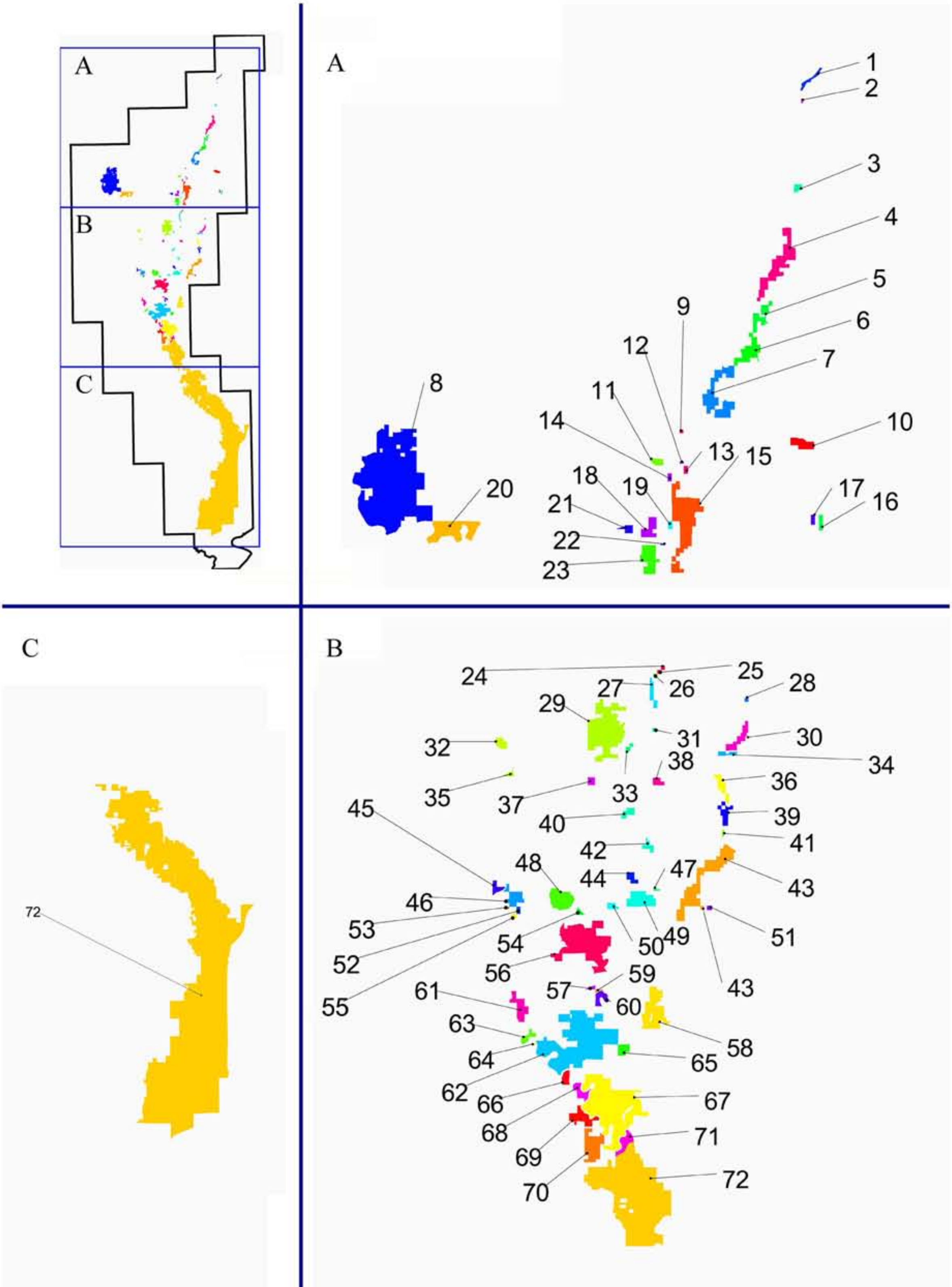
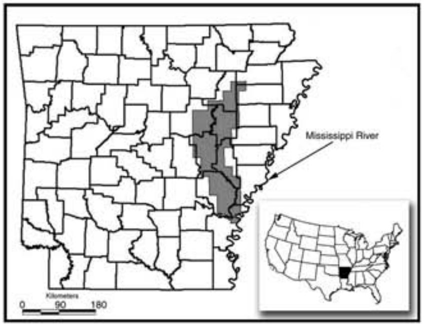
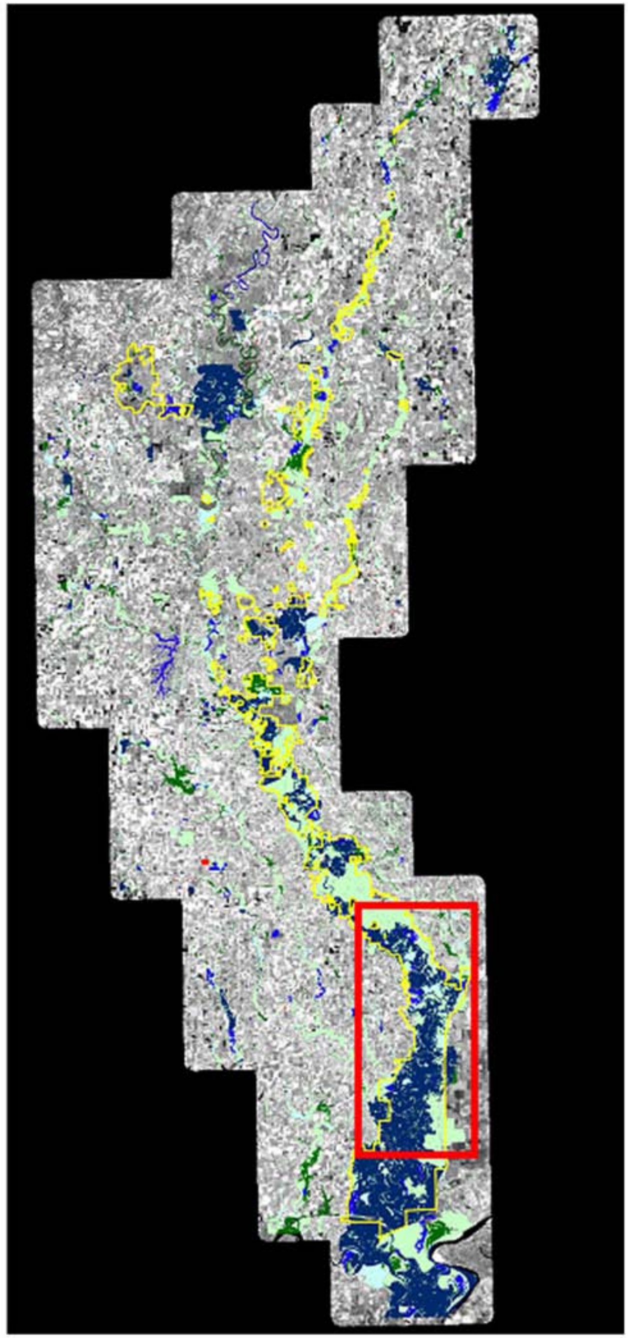


Figure 42. Seventy-two federal refuge zones in the Lower White River Region were compared using mallard duck winter habitat vulnerability models. Federal refuge zones are all within a larger Lower White River Region study area. Overview image (upper left) is separated into three areas to show the location and identification number of each federal refuge zone (enlarged in images, A-C). Because of its larger area, federal refuge zone 72 is shown both in image quadrant B (northern zones), and in image quadrant C (southern zones).





Mallard Winter Habitat - Unified Vulnerability Index, patches > 2 ha

- < -3 Std. Dev. (Greatest Vulnerability)
- -3 - -2 Std. Dev.
- -2 - -1 Std. Dev.
- -1 - 0 Std. Dev.
- Mean
- 0 - 1 Std. Dev.
- 1 - 2 Std. Dev.
- 2 - 3 Std. Dev.
- > 3 Std. Dev. (Least Vulnerability)

Figure 43. The unified vulnerability index was applied to a hypothetical landscape where change in the riparian wetland hydrology has occurred. Red rectangle indicates the portion of the South Unit in the White River National Wildlife Refuge where landscape change is hypothesized.

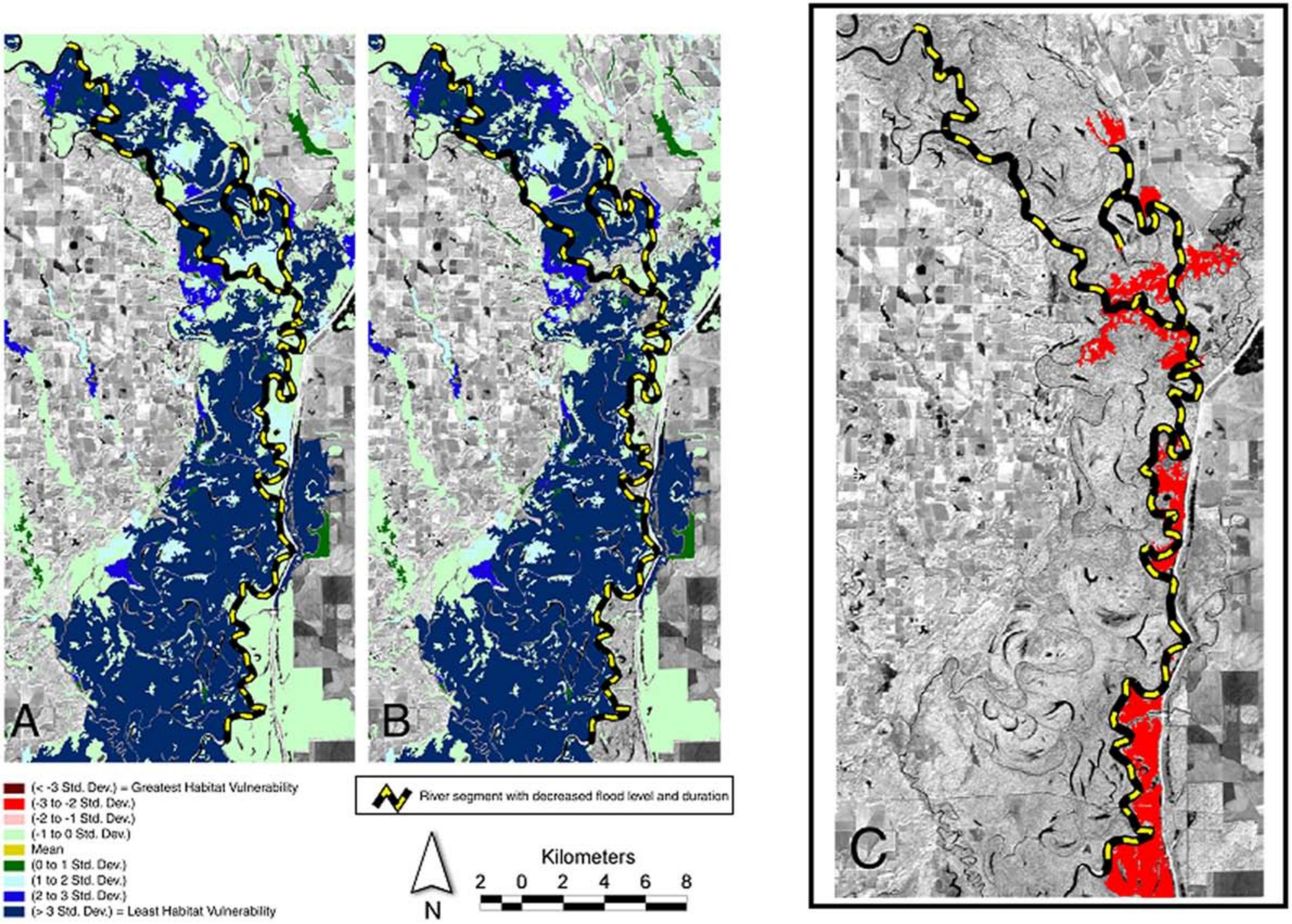


Figure 44. (A) Mallard duck winter habitat vulnerability under current hydrologic conditions in the South Unit of the White River National Wildlife Refuge; (B) Loss of mallard duck winter habitat under hypothetical decrease in flood stage and duration on the White River; (C) enlarged view of predicted net loss of mallard duck (winter) habitat under hypothetical decrease in flood stage and duration on the White River.