Ecological Approach to Infrastructure Development
For the East-West Gateway
Final Report for FY2011

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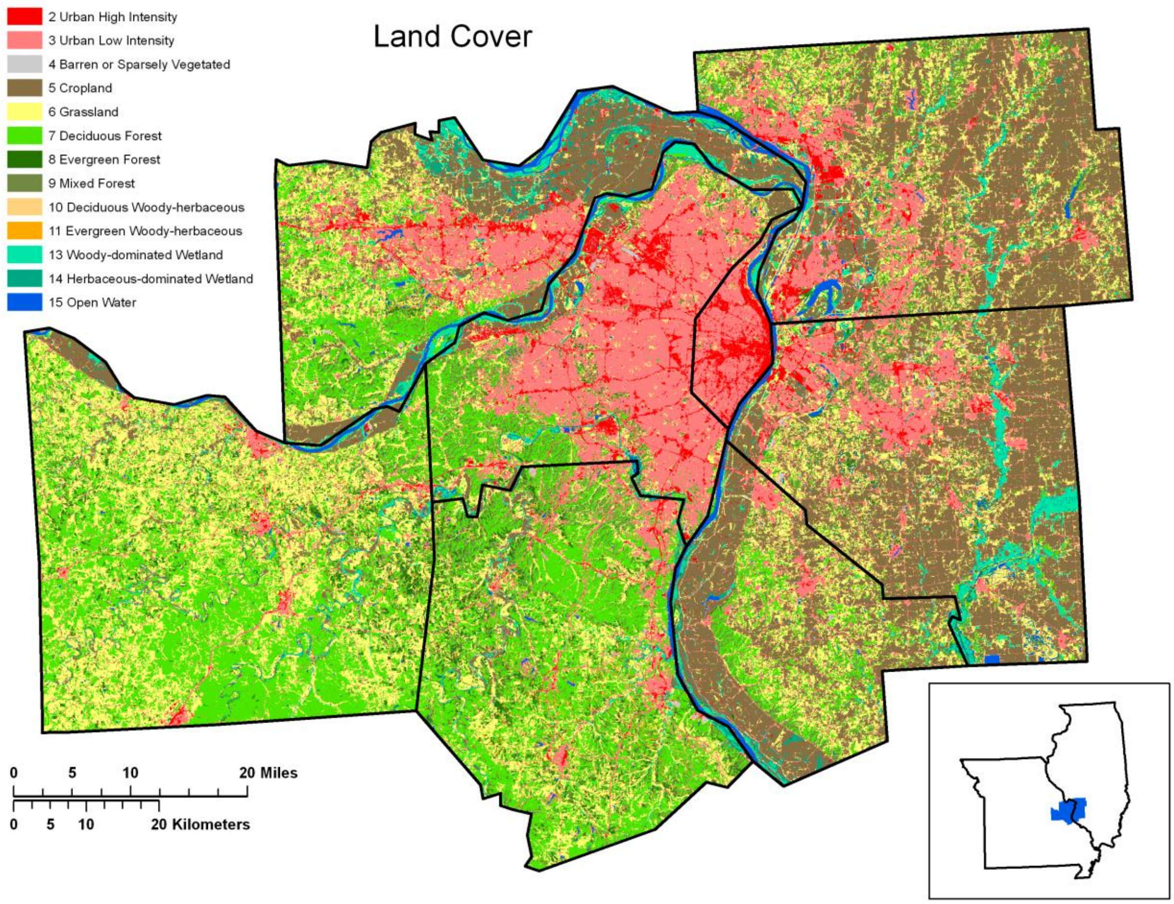
Abstract. We created an ecological significance layer for the eight-county East-West Gateway planning region surrounding St. Louis in Missouri and Illinois. We manipulated the results of existing riverine assessments, and ranked individual patches of natural and semi-natural vegetation using a suite of attribute variables important to ecological significance. The guiding principles on which the ranking algorithm was based included the assertions that natural and semi-natural vegetation is more important than cultural vegetation or urban land cover; that larger patches are more functional for long-term ecosystems viability and therefore more important that smaller patches; that both coarse-filter (landscapes and communities) and fine-filter (species) elements of natural diversity are important; and that public lands and adjacent areas are important in that they offer increased potential for maintenance or creation of large, functional landscapes. Eight tiers of importance were identified primarily by creating selection sets of vegetation patches based on attributes such as patch size, area of significance communities, and occurrences of rare species. In addition, riverine conservation assessments for Missouri and Illinois stood on their own, and aquatic conservation opportunity areas and biologically significant streams were considered of maximum ecological significance. A total of 56,404 hectares (4.8% of the study region) was considered of maximum or very high significance, and an additional 90,070 hectares (7.6% of the region) was of high significance. A total of 739,129 hectares (62.7% of the region) was of very low ecological significance, and 39,418 hectares (3.4% of the region) was urban high intensity land cover, of minimum ecological significance. Fairly large, continuous swaths of the southern and southwestern portions of the region are forested or in other natural or semi-natural vegetation types, and offer exceptional promise for conservation of viable, functional landscapes through time. Additional smaller, yet functional patches support regionally or nationally significant communities or populations of species of conservation concern and deserve special consideration as ecologically significant areas.

The East-West Gateway Council of Governments serves an eight county region, five in Missouri and three in Illinois, and has an overall mission of helping the region to "offer its residents and unexcelled quality of life" (Figure 1). One current thrust is to use an ecological approach to planning, which requires in turn a sound basis for assessment of current conditions, including ecological significance, and forecasting of future development pressures. The goal of our effort was to help provide a uniform, scientifically sound evaluation of ecological significance for use in both reactive (e.g. mitigation of needed development) and proactive (e.g. planning for transportation corridors; development of parks and conservation easements) planning efforts.

Figure 1. Location and land cover for the East-West Gateway planning region.



Project Need

Currently available land cover data are old (circa 2000), too coarse (30 meter spatial), and too general (about 15 land cover classes) to be adequate for current planning efforts. A variety of government and non-government organizations in Missouri and Illinois have provided assessments of ecological significance, but the results of these are not comparable are not comparable across the region (Table 1). Our goal was to generate new current vegetation maps and use the most consistent available data on variables important to ecological significance in order to provide a standardized, scientifically sound ecological significance data layer for the East-West Gateway planning region.

Table 1. Evaluations of ecological significance done by different entities within the East-West Gateway Region.

Evaluation	Entity	Outcome	Reference
Overall Conservation Opportunity Areas (MO)	Missouri Department of Conservation	spatially specific polygons	http://mdc.mo.gov/nathis/cws/coa/
Terrestrial Conservation Opportunity Areas	Missouri Department of Conservation	spatially specific polygons	internal agency document
Terrestrial Hotspots	Missouri Department of Conservation	spatially specific polygons	internal agency document
Aquatic Conservation Opportunity Areas	Missouri Department of Conservation	spatially specific polygons	http://www.cerc.usgs.gov/morap/Maps.aspx?MapId=9
Conservation Opportunity Areas (IL)	Illinois Department of Natural Resources	conceptual places on the landscape	http://dnr.state.il.us/ORC/WildlifeResources/theplan/final/
Biologically Significant Streams (IL)	Illinois Department of Natural Resources	stream reaches	http://dnr.state.il.us/ORC/BioStrmRatings/index.htm
ranking of forest, wetland, and prairie patch importance	Illinois Department of Natural Resources	polygons that correspond to land cover patches	http://dnr.state.il.us/ORC/WildlifeResources/theplan/final/
Portfolio Sites	The Nature Conservancy	spatially specific polygons	internal document

Process

The vision for this project sprang from the desire to improve on past work done by the East-West Gateway and partners. Initial data gathering, conceptualization of methods, and technical work was completed by Missouri Resource Assessment (MoRAP) and East-West Gateway staff. Concepts, methods, and preliminary current vegetation mapping results were presented to partners in Springfield (Feb 26, 2010), Jefferson City (March 5, 2010), and St. Louis (April 6, 2010). During those meetings, new data sources important to ecological significance were identified and mapping methods were adjusted. Initial ecological significance data summaries and modeling results were presented at a second set of meetings on May 12 and May 14, 2010, held in Columbia, MO, and Alton, IL, respectively. Important questions addressed included which variables to use to evaluate ecological significance, what variables were still missing from the analyses, how to incorporate information on public lands, and how to evaluate aquatic versus terrestrial significance analyses (see *Initial Scoping* section, below). Partners reviewed initial results at those meetings and provided input to inform adjustments based on professional knowledge of the region. A draft final report was provided for review to East-West Gateway staff in late August, and final revisions were made based on their review.

Mapping Current Vegetation

Remote Sensing for Land Cover Classification

We used three dates of Landsat Thematic Mapper satellite data (April 6, June 25, and November 11, 2008), combined with other information, to classify the land cover (Figure 1). This images were selected because they were the most recently available, cloud-free images that represented a spring, summer, and fall sequence. After data acquisition, the next step was to create a seamless mosaic of Landsat scenes for all dates. We then used a decision tree classification approach to create the initial 13-class land cover classification (Table 2). This approach allows for the combination of remotely sensed data with ancillary data in a flexible way.

Table 2. Land cover classes mapped from satellite data and selected ancillary data sets.

Landcover Class	Description	Examples
Open Water	open water with little or no emergent vegetation	
High Intensity Urban	vegetated urban environments with a high density of buildings	city centers, highways
Low Intensity Urban	vegetated urban environments with a low density of buildings	residential areas
Barren / Sparsely Vegetated	little or no vegetation year-round	river beds, quarries, areas cleared for development
Cold Deciduous Forest and Woodland	>60% total canopy of deciduous trees	oak forests, bottomland forests
Coniferous Evergreen Forest and Woodland	>60% total canopy of coniferous evergreen trees	eastern redcedar woodlands, pine plantations
Mixed Cold Deciduous / Evergreen Forest and Woodland	>60% total tree canopy consisting of a mixture of deciduous and evergreen trees	mixed eastern redcedar/oak or pine/oak woodlands
Deciduous Woody / Herbaceous	open woodland (including young woodland) with <60% canopy cover of mainly deciduous trees	old fields, thinned woodlands and forests
Evergreen Woody / Herbaceous	open woodland (including young woodland) with <60% canopy cover of mainly evergreen trees	old fields with eastern redcedar
Grassland	dominated by herbaceous vegetation, usually graminoid, with less than 25% woody cover	tall fescue pasture
Row Crops	low, close-grown, and forage crops	corn, soybeans
Herbaceous-dominated Wetland	seasonally or semi-permanently flooded, or saturated soil wetlands dominated by herbaceous vegetation	rushes, sedges, grasses
Woody-dominated Wetland	seasonally or semi-permanently flooded, or saturated soil wetlands dominated by >60% cover of trees or shrubs	river corridors, ponds, or oxbows with species such as willow or buttonbush

The decision tree classification approach requires a training data set for each land cover class mapped. We generated this dataset primarily via air photo interpretation of randomly selected sample points and limited ground-collected data. Air photo interpretation required the use of the most recently available leaf-on and leaf-off photos in order to accurately distinguish all thirteen classes. Leaf-off photos are especially useful for separating cropland from grassland, and in distinguishing among deciduous, evergreen, and mixed woody cover types because the differences are not dramatic in leaf-on photos.

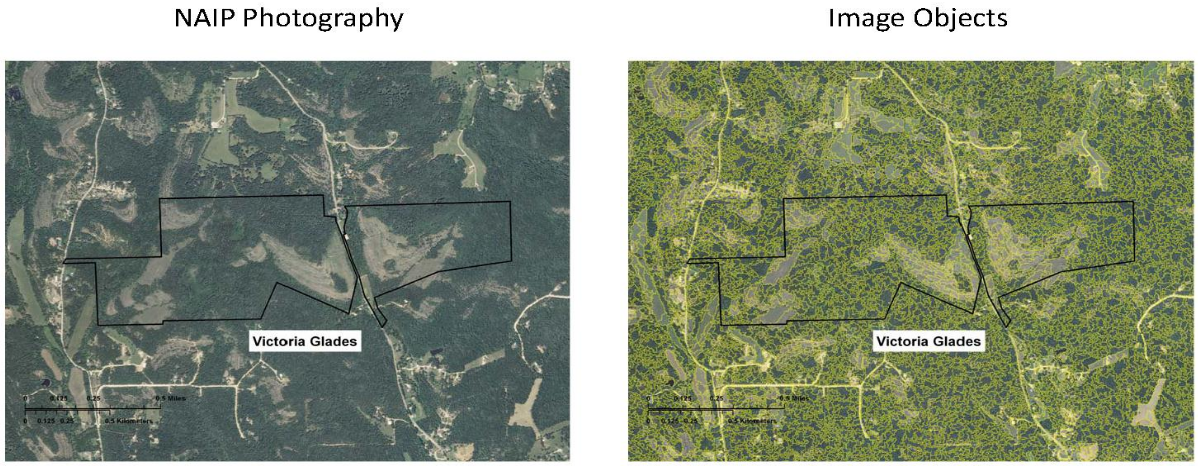
The decision tree classification process assigns pixels to land cover classes using the statistical relationship between training data and satellite imagery and ancillary data of a given area. All decision tree classifications were run using a 30 meter spatial resolution, which is the native resolution for Landsat Thematic Mapper imagery. The classification procedure was implemented multiple times, using different combinations of data, in an effort to maximize classification accuracy. We generated more than 20 different classification results. The most accurate classification used satellite reflectance data from all three dates together with slope, aspect divided into nine equal classes, landscape position, solar insolation, percent canopy cover from the National Landcover Dataset (NLCD, see http://www.mrlc.gov/), and percent impervious cover from the NLCD.

Achieving Higher Spatial Resolution

A post hoc process was implemented to improve spatial resolution using image objects generated with the eCognition Developer software. Image objects, which result in the circumscription of areas that appear similar visually, were generated from stacked leaf-on (2009) and leaf-off (2007) NAIP imagery at six meter spatial resolution (Figure 2). Due to software processing limitations, this procedure was run on four to six subdivisions of each county, or about 40 independent segments. To reduce file size, all image objects less than 324 square meters (three, 6 meter grid cells) were merged with adjacent objects. This resulted in about eight million image objects. The image objects were then used to summarize the land cover classification resulting from the decision tree classification procedure described above. The statistic of interest during the summarization process was the mode. Erdas Imagine was used to determine the mode for each of the nearly eight million image objects and the resulting land cover combined with soils and environmental data were used for modeling of current vegetation.

We assigned the ELT (in Missouri) or SURGO soil (in Illinois) that made up the greatest total area of each object to that object using ArcGIS. This method allowed us to maintain the higher resolution outlines of the objects as opposed to the courser resolution of the soils (ELT's are based on soil polygons). We decided to run a solar insolation AML (shortwavc.aml) created by Lalit Kumar, in order to identify mesic vegetation types. This AML calculated the cumulative shortwave radiation received for each 10 meter grid cell of the DEM (Digital Elevation Model) on the Spring Equinox (day 80) assuming a cloud-free day. The grid cells representing the "wettest" 1% of the area were converted to polygons and intersected with the objects. We also used the 10 meter DEM's to identify steep slopes. Areas with a slope greater than 20% were converted to polygons and intersected with the objects. Since the 10 meter DEM's are of a similar spatial resolution to the objects, we chose to maintain the spatial outline of the polygons created from the DEM's by intersecting them with the objects. Objects with the same attributes (land cover, soils, and environmental data) were then dissolved using ArcGIS, resulting in 1.15 million image objects.

Figure 2. Generation of image objects at six meter resolution using merged leave-on and leaf-off National Agriculture Imagery Program (NAIP) imagery for an area surrounding Victoria Glades.



Modeling to Achieve the Final Mapped Vegetation Types

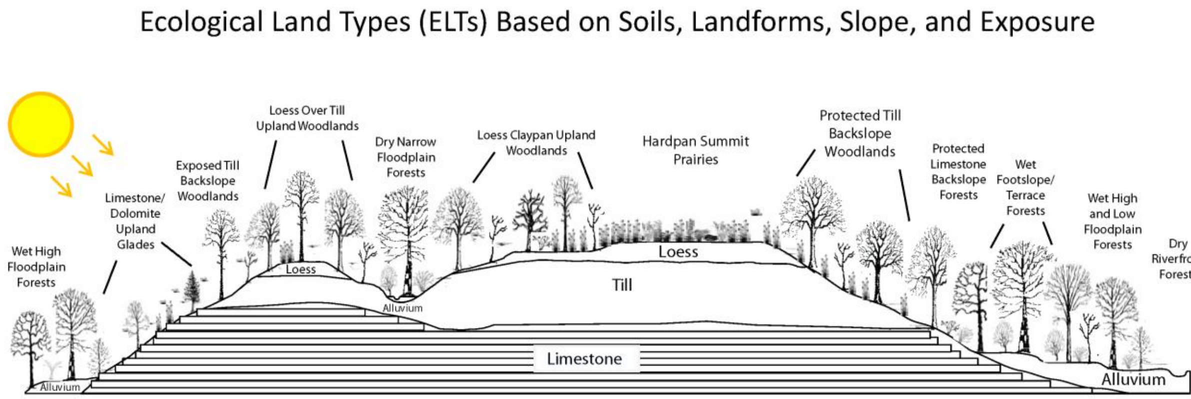
Basic modeling data included the following:

(1) For Missouri, Ecological Land Type (ELT) polygons created using soils map unit polygons from the Natural Resources Conservation Service (NRCS) Soil Geographic Database (SSURGO; Figure 3). For Illinois, the SSURGO soil map units were grouped together into similar types without a formal ELT process in place. The ELT project is a cooperative effort involving MoRAP, the Natural Resource Conservation Service (NRCS), and the Missouri Department of Conservation (Nigh and Schroeder 2002; see SURGO data tables at http://soils.usda.gov/survey/geography/ssurgo/).

(2) Slope generated from 10 meter digital elevation models (DEMs; see USGS National Elevation Dataset, http://ned.usgs.gov/). All land cover on slopes greater than 20% was assigned to "slope" or "backslope" current vegetation types (e.g. Illinois Loess and Till: Typic Backslope White Oak/Red Oak-Hickory Woodland and Forest).

(3) Solar insolation, or the amount of sun that strikes a given spot, which varies by aspect (north aspects receive less sun) and shading. Areas of low solar insolation were modeled as "mesic" current vegetation types (e.g. Illinois Loess and Till: Mesic Backslope Rod Oak/Basswood-Sugar Maple Forest).

Figure 3. Development of Ecological Land Types (ELTs) based on abiotic variables such as soils, landform, geology, percent slope, and exposure. Different ELTs support different prevailing historic vegetation types.



The land cover classification results were overlain with the data layers listed above which allowed the assignment of the original thirteen-class land cover classification to sixty different mapped vegetation types (Figure 4). In other words, different combinations of land cover with different soils, slope, and solar insolation were assigned to different final mapped current vegetation types (Tables 3, 4). The identified types were also grouped into four levels of relative naturalness based on their relationship to historic vegetation patterns including urban and cropland (level 1), cultural and disturbance vegetation (level 2), natural and semi-natural vegetation (level 3), and special communities (level 4; Figure 5). Special communities are those that are of elevated conservation concern due to apparent importance to elements of biological diversity, including glades, mesic slopes, and floodplain vegetation types.

Figure 4. General process used to assign sixty current mapped vegetation types to image objects by use of current land cover together with mapped information related to abiotic environmental variables. Wetness was defined as amount of solar insolation, and the lowest 1% of the region was considered "wet." For Illinois, Ecological Land Types (ELTs) were not available, so land cover, digital county soils surveys, percent slope, and solar insolation were used directly.

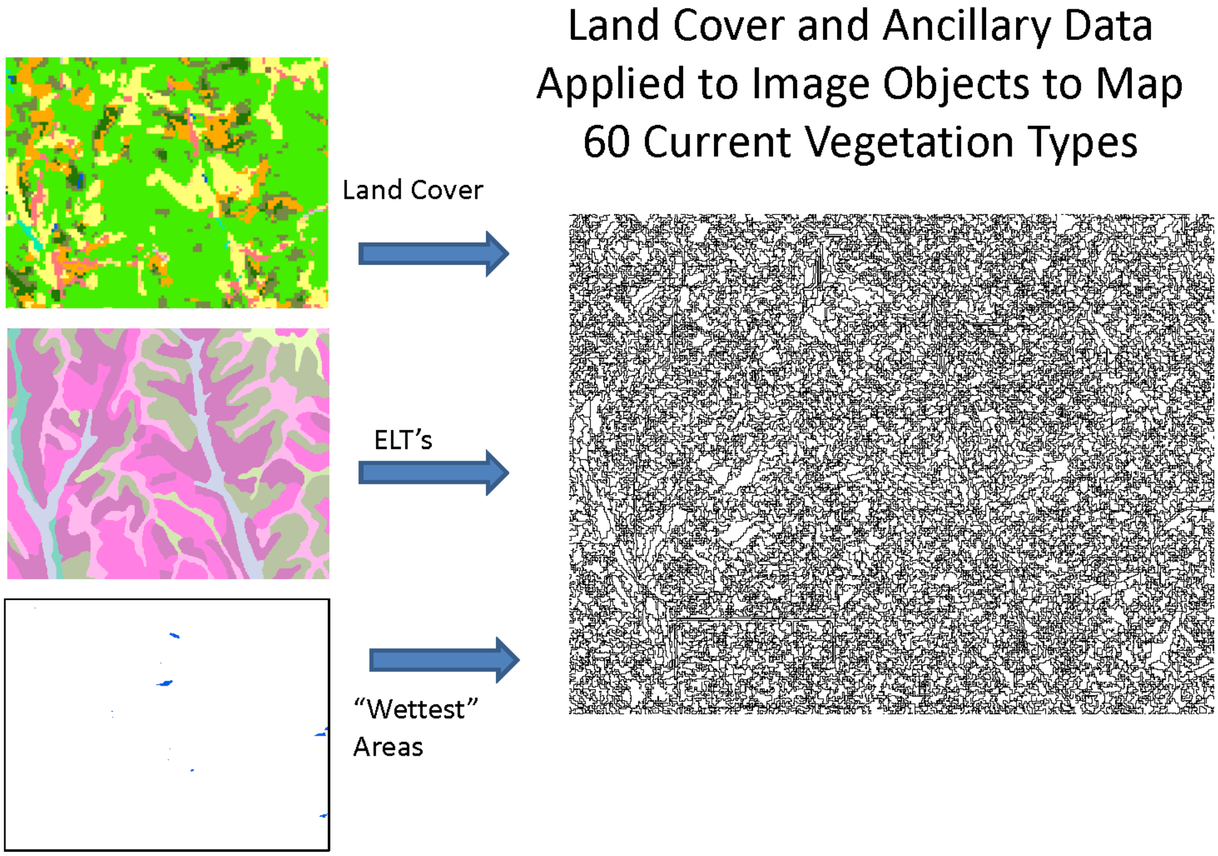


Table 3. Original satellite-based land cover versus final mapped vegetation type for the area near Victoria Glades. Variation in soils, slope, land position, and solar insolation (wetness) were used to model existing vegetation.

Satellite-based Land Cover	Mapped Current Vegetation
Urban Low Intensity	Urban Low Intensity
Cropland	Cropland
Grassland	Bottomland: Herbaceous Vegetation
	Cultural/Disturbance: Upland Limestone/Dolomite and Chert Grassland
	Cultural/Disturbance: Upland Loess and Till Grassland
	Ozark Highlands: Limestone/Dolomite Upland Glade/Chinquapin Oak Woodland Complex (grassy)
Cold Deciduous Forest and Woodland	Bottomland Forest: Mixed Bottomland Hardwood Forest
	Bottomland Forest: Sycamore, Cottonwood, Elm, Ash Hackberry Riverfront Forest
	Ozark Highlands: Mesic Backslope and Valley Red Oak/White Oak-Sugar Maple/Basswood Forest
	Ozark Highlands: Chert Backslope White Oak/Black Oak-Dogwood Woodland and Forest
	Ozark Highlands: Chert Upland Post Oak-Bluestem Prairie and Savanna (wooded)
	Ozark Highlands: Limestone/Dolomite Backslope White Oak/Chinquapin Oak-Dogwood Woodland and Forest
	Ozark Highlands: Limestone/Dolomite Upland Chinquapin Oak-Post Oak/White Oak Woodland
	Ozark Highlands: Limestone/Dolomite Upland Glade/Chinquapin Oak Woodland Complex (deciduous woods)
	Ozark Highlands: Loess and Till Upland Post Oak/White Oak-Black Oak Woodland
Coniferous Evergreen Forest and Woodland	Bottomland: Successional Eastern Redcedar Woodland
	Ozark Highlands: Sandstone Upland Glade/Post Oak Woodland Complex (juniper or mixed woods)
	Successional Upland Eastern Redcedar Evergreen Woodland and Forest
Mixed Cold Deciduous / Evergreen Forest and Woodland	Bottomland: Successional Eastern Redcedar-Deciduous Mixed Woodland and Forest
	Ozark Highlands: Sandstone Upland Glade/Post Oak Woodland Complex (juniper or mixed woods)
	Successional Upland Eastern Redcedar-Deciduous Mixed Woodland and Forest
Deciduous Woody / Herbaceous	Ozark Highlands: Limestone/Dolomite Upland Glade/Chinquapin Oak Woodland Complex (deciduous woods)
	Successional Upland Deciduous Sparse Woodland and Shrubland

Satellite-based Land Cover	Mapped Current Vegetation
Evergreen Woody / Herbaceous	Bottomland: Successional Eastern Redcedar Sparse Woodland and Shrubland
	Ozark Highlands: Limestone/Dolomite Upland Glade/Chinquapin Oak Woodland Complex (juniper or mixed woods)
	Successional Upland Eastern Redcedar Evergreen Sparse Woodland and Shrubland
Woody-dominated Wetland	Bottomland: Buttonbush/Black Willow-Water Locust Woody Wetland
	Woody-dominated Wetland (non-riverine)
Open Water	Open Water

Figure 5. Current vegetation types of the East-West Gateway region coded by relative naturalness in relation to prevailing historic vegetation patterns (see Table 4).

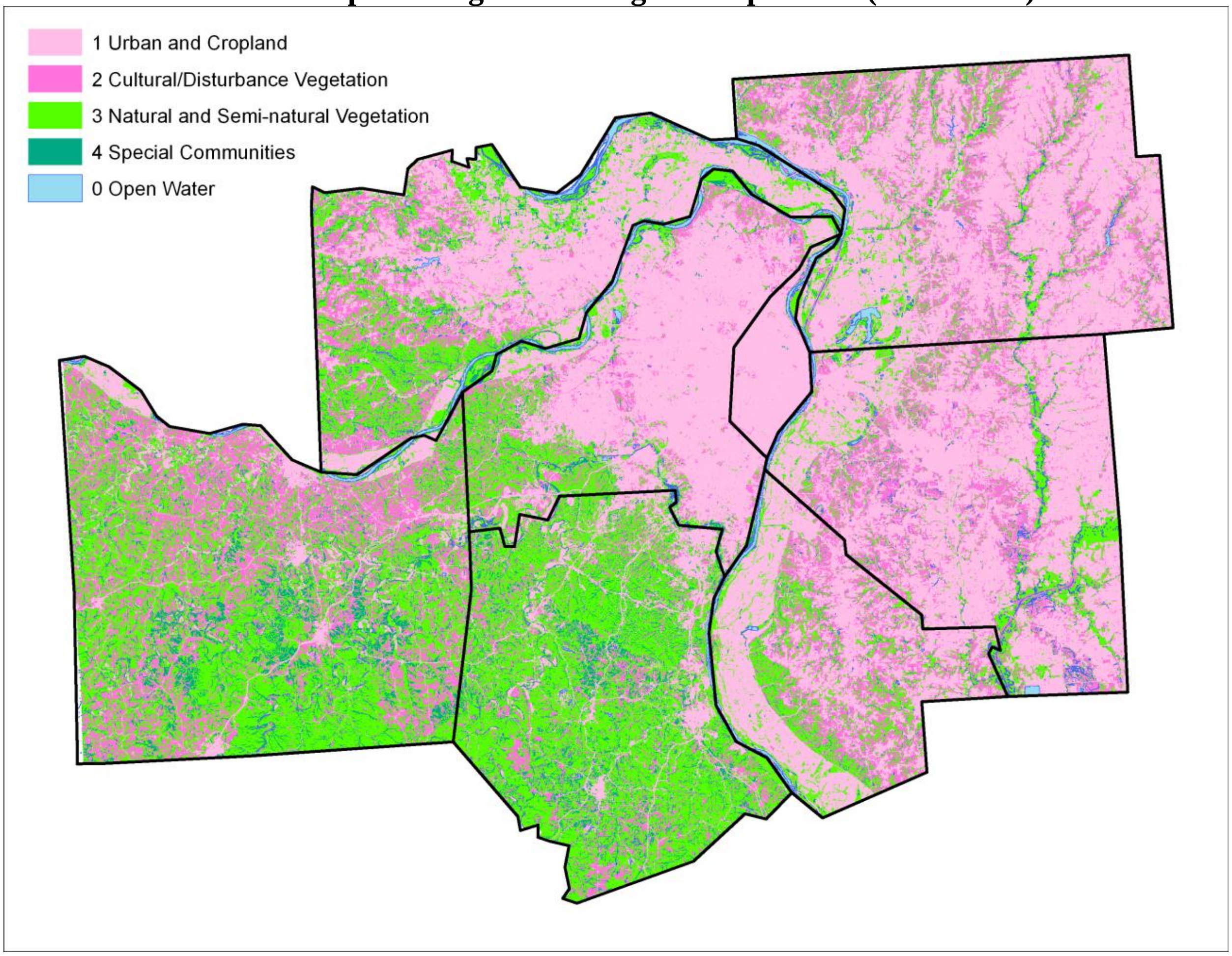


Table 4. Mapped current vegetation, area, and relative naturalness score. Types ranked as 1 or 2 are considered non-natural for the purposes of identification of patches, and types ranked as 4 are communities of increased conservation concern

Current Vegetation	Area (ha)	Relative Naturalness Score
Barren or Sparsely Vegetated	3,638	1
Bottomland Forest: Mixed Bottomland Hardwood Forest	7,135	4
Bottomland Forest: Pin Oak/Bur Oak-Swamp White Oak/Pecan Forest	5,504	4
Bottomland Forest: Sycamore, Cottonwood, Elm, Ash Hackberry Riverfront Forest	7,613	4
Bottomland Forest: White Oak/Red Oak-Dogwood/Sycamore Forest	1,319	4
Bottomland: Wooded Wetland	29,991	4
Bottomland: Herbaceous Vegetation	70,147	3
Bottomland: Successional Deciduous Woodland and Shrubland	1,911	2
Bottomland: Successional Eastern Redcedar Sparse Woodland and Shrubland	1,877	2
Bottomland: Successional Eastern Redcedar Woodland	3,043	2
Bottomland: Successional Eastern Redcedar-Deciduous Mixed Woodland and Forest	6,724	2
Bottomland: Successional or Disturbance Woodland and Forest	618	2
Central Dissected Till Plains: Loess and Till Upland Bur Oak/Post Oak Upland Woodland	5	3
Central Dissected Till Plains: Loess or Till Upland Bur Oak/Post Oak-Bluestem Prairie and Savanna (wooded)	1,461	3
Cropland	267,931	1
Cultural/Disturbance Upland Sandstone Grassland	101	2
Cultural/Disturbance: Upland Limestone/Dolomite and Chert Grassland	44,938	2
Cultural/Disturbance: Upland Loess and Till Grassland	114,157	2
Disturbance or Successional Upland Grassland	11,282	2
Herbaceous-dominated Wetlands (non-riverine)	4,672	3
Illinois Hill Prairie or Glade (grassy)	2,234	4
Illinois Hill Prairie or Glade (wooded)	4,264	3
Illinois Loess and Till: Mesic Backslope Red Oak/Basswood-Sugar Maple Forest	669	4
Illinois Loess and Till: Typic Backslope White Oak/Red Oak-Hickory Woodland and Forest	4,760	3
Illinois Loess and Till: White Oak/Red Oak-Hickory Woodland and Forest	16,166	3
Illinois Pin Oak/Post Oak-Hickory Flatwood Forest	48	3
Illinois Post Oak-Bluestem Prairie and Savanna (wooded)	246	3
Mississippi River: Mesic Bottomland Prairie	84	4
Mississippi River: Wet Bottomland Prairie	1,115	4
Mississippi River: Wet-mesic Bottomland Prairie	130	4
Open Water	25,668	0
Ozark Highlands: Chert Backslope White Oak/Black Oak-Dogwood Woodland and Forest	59,712	3
Ozark Highlands: Chert Upland Mixed Oak Woodlands	4,843	3
Ozark Highlands: Chert Upland Post Oak-Bluestem Prairie and Savanna (wooded)	8,391	3
Ozark Highlands: Limestone/Dolomite Backslope White Oak/Chinquapin Oak-Dogwood Woodland and Forest	12,777	3
Ozark Highlands: Limestone/Dolomite Cliff/Talus Complex	710	3
Ozark Highlands: Limestone/Dolomite Upland Chinquapin Oak-Post Oak/White Oak Woodland	7,986	3
Ozark Highlands: Limestone/Dolomite Upland Glade/Chinquapin Oak Woodland Complex (deciduous woods)	10,887	3

Current Vegetation	Area (ha)	Relative Naturalness Score
Ozark Highlands: Limestone/Dolomite Upland Glade/Chinquapin Oak Woodland Complex (grassy)	15,269	4
Ozark Highlands: Limestone/Dolomite Upland Glade/Chinquapin Oak Woodland Complex (juniper or mixed woods)	32,864	3
Ozark Highlands: Loess and Till Backslope Grassland, Sparse Woodland, and Shrubland	718	2
Ozark Highlands: Loess and Till Backslope White Oak/Black Oak-Hickory Woodland and Forest	12,011	3
Ozark Highlands: Loess and Till Upland Post Oak/White Oak-Black Oak Woodland	16,744	3
Ozark Highlands: Mesic Backslope and Valley Red Oak/White Oak-Sugar Maple/Basswood Forest	8,034	4
Ozark Highlands: Sandstone Backslope Red Oak/White Oak-Sugar Maple Forest	8,966	4
Ozark Highlands: Sandstone Upland Glade/Post Oak Woodland Complex (deciduous woods)	215	3
Ozark Highlands: Sandstone Upland Glade/Post Oak Woodland Complex (grassy)	1,890	4
Ozark Highlands: Sandstone Upland Glade/Post Oak Woodland Complex (juniper or mixed woods)	2,381	3
Ozark Highlands: Sandstone Upland Post Oak/Black Oak-Blackjack Oak/Scarlet Oak Woodland	5,595	3
Ozark Highlands: Upland Dry Post Oak-Bluestem Flatwoods (wooded)	15,889	3
Riverine and Bottomland Unvegetated Soil, Mud, Sand, or Gravel	591	3
Riverine Marsh	927	3
Successional Upland Deciduous Sparse Woodland and Shrubland	2,902	2
Successional Upland Eastern Redcedar Evergreen Sparse Woodland and Shrubland	6,202	2
Successional Upland Eastern Redcedar Evergreen Woodland and Forest	16,311	2
Successional Upland Eastern Redcedar-Deciduous Mixed Woodland and Forest	38,336	2
Urban High Intensity	39,481	1
Urban Low Intensity	205,926	1
Woody-dominated Wetland (non-riverine)	1,619	3

Generation of Ecological Significance Model

Initial Scoping

A variety of ecological significance algorithms were evaluated and presented to partners for early review. Initially, we simply created patches of natural and semi-natural vegetation, attached attributes to the patches (e.g. the size, the number of rare species occurrences), ranked patches for the attributes using natural breaks in the data as identified by ArcGIS software, and added the ranks for attributes by patch to come up with a final patch rank. This process helped facilitate viewing by partners, who were asked several questions: (1) have we missed any important data layers? (2) does the process of ranking patches make sense overall, and what should our guiding principles include? (3) should some data layers be excluded, or should some be more important than others in terms of ecological significance? (4) can we reasonably merge terrestrial and aquatic ranking results? and most important, (5) which variable combinations and ranking outcomes make the most sense in terms of the existing expert knowledge of the group? Based on input from the group, we gathered additional data layers (e.g. wetland reserve program easement polygons; GAP analysis species distribution models), and excluded other variables (e.g. caves and karst landscapes, designated federal emergency management floodplains, environmental justice areas, centennial and sesquicentennial farms). We also formulated basic ideas and principles about what is most important for ecological significance ranking.

Basic Principles

Underpinning the ecological significance model are three basic principles: First, natural and semi-natural vegetation are more important to native flora and fauna and therefore are more ecologically significant than non-natural vegetation; second, large patches of habitat are more significant because they are better suited to support functional communities and populations of species that remain viable through time; and third both coarse-filter (e.g. landscapes and their component communities) and fine-filter (e.g. species) elements of natural diversity should be considered in estimations of ecological significance (Diamond et al 2003, Groves 2003, Margules and Pressey 2000, Noss et al. 1999). In addition, we considered the area of public lands within a patch in ranking because public lands offer the promise of existing and on-going conservation of natural communities and species, and enhanced opportunities for blocking up large, functional natural landscapes that will be viable into the future. This fourth concept is linked to ecological significance in a less direct way than the first three, since it relates more to the practical need to protect the integrity and functionality of existing conserved areas and to safeguard the potential for improved reserve viability in the future.

Data Layers and Ranking Algorithm

With the basic principles outlined above in mind, we used five existing data layers and created eight entirely new data layers to help define ecological significance (Table 5). Primary data providers included the East-West Gateway Council of Governments, the Missouri Department of Conservation, the Illinois Department of Natural Resources, the United States Geological Survey, and the Natural Resources Conservation Service. Many data layers were compiled or merged from separate, original sources, so more than 20 GIS data layers were manipulated to create those that were used. Many additional GIS data layers were assembled, viewed, and evaluated on-screen but were not used for ranking algorithms. The basic process for generation of the final ecological significance model was to:

(1) Group identified natural and semi-natural vegetation into patches;
(2) Segment the resulting patches by roads that bisected the patches, thus creating road-bounded patches;
(3) Summarize data important to ecological significance by patch (see below);
(4) Buffer streams within important aquatic conservation opportunity areas or biologically significant streams by 50 meters; and
(5) Assign all patches, stream buffers, and the remaining current vegetation or land cover types to one of eight tiers of ecological significance based on the principles outlined above.

Ranking Algorithm and Results

Eight tiers of significance were identified (Figure 6). Within most tiers, the focus was on the creation of a selection set of natural and semi-natural vegetation patches that satisfied one of several criteria based on patch attributes (Table 6). Vegetation patches were added to a selection set if they satisfied the criteria for any of the attributes evaluated. For example, for Tier 1, a patch was within the selection set if it was among the five largest within the study area, or if it was among the five patches with the largest area of special communities, and so on. Thus, each attribute was evaluated in relation to all patches not already belonging to a previous, higher tier selection set. Sometimes one patch satisfied several of the selection criteria (e.g. for Tier 1, was both among the five largest patches and among the five patches with the most area of special communities).

Figure 6. Ecological significance for the East-West Gateway region. Significance was assigned to land cover patches based on values for attributes such as size, area of significant natural communities, and number of rare species occurrences.

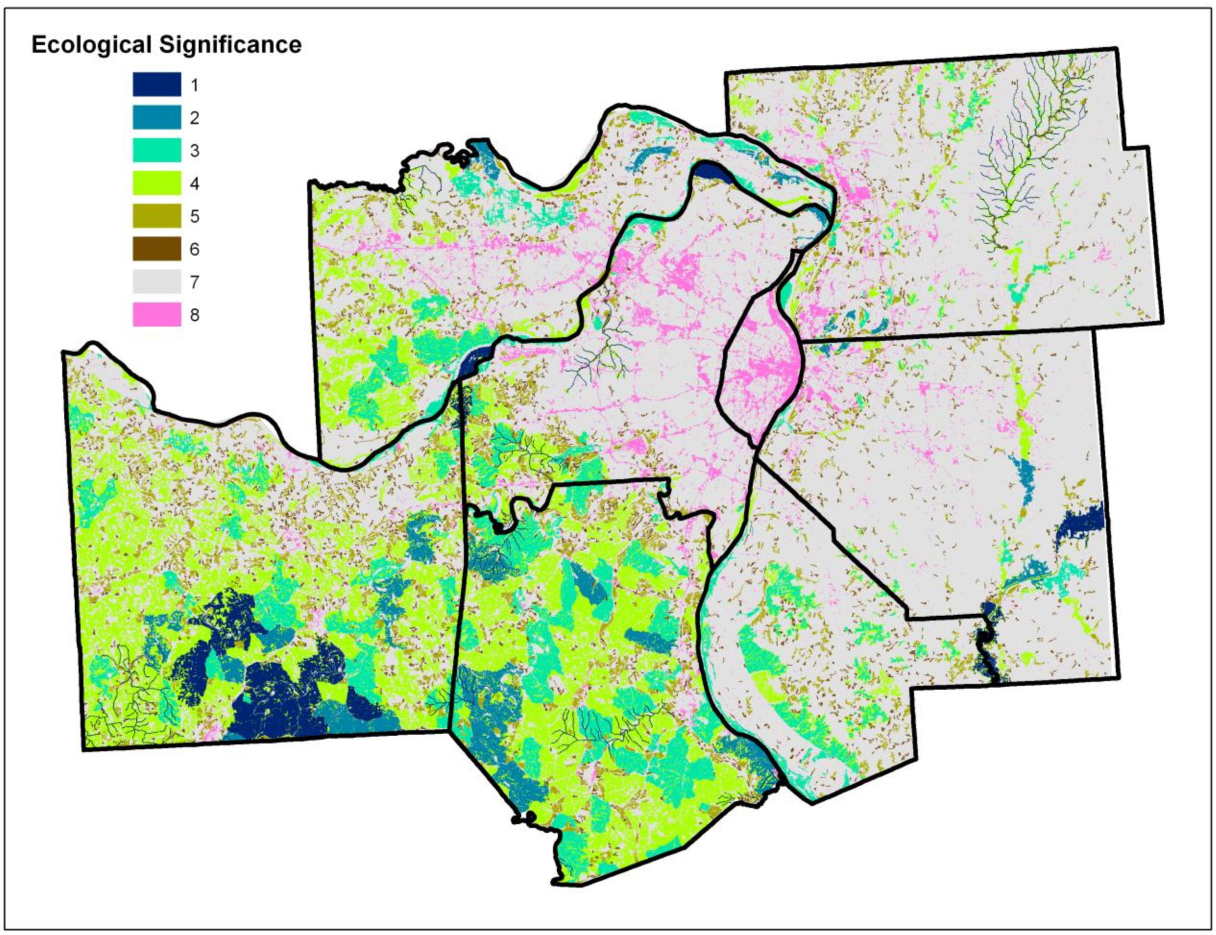


Table 5. Input data layers for ecological significance modeling.

Large-Scale	**Source**	**Comments**
Large patches of natural and semi-natural vegetation	MoRAP-created	land cover was created from remote sensing, air photos, and modeling from ecological land types, soils, and %slope and exposure (see text); natural and semi-natural patches excluded urban and disturbance types (rank 1 & 2, Table 4), with patches segmented by roads
Large areas of contiguous forest (>2000 ha patches)	MoRAP-created	all forest types were combined and forest patch area determined
Mid-scale		
Bottomland Communities (rank 4, Table 4)	MoRAP-created	all herbaceous and wooded types on bottomlands soils
Glades (rank 4, Table 4)	MoRAP-created	all cover types on glade or glade/woodland soils in Missouri
Hill Prairies or Glades (rank 4, Table 4)	MoRAP-created	mapped on loess hills in Illinois based priarily on digital soil surveys
Mesic Slope and Valley Forests (rank 4, Table 4)	MoRAP-created	mapped in forested areas with modeled low solar insolation, including north-facing slopes and adjacent toe slopes and narrow valleys
Modeled High Amphibian, Mammal, and Bird Diversity Areas	MoRAP-created from United States Geological Survey Gap Analysis Program for Missouri and Illinois	all species of amphibians, mammals, and birds were pooled; only summer (breeding) birds were sued of Illinois
Stream Buffers of High Conservation Value	MoRAP-created from Missouri Department of Conservation Aquatic Conservation Opportunity Areas and Illinois Biologically Significant Streams from the Illinois Department of Natural Resources	streams mapped within the 100:000 scale National Hydrologic Dataset (NHD) that occurred within watersheds of high conservation value were buffered by 50 meters on each side of the center line
Small-scale		
Mapped Globally Rare Species Occurrences	Biological and Conservation Data Center Managers, Missouri Department of Conservation and Illinois Department of Natural Resources	species ranked G1 or G2 by NatureServe, or globally endangered or threatened

Small-scale	**Source**	**Comments**
Mapped Regionally Significance Species Occurrences	Biological and Conservation Data Center Managers, Missouri Department of Conservation and Illinois Department of Natural Resources	includes all species tracked by Missouri or Illinois exclusive of invasive and pest species; most species are state rare or otherwise of conservation concern; for Missouri, records older than 1980 were excluded; some records were excluded due to special uncertainty; only one occurrence of each species was counted per patch
Sinkholes	East-West Gateway for Illinois, and Missouri Department of Natural Resources for Missouri	Illinois data was compiled originally b Monroe County Soil and Water Conservation office; Missouri data from MDNR Division of Geology and Land Survey
Springs	USGS National Hydrological Dataset and Missouri Department of Natural Resources, Division of Geology and Land Survey	most spring locations were derived from USGS 24:000 scale quad sheets, but various additional sources were included for Missouri
Additional Input Data		
Public Lands	East-West Gateway Open Space datalayer together with primary public landowners by state and the Natural Resources Conservation Service (NRCS)	Open Space datalayer was modified to exclude areas devoted to cultural uses such as soccer fields and highly developed urban parks via on-screen analysis; includes natural areas and wetland reserve program areas (NRCS)
Data Considered but Not Used		
Cave Locations	not listed	not as significant and somewhat redundant when rare cave and karst species are included
Centennial and Sesquicentennial Farms	not listed	not mapped well and not as significant
Environmental Justice Areas	not listed	not appropriate for use
Federal Emergency Management Agency Floodplains	not listed	not mapped well and not as significant
Illinois Designated "Star" Areas	not listed	a finished analysis based on primary input data similar to those used here; results of a more detailed, original analysis ranking patches could not be found in GIS form

Data Considered but Not Used	**Source**	**Comments**
Illinois Resource Rich Areas	not listed	a finished analysis based on primary input data similar to those used here but very large areas circumscribed
Karst Landscapes	not listed	not as significant and inclusion would have driven the ranking process; redundant when rare cave and karst species are included
Missouri Outstanding Waterways	not listed	not appropriate for use
Missouri Statewide Conservation Opportunity Areas	not listed	not appropriate for use
Missouri Terrestrial Conservation Opportunity Areas	not listed	not appropriate for use
Missouri Terrestrial Hotspots	not listed	not appropriate for use
Prime Farmland	not listed	not appropriate for use
The Nature Conservancy Portfolio Areas	not listed	a finished analysis based on primary input data similar to those used here; results based on different planning regions that that used here

Tier 1 (Maximum Significance) (33,661 hectares, 2.9% of the study region)

This selection set consisted of 50-meter buffers on either side of the center line of streams within watersheds identified as aquatic conservation opportunity areas in Missouri or biological significant streams in Illinois, plus natural and semi-natural patches of vegetation that satisfied one or more of the following criteria:

(1) Among the five largest patches in the study area,
(2) Among the five patches with the largest area of special communities (rank 4, Table 4),
(3) Among the five patches that contained the most area of contiguous forest,
(4) Among the five patches with the lowest perimeter to area ratio.

Thus, the focus for Tier 1 was on riverine communities of conservation significance, and coarse-filter elements of natural diversity (e.g. large patches and large areas of significant natural communities).

Tier 2 (Very High Significance) (31,615 hectares, 2.7% of the region)

This selection set consisted of patches that satisfied one or more of the following criteria, with Tier 1 patches excluded from the evaluation:

(1) Among the next five largest patches,
(2) Among the next five patches with the largest area of special communities,
(3) Among the next five patches that contained the most area of contiguous forest,
(4) Among the next five patches with the lowest perimeter to area ratio, or
(5) Among the patches that contain an occurrence of a globally rare terrestrial species (43 patches).

Thus, the focus for Tier 2 was both on coarse-filter (large patches, area of significant natural communities) and fine-filter (globally rare species) elements of natural diversity.

Tier 3 (High Significance) (83,455 hectares, 7.1% of the region)

This selection set consisted of patches that satisfied one or more of the following criteria, unless they were already included within Tier 1 or Tier 2:

(1) Among the next 20 largest parches,
(2) Among the next 20 patches with the largest area of special communities,
(3) Among the next 20 patches that contained the most area of contiguous forest,
(4) Among the next 20 patches with the lowest perimeter to area ratio,
(5) Among the patches with an occurrence of a state rare species (178 patches),
(6) Among the 20 patches with the largest area of public land,
(7) Among the patches with a sink count >19 (20 patches),
(8) Among the patches with a spring count >2 (19 patches), or
(9) Among the most diverse patches from evaluation of GAP Analysis data:
    a. Illinois maximum amphibian richness = 23 (33 patches),

b. Missouri maximum amphibian richness > 29 (20 patches),
c. Illinois maximum mammal richness = 29 (69 polygons),
d. Missouri maximum mammal richness >36 (24 polygons),
e. Illinois summer (breeding) bird maximum richness >64 (43 polygons)
f. Missouri total (forest, grassland, and wetland) bird maximum richness >85 (26 polygons).

Thus, this selection set incorporated a variety of coarse-filter and fine-filter targets, as well as the area of public lands, which relates to maintenance of long-term ecosystem functionality and viable reserve design. Thresholds for patch selection relative to the number of sinks and springs were determined by on-screen evaluation of the data. Use of GAP Analysis data was not straight-forward, since different methods and species were considered in Illinois versus Missouri, and data had to be extensively manipulated using GIS techniques to be useful. In the final evaluation, the maximum modeled richness within a given patch was tallied, and thresholds for patch selection were determined by on-screen examination of the data.

Tier 4 (Medium Significance) (173,429 hectares, 14.7% of the region)

This selection set consisted of all remaining natural and semi-natural patches > 100 ha, and all cultural and successional vegetation types that are immediately adjacent to Tier 1, 2, or 3 patches. Emphasis was on overall ecosystem functionality based on patch size.

Tier 5 (Medium Low Significance) (48,175 hectares, 4.1% of the region)

This selection set consisted of all remaining natural and semi-natural patches between 20 ha and 100 ha, and thus the emphasis again was on functionality. These patches may require additions or active management to remain viable through time.

Tier 6 (Low Significance) (29,509 hectares, 2.5% of the region)

This selection set consists of all remaining natural and semi-natural patches between 5 and 20 hectares. These patches might need additions or active management to maintain their integrity into the future.

Tier 7 (Very Low Significance) (739,129 hectares, 62.7% of the region)

This selection set includes all remaining cover types exclusive of urban high intensity. Cropland, urban low intensity, cultural vegetation not adjacent to a Tier 1, 2, or 3 patch, and patches <5 ha are included. These land cover types provide habitat to many species but are common within the region and beyond, and are therefore considered to be of very low significance.

Tier 8 (Minimum Significance) (39,418 hectares, 3.3% of the region)

This selection set consists only of urban high intensity land cover and is generally not important to elements of natural diversity.

Table 6. Scoring criteria and results for eight Tiers of ecological significance within the East-West Gateway region.

Rank	**% of Region**	**Ecological Significance**	**Criteria**	**Notes and Interpretation**
Tier 1	2.9%	maximum	5 largest natural and semi-natural vegetation patches in terms of size, area of contiguous forest, or area of special communities, or lowest perimeter to area ratio; plus 50-meter buffer on each side of streams within aquatic conservation opportunity areas	large, contiguous patches with significant natural communities offer maximum opportunity for conservation of functional landscapes; aquatic analyses stand on their own merit and previous state-based results are included; overall focus is on coarse-filter elements
Tier 2	2.7%	very high	next 5 largest natural and semi-natural vegetation patches under criteria similar to Tier 1, plus all patches with known occurrences of globally significant terrestrial species	large, contiguous patches similar to those in Tier 1, plus all patches with globally rare species (fine-filter targets); these patches are of very high ecological significance and may be as significant as Tier 1 upon more detailed analyses
Tier 3	7.1%	high	next 20 largest natural and semi-natural vegetation patches under criteria similar to Tiers 1 & 2, plus patches with occurrences of species of special concern within MO and IL, plus areas of high species diversity or containing relatively large numbers of springs or sinks	this selection set focuses both on coarse-filter (landscapes and community) and fine-filter (species) elements of natural diversity; these patches may be relatively important for a variety of attributes
Tier 4	14.7%	medium	all remaining natural and semi-natural vegetation patches >100 hectares, and all cultural and disturbance vegetation patches immediately adjacent to Tier 1, 2, and 3 patches	patches within the size range selected should be considered functional; cultural and disturbance vegetation adjacent to higher ranked areas offer opportunities for restoration and enhance the viability of higher ranked areas
Tier 5	4.1%	medium low	all remaining natural and semi-natural vegetation patches between 20 and 100 hectares	patches within this size range are functional but active management or enhancement may be needed
Tier 6	2.5%	low	all remaining natural and semi-natural vegetation patches between 5 and 20 hectares	patches within this size range will require additions or active management to maintain integrity
Tier 7	62.7%	very low	all remaining natural and semi-natural vegetation patches <5 hectares, and all remaining cultural and disturbance vegetation patches	cropland makes up the majority of this class, along with urban low and cultural or disturbance land cover types; these provide benefit for elements of natural diversity but are common within the region
Tier 8	3.3%	minimum	urban high intensity land cover	areas offer little importance to elements of natural diversity

Summary and Discussion

The ranking of areas with regard to ecological significance is difficult in large part because the most important areas for different elements of natural diversity often do not overlap as much as might be expected. For example, for a study region consisting of four contiguous ecological subsections within the heart of the Missouri Ozarks, Diamond et al. (2005) created selection sets of land cover patches for each of five conservation targets until 50% of the entire study area was selected. Only 1.6% of the total study area, and 2.1% of the land cover patches, was selected as being among the top 50% of the area by all five conservation targets. The issue of non-overlap in priority areas is even more pronounced when terrestrial and riverine communities are evaluated, and thus we adopted state-based, independent evaluations of riverine resources directly.

Because of the difficulty of dealing with all elements of natural diversity simultaneously, workers have often used a coarse-filter / fine-filter approach to assessment and planning. This terminology can be traced to the inception of state-based Natural Heritage Programs by The Nature Conservancy (see Groves 2003). The idea is that conservation of all communities will capture most elements of natural diversity, but rare species may "fall through the cracks" so need to be considered independently. We followed this approach and focused first on accurately defining and mapping all communities, and then considering both landscapes and species in assigning ecological significance.

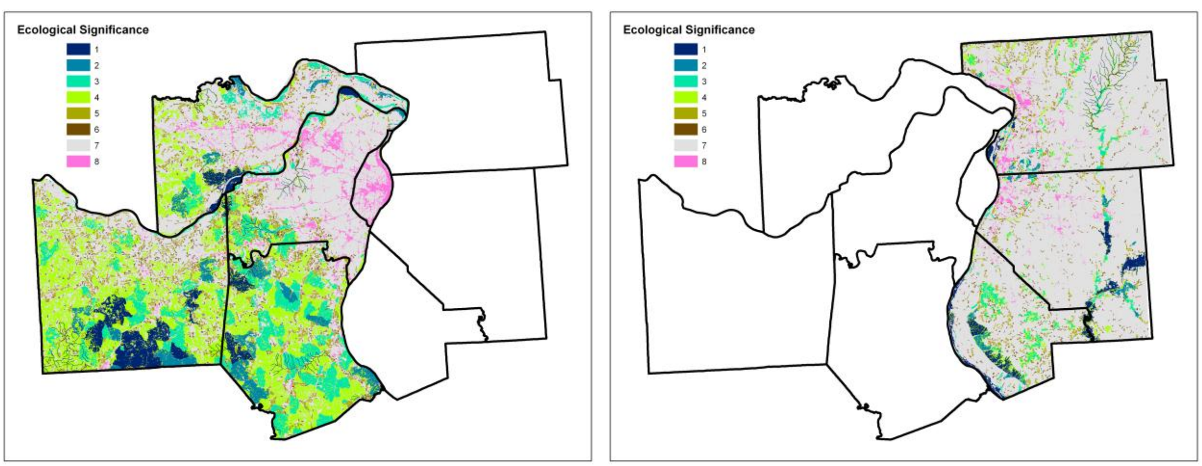
Undeveloped areas within the East-West Gateway region continue to be rapidly converted to urban land uses. From 1972 until 1999, urban land cover for roughly the 59% of the East-West Gateway region within Missouri increased a total of more than 965 square miles (Diamond and Blodgett 2003). Grassland loss was 799 square miles, and 196 square miles of forest was converted to urban land use. In addition, the remaining land cover patches have been reduced in size on average. The overall prospect for natural resource conservation has been reduced over time and this is likely to continue. All currently remaining natural and semi-natural patches are at some level of risk from urban encroachment. Thus, we considered the area of public lands within each patch as an important attribute impacting ecological significance, because these lands offer some level of current and future protection from urbanization.

The meaning of numbers assigned to ranking tiers cannot be precisely quantified, and thus these analyses offer an index of ecological significance, not an exact value. We do not have precise knowledge from ground information, and the reason for any individual patch assignment to a given rank cannot be inferred by simply viewing the end result of the analyses. Little difference in importance may exist between areas ranked in adjacent tiers (e.g. Tier 1 versus Tier 2; Tier 2 versus Tier 3; Tier 3 versus Tier 4; etc). Furthermore, and most important, the area of all patches ranked Tier 4 and higher is among approximately the top quarter (27.4%) of the region in terms of ecological significance.

The most significant drop-off in ecological significance occurs between Tier 6 and Tier 7, whereas all other breaks among tiers are small and not as significant. Two-thirds of the region is ranked in the lowest two tiers of significance. These results may need to be re-evaluated for various uses. For example, a mitigation scoring procedure may include a weighting system that involves the Tier ranks and possibly other variables. All extant patches of natural and semi-natural vegetation, and cultural or disturbance types adjacent to these patches, are potentially ecologically significant within this urbanizing landscape.

The results of these analyses are most appropriate for use at a regional or county level of resolution. Several issues limit utility at finer resolutions, including (1) the accuracy of input data such as current vegetation; (2) any given spot may be more or less important than these results show, since we do not have perfect knowledge of local conditions; (3) conditions such as urban development are constantly changing; (4) our knowledge of elements of natural diversity such as the location of rare species is constantly changing; and (5) the meaning of quantitative values assigned to ranking tiers is open to interpretation, as previously discussed. Last, the perceived significance of a given spot depends on the assessment region. For example, the patterns of significance ranks vary when only Illinois, or only Missouri, are analyzed (Figure 7). this type of variation in perceived significance holds true when smaller areas such as counties or watersheds are analyzed as compared with larger areas such as states or regions (Diamond et al. 2005).

Figure 7. Ecological significance patterns vary when only Missouri or only Illinois are analyzed independently versus the entire East-West Gateway region. Note as compared with Figure 6, more patches in north central Missouri, and along rivers and the loess hills in Illinois, appear within the highest tier of significance. This type of variation holds true whenever the planning region changes size or configuration.



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