National Projections of Forest and Rangeland Condition Indicators

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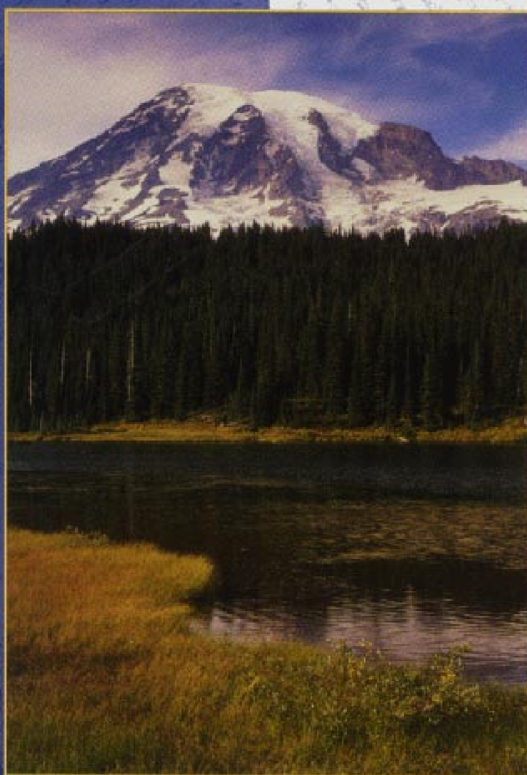

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Abstract

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The 1999 forest and rangeland condition indicator model is a set of independent econometric production functions for environmental outputs (measured with condition indicators) at the national scale. This report documents the development of the database and the statistical estimation required by this particular production structure with emphasis on two special characteristics of environmental output production processes: (1) the independence of ecological systems from human control, and (2) the broad-scale spatial nature of these processes. Resolution of data deficiencies also is examined. Finally, the model projections are presented and discussed by using national-scale maps.

Keywords: Resource interactions, land management planning, econometric production functions, modeling, environmental outputs.

Contents

Background

The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 as amended by the National Forest Management Act (NFMA) of 1976 and the three national renewable resource assessments that have been completed as mandated by that legislation have all emphasized the importance of quantitative information on renewable resource interactions. The interactions analysis for the 1989 RPA assessment (Hof and Baltic 1988) focused on National Forest System lands. It analyzed the capability of the National Forest System to maintain a constant share of total national resource production, as indicated by the demand (consumption) projections developed for individual resources in other recent assessment analyses, and the impacts on costs and environmental conditions. The analysis was not completely successful in determining the environmental impacts of increasing output levels but did indicate previously unrecognized limits to the production capabilities of the National Forest System. These results were used in the development of the recommended 1990 RPA Program (USDA Forest Service 1990). In the "Implications" chapter, the program also emphasized the critical importance of interactions research:

> Without improved information [about resource interactions], there could be misjudgments about the resource output capability of the Nation's forests and rangelands. This could
>
> - Lead to errors in management decisions that could stress the resource base or, conversely, underutilize the resource capability.
> - Misdirect public and private programs that target just one renewable resource, without giving adequate attention to effects on other resources.

Since this last assessment and program development, the Forest Service has undergone a significant change in the way it considers and manages natural resources. The 1989 interactions analysis focused on harvestable resource outputs, and the 1990 program endorsed this approach to interactions analyses when it stated that the objective of research in resource interactions "is to determine which management systems and practices are most suitable for the production and use of natural resources." In 1992, however, the Forest Service officially committed to using an approach to management called "ecosystem management" defined as

> an ecological approach to achieve the multiple-use management of the National Forests and Grasslands by blending the needs of people and environmental values in such a way that the National Forests and Grasslands represent diverse, healthy, productive, and sustainable ecosystems.[1]

The subsequent 1993 RPA assessment update (USDA Forest Service 1994) stated in the section "Ecosystems Management and Resource Interactions," that "an emphasis on ecosystem management may change the nature of production possibilities and feasibilities." This section concluded that future resource interactions analyses need to involve "assessments of [ecosystem] function, process, and condition." Both the 1993

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[1] Robertson, F.D. 1992. Policy letter, June 4, 1992. Ecosystem management of the National Forest and grasslands. On file with: USDA Forest Service, Washington, DC.

update and the draft 1995 RPA Program (USDA Forest Service 1995) continued to emphasize the importance of resource interactions research but within this new context.

Based on this new direction for management and research, the 1999 resource interactions model and supporting database emphasizes analysis of the interactions between resource use and condition indicators, as opposed to production possibilities and feasibilities, which was emphasized in the 1989 interactions analysis. This report describes the rationale and structure of this new model and the development of its supporting database, the implementation of the model in analyzing resource condition indicators, and the results of our analysis as displayed with national-level maps.

We will begin by discussing a "production" structure that is appropriate for this analysis. The production functions in this structure were statistically estimated with regression methods. Naturally, the resulting regression equations identify patterns of correlation between dependent and independent variables, not actual cause-effect relations. We used this estimated production structure and projections of selected independent variables (measures of human activity) to project changes in the forest and rangeland condition indicators over time. The projected independent variables were inserted into the model production functions to project the dependent variables.

Structure of the Model

The purpose of this analysis is to identify broad-scale (national) relations among natural characteristics, harvest levels of various resources, and indicators of the forest and rangeland condition. Many studies have quantified these types of relations at the local scale (see Hof and Baltic 1988, for a survey). Far less is known about these relations at the national scale. This study does not analyze biological processes or capture detailed impacts. Rather, its intent is to analyze coarse effects at a broad scale. This study misses many fine-scale relations, but may capture broad-scale effects that would be missed with a tightly focused view. We are, so to speak, trying to see the forest, not the trees. We begin with a brief discussion of the theory behind this analysis and then focus on the suggested empirics.

The production processes for environmental outputs of forest and rangelands are obviously different than those for traditional economic outputs. The ecosystems that "produce" environmental outputs on forest and rangelands are far more complex and far less controllable by human management than a traditional economic production unit, such as a factory or a farm. In addition, the production unit for forest and rangeland ecosystems covers large landscapes rather than the spatially limited traditional economic production units. Thus, in this paper, we will focus on two special characteristics of the environmental output production process: (1) a production function structure will be used that reflects the independence of ecological systems from human control, and (2) special consideration will be given to the broad-scale spatial nature of our data. Each of these will be discussed in more detail before proceeding.

Production Structure

First, we define three vectors of variables: $\underset{\sim}{X}$ is a vector of inputs that include human-generated inputs embodied in management actions as well as "natural" inputs such as climate and landscape characteristics; $\underset{\sim}{Y}$ is a vector of harvested outputs such as timber, livestock grazing, recreation use, and mining activity; and $\underset{\sim}{Z}$ is a vector of forest and rangeland condition indicators that serve as our environmental outputs. The traditional economic analysis would treat the $\underset{\sim}{Y}$ vector as the outputs, produced from the $\underset{\sim}{X}$ vector, with the $\underset{\sim}{Z}$ vector left largely unaccounted for. Our focus here is the $\underset{\sim}{Z}$

vector, so we will treat it as the output vector with the $\tilde{X}$ and $\tilde{Y}$ vectors as inputs. It might be more appealing in this context to regard the Y vector as harvest-related management intensity variables that are inputs (positive or negative) to the production of the environmental outputs.

The textbook treatment of joint production would use an implicit-form production function as:

$$0 = f(\tilde{X}, \tilde{Y}, \tilde{Z}) \tag{1}$$

to relate these three variable vectors. Mittelhammer and others (1981) show that this approach is limiting because it does not allow any of the variables ($\tilde{X}$, $\tilde{Y}$, and $\tilde{Z}$ in our case) to be unrelated. In a traditional economic production unit, we expect to be able to fix inputs and then define a locus of output combinations—the product transformation curve. Because our outputs are the $\tilde{Z}$ environmental outputs, this expectation may not be appropriate. In ecological systems theory, management actions are viewed as altering the structure and function of the ecosystem, which then results in a particular system response (see Allen and Hoekstra 1992, Barrett and others 1976, Hall and Day 1977). Viewed deterministically, any combination of $\tilde{X}$ and $\tilde{Y}$ is associated with a particular set of environmental outputs $\tilde{Z}$, and the product transformation curve would be a single point. For example, once a certain fire-suppression and harvesting schedule is applied, a set of environmental outputs such as sedimentation and wildlife habitat are determined by the resulting ecosystem structure and function. This would suggest that an appropriate production structure should have the property that:

$$\frac{\partial Zi}{\partial Zj} = 0 \qquad\qquad i \neq j \tag{2}$$

with all $\tilde{X}$ and $\tilde{Y}$ held constant. Mittelhammer and others (1981) show that such a property is not obtainable with equation (1). A production structure that has this property would be,

$$Z_i = g_i(\tilde{X}, \tilde{Y}), \qquad\qquad \forall\ i \tag{3}$$

which also has the convenient property of being estimable econometrically. Note that equation (3) is not a simultaneous system but is potentially a set of seemingly unrelated regressions (which we will investigate empirically below). Equation (3) is still a joint production structure because the $\tilde{Z}$ are simultaneously affected by the $\tilde{X}$ and $\tilde{Y}$ inputs. If the $\tilde{X}$ and $\tilde{Y}$ vectors are fixed, however, only a single $\tilde{Z}$ results, thereby reflecting the autonomy of the ecosystem, as desired. In a complex ecosystem, interactions between any of the $\tilde{X}$ and $\tilde{Y}$ variables in affecting the Z_i variables are potentially important, suggesting a functional form such as the translog (discussed below).

Spatial Considerations

Because the problem defined for this paper is broad scale and because the process of producing environmental outputs takes place over large landscapes, the estimation of the desired functions has more of a spatial nature than traditional economic models of production. Thus, the desired sampling scheme for environmental output production analyses would yield observations that spatially represent the ecological systems included. Broad-scale data are not typically available on this basis. For the purposes of this analysis, data are available in many different formats, from microdata with many sample points to county-level numbers that are highly reliable but also highly aggregated. We tested two approaches to this problem. The “COUNTY” approach aggregates all microdata into county averages and treats the county as the fundamental observation definition. This approach is typical in broad-scale statistical modeling (see Cressie 1991:383), but differential county size results in inequitable sampling of landscapes across the conterminous United States. In our "GRID" approach, we start with the data in its most disaggregated (and nonhomogeneously defined) format, and then use kriging (see next section) to spatially interpolate observations onto a uniform grid across the country. This approximates the more equitable sampling scheme that would have been desirable in the first place. Using this intermediate step increases the possibility of information loss from smoothing or averaging in the interpolation process but creates a much more homogenous observation unit than counties.

Database Development

The 1999 Resource Interactions Database consists of 7 dependent variables (outputs) representing forest and rangeland conditions (defined in table 1) and 27 independent variables (inputs) representing natural and management inputs (defined in table 2) including the intensity of commodity harvest. Because of data availability, only the conterminous United States will be included. This database is compiled in two separate structures that were used to develop the econometric models. Each structure includes all variables and complete coverage for the conterminous United States. The COUNTY data file contains observations on each variable by state and county as identified by Federal information processing standard (FIPS) codes (USDC National Institute of Standards and Technology 1990). There are 3,064 counties (observations) in the COUNTY data file. The GRID data file contains observations by unique latitude and longitude locations configured into a uniform grid across the country. This grid was constructed to match the number of observations in the county data as closely as possible. There are 3,280 observations in the GRID data file.

The theoretical production structure discussed above suggests that indicators of forest and rangeland condition should be related to measures (including surrogate measures) of land use, land ownership, climate variables, topography variables, human population levels, economic activity levels, and commodity harvest levels. The indicators of forest and rangeland condition chosen were those most likely to be affected by human activity on forest and rangelands and those of interest to policymakers (including an emphasis on wildlife and threatened and endangered species). Data were obtained from many sources in formats ranging from highly aggregated county data to microdata with many

Table 1—Dependent variables—indicators of environmental condition

Variable	Measure
PLA	Threatened and endangered plants (number per acre)
ANI	Threatened and endangered animals (number per acre)
STR	Streamflow (cubic feet per second)
SED	Sediment discharge (tons per day)
HAB	Habitat structure index (ratio)
BIR	Native breeding birds (number of species)
EXO	Exotic breeding birds (ratio)

Table 2—Independent variables (measures of natural and management inputs)

Variable	Measure
URB	Urban land use and cover (percentage)
AGR	Agricultural land use and cover (percentage)
RNG	Rangeland use and cover (percentage)
FOR	Forest land use and cover (percentage)
WAT	Water use and cover (percentage)
WET	Wetlands use and cover (percentage)
FED	Land area in Federal ownership (percentage)
PVT	Land area in private ownership (percentage)
EVA	Evaporation (inches per day)
PRC	Rainfall (inches per year)
SNO	Snowfall (inches per year)
TMX	Maximum temperature (degrees Fahrenheit)
TMN	Minimum temperature (degrees Fahrenheit)
ELV	Elevation (meters)
ELS	Elevation (standard deviation)
POP	Population (number per acre)
CRP	Land area in conservation reserve program (percentage)
IRR	Land area irrigated (percentage)
CRU	Land area unlikely to be converted to cropland (percentage)
CRM	Land area with medium potential to be converted to cropland (percentage)
CRH	Land area with high potential to be converted to cropland (percentage)
DIV	Economic diversity (index)
TBR	Timber harvesting intensity (stumpage value) (dollars per acre)
BFC	Beef cows (number per acre)
MIN	Mining activity (mine sites) (number per acre)
HWY	Land area in highways and interstates (percentage)
RDS	Land area in dirt, gravel, and paved local roads (percentage)

sample points. Most of the data had to be reformatted or otherwise processed and synthesized to be consistent with the data structure requirements of the analytical approach. This processing was not trivial because of the spatial scope of the analysis, the wide range of the variables of interest, and the magnitude and complexity of many of the source databases. Data gaps were particularly problematic because the threshold for rejecting variables on the grounds of insufficient coverage is not clear. Interpolations and other estimations were necessary to ensure data completeness of critical variables. The COUNTY data set does not include observations for 45 independent cities (that are not a part of any county) because the full set of variables was not sufficiently reported for these administrative units.

Processing of the raw data generally involved extraction, interpolation, synthesis, standardization, scaling, georeferencing, and log transformation. Most of the source databases included many variables, and individual variables were often reported in multiple temporal and spatial dimensions. Thus, extraction was a significant undertaking. Kriging was used to fill data gaps reported by county, to interpolate microlevel data to the county and grid levels, and to interpolate county level data to the grid structure. Standardization involved three kinds of processing. First, there were some data with observations for different parts of a given county that had to be averaged to obtain a single county observation. Second, spatial standardization to a common land area (acres) often was required because counties and other spatial reporting areas (for example, watersheds) differ greatly in size. Third, temporal standardization was also necessary for data that varied over time (climate data for example).

Georeferencing was another processing step that was necessary. Georeferencing is the geographic location of data. An identifier is assigned as a unique variable for each data observation representing either a land area or specific point on the ground. For example, FIPS codes identify the county data, and each observation in the grid data is identified by a geographic coordinate (point of latitude and longitude). These geographic identifiers represent the observation units in the model structures.

The extraction, interpolation, synthesis, and standardization procedures are unique to each variable and are summarized below in a detailed discussion of each variable included in the analysis. Log transformation procedures are a requirement in the compilation of the full COUNTY and GRID data sets to obtain the desired functional form (translog) and also are summarized below in a detailed discussion of those data sets. All database files and the complete set of notes detailing their development are stored at the Rocky Mountain Research Station in Fort Collins, Colorado.

Because the kriging procedure is so prominent in the development of the county and grid data for each variable, a brief overview of kriging is given before proceeding.

Kriging

Kriging is a minimum-mean-squared-error geostatistical method of spatially or temporally predicting the unobserved values of a random process based on data observed at known spatial or temporal locations. The technique grew out of empirical methods developed in the mining industry for determining ore-grade distributions based on sampled ore grades. The method has been refined to provide optimal linear prediction (interpolation) capability and has been applied extensively in the earth sciences in areas such as rainfall, atmospheric, forestry, soils, and ground-water data.

The kriging algorithm performs a semivariance analysis to determine the degree of relatedness (autocorrelation) among sample points within a spatially defined area. This degree of relatedness differs with the distance between sample points. Based on this variance analysis, the algorithm uses a least-squares procedure to build a mathematical function, called a variogram, that defines the most efficient (optimal) line through all the sample points. The variogram model is essentially an “interpolation surface” that can be used to predict (interpolate) for any georeferenced point on that surface. Kriging has been shown to be superior to standard regression techniques for spatial interpolation because standard regression techniques assume that the residuals are independent of one another (that is, spatially uncorrelated). The reader is referred to Cressie (1991), Ripley (1981), and Haining (1990) for a detailed discussion of kriging and geostatistical techniques in general.

The geostatistics software we used for this study (GS^+ 1994) could interpolate for only one variable at a time. The algorithm required that each input data observation (sample point) contain a value variate and x,y Cartesian coordinate variates. The input data we used were either the available microlevel or county-level data with a single observation on each county. The standard georeference coordinates reported for microdata are meridian latitude-longitude. Counties are georeferenced at their geographic centers (centroids) with their latitude and longitude. We used geographical information system software to locate these centroids and to convert them to x,y Cartesian coordinates before analysis with the kriging algorithm. If the sample data were highly skewed (which could bias the results of kriging), an option to automatically transform the data to more closely approximate a normal distribution was invoked. The data were automatically back transformed after analysis was complete.

For the semivariance analysis, the distance parameters involved in assessing autocorrelation (lag) and building the variogram (step) were set automatically by the kriging algorithm. We assumed none of the sample data differed significantly with compass direction (that is, within the distance parameters involved in the semivariance analysis or with respect to other variables). Thus, it was specified that the algorithm build isotropic (direction-independent) variogram models. Five different variogram models were fit, and the model with the best R^2 was chosen for the kriging analysis.

Finally, the kriging analysis required the input of an interpolation file containing the locations of points to be kriged (x,y Cartesian coordinates). This file consisted of either county centroids for the COUNTY approach or systematic grid locations for the GRID approach. Default values were accepted for the maximum search radius and number of sample points (nearest neighbors) to be used in constructing the interpolation estimates. The output file from kriging includes each interpolation file point along with its associated estimate for the variable of interest and its standard deviation.

Database Development for the Dependent Variables

Plant and animal threatened and endangered species—Information on both threatened and endangered plants and animals was obtained from a database on 667 threatened and endangered species compiled by BioData, Inc.,[2] of Golden, Colorado, under contract with the USDA Forest Service (BioData 1990). Various sources were used to compile distributional, biological, and administrative information on threatened and endangered species, including Federal registers, U.S. Fish and Wildlife Service (USFWS) endangered species technical bulletins, species recovery plans, other Federal agency reports, and consultations with USFWS regional biologists and state Natural Heritage Programs. The data were reported as number of species by county but standardized by total county area (acres) for the COUNTY data in this analysis. County land and water areas were obtained from Bureau of the Census records (USDC Bureau of the Census 1980a). These COUNTY data were georeferenced with the county centroids and used as the input sample points to krige for the GRID data.

[2] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Streamflow and sediment discharge—The streamflow and sediment discharge data were extracted from a CD-ROM-based data set (HYDRODATA 1992) compiled by Hydrosphere, Inc. of Boulder, Colorado, from U.S. Geological Survey daily and peak values files for streamflows, lake levels, water quality, and meteorology, which are based on observations collected for more than 100 years at river, lake, and off-stream sites throughout the United States. The data extracted were the yearly average of daily observations for the period of record at each sample point; cubic feet per second streamflow and tons per day sediment discharge. Both were further standardized to the drainage area that also was reported at each sample point. There were 15,003 observations for streamflow and 1,105 observations for sediment discharge across the conterminous United States. Each observation was georeferenced, which enabled kriging to produce the COUNTY and GRID data for these variables.

Habitat structure index—The habitat structure index is a ratio of acres of relatively undisturbed land uses and cover (forest, range, and wetlands) to total acres. This ratio has been used as a measure of human activity and landscape disturbance (O'Neill and others 1988). Although this index cannot distinguish differences in habitat structure within a land cover class (e.g., a multilayered vs. a single-layered forest stand), it is regarded as the simplest indicator of biotic integrity (O'Neill and others 1997). Indices that account for variation in habitat structure within a land cover class affect biotic integrity (Flather and others 1992), but data to estimate such indices nationally were not available. County-level land use and cover area data were extracted from USGeoData, land use and land cover digital data (from 1:250,000 and 1:100,000 scale maps) compiled by the USDI Geological Survey's National Cartographic Information Center at Reston, Virginia. The data were derived from National Aeronautics and Space Administration high-altitude aerial photographs, and National High-Altitude Photography program photographs (USDI Geological Survey 1990b). Complete coverage was available for the conterminous United States so ratios could be calculated for every county to represent the COUNTY data. County data were georeferenced to the county centroids and used to krige the GRID data.

Native breeding birds and exotic breeding birds—Information about the abundance and distribution of native and exotic breeding birds in the United States and Canada is collected annually for the North American Breeding Bird Survey (BBS), coordinated and maintained by the USFWS and the Canadian Wildlife Service (Peterjohn and Sauer 1993). Data were collected along individual BBS routes, which are 24.5 miles long and comprise 50 sampling point stops. Routes are randomly distributed and have been established within every 1-degree block of latitude and longitude in the conterminous United States. We used the route center locations (in latitude and longitude) developed by Flather and Sauer (1996) as the observation point for each route. For this analysis, the average number of species per year (species richness) of native breeding birds reported and the average number of total individuals per year (natives and exotics) reported were calculated for 2,396 routes based on data for the survey period from 1980 through 1990. The proportion of total individuals observed that were exotics was calculated for each route. These georeferenced data were then used to krige the COUNTY and GRID data for the native breeding bird species richness and the proportion of exotics abundance variables.

Database Development for the Independent Variables

Land use and land cover—Land use and cover data from the USGeoData database described earlier were used to calculate proportion of total county area for the cover and use classes urban or built-up land, agricultural land, rangeland, forest land, water, and wetland. These COUNTY data were georeferenced to the county centroids and kriged to develop the GRID data.

Land ownership—County-level data on land area in private ownership were extracted from the 1982 National Resource Inventory (NRI) compiled by the USDA Soil Conservation Service (1987), and this data set also was used in conjunction with USDC Bureau of the Census land and water area data (1980a) to calculate county-level data on land area in Federal ownership. A synthesis using these two data sets was necessary because the NRI only inventories non-Federal land (including private, state, county, municipal and Indian ownerships), and the census reports total county area. The data include terrestrial and aquatic areas and were converted to a proportion of total county area. This COUNTY data set was georeferenced to the county centroids and kriged to develop the GRID data set.

Climate—Climatic data was extracted from a CD-ROM-based data set (CLIMATEDATA 1990) compiled by Hydrodata, Inc., from the National Climatic Data Center files of daily observations. The daily data result from more than 100 years of observations of temperature, precipitation, snowfall, and evaporation by the Cooperative Observation Network. The data extracted were the yearly average of daily observations of maximum temperature, minimum temperature, and evaporation and the average yearly total of precipitation and snowfall at each sample point. There were between 628 and 14,186 valid observations across the conterminous United States for these five climate variables. Each observation sample point was georeferenced, which enabled kriging to develop the GRID data set and the COUNTY data set (by using county centroids).

Elevation—A data set of 117,615 elevation observations georeferenced by state and county FIPS code was extracted from digital elevation models of the conterminous United States compiled by the USDI Geological Survey, National Mapping Program in Reston, Virginia, as part of a larger database (USDI Geological Survey 1990a). Mean elevations and their standard deviations were calculated by county and used as the COUNTY data set. These county data were georeferenced to the county centroids and kriged to develop the GRID data.

Population—The average population density by county from the 1980 and 1990 Census of Population and Housing (USDC Bureau of the Census 1980b and 1990) was calculated and used for the COUNTY data set. These county data were georeferenced to the county centroids and kriged to develop the GRID data.

Special land designations—The number of acres of land in each county that is irrigated and the number of acres that is in the Conservation Reserve Program (CRP) was extracted from the 1987 Census of Agriculture (USDC Bureau of the Census 1987). Irrigation data for 340 counties and CRP data for 675 counties were unavailable because of nondisclosure rules. These missing data were interpolated by using the kriging method. The data were then converted to the proportion of total county area. This COUNTY data set was georeferenced to the county centroids and kriged to develop the GRID data.

Potential for conversion to cropland—The number of acres in each county classed as to potential for conversion to cropland (unlikely, medium, high) was extracted from the 1982 National Resource Inventory (USDA Soil Conservation Service 1987) and converted to proportion of total county area. This COUNTY data set was georeferenced to county centroids and kriged to develop the GRID data.

Economic diversity—The economic diversity index is a relative measure of the extent to which the economic activity of a region is distributed among multiple industries. Indices for each county were extracted from the 1985 Micro IMPLAN database compiled by USDA Forest Service, Land Management Planning Systems (1985c). The indices for 29 counties were missing. The data for these counties were interpolated with the kriging method. Indices were normalized to facilitate comparison among counties and range from 0.0 (no diversity) to 1.0 (perfect diversity). The COUNTY data set was georeferenced and kriged to develop the GRID data.

Timber harvesting intensity (stumpage value)—The value of stumpage sold was used as the (only available) measure of intensity of timber harvest (assuming approximately consistent timber prices across observations). Actual volumes harvested would have been preferable but are not currently available at the county level of resolution for the entire country. Unaccounted for price variation may distort the effects of this variable as a measure of timber harvest intensity. Value, by county, by ownership, was extracted from the 1985 Micro IMPLAN database (USDA Forest Service 1985b). Total value by acre was calculated and used as the COUNTY data set.

These county data were georeferenced to county centroids and kriged to develop the GRID data.

Grazing intensity (of beef cows)—The number of beef cows not in feedlots (by definition) was used as a measure of intensity of grazing. The number of beef cows by county was extracted from the 1987 Census of Agriculture (USDC Bureau of the Census 1987). Data for 317 counties were unavailable because of nondisclosure rules. These missing data were interpolated by using the kriging method. The data were standardized to number of beef cows per acre and used as the COUNTY data set. These county data were georeferenced to the county centroids and kriged to develop the GRID data.

Mining intensity—The number of mining sites was used as a measure of intensity of mining activity. Data on each individual site by county were extracted from the minerals availability system nonproprietary (MAS/MILS) database compiled by USDI Bureau of Mines (1992). Only metallic, mineral, and sand and gravel mining operations were included in these site data. The status of each site also was identified (for example, current producer, past producer, developmental deposit, and exploratory prospect). The number of sites was calculated by county (all status categories were included) and standardized to number of sites per acre of total county area. This COUNTY data set was georeferenced to the county centroids and kriged to develop the GRID data.

Access—The land area in transportation rights-of-way was used as a measure of access for the purpose of commodity development and use (for example, recreation). The area of rights-of-way by county and by class of road (dirt, gravel, paved, state, or interstate) was extracted from a county-level environmental database (GEOECOLOGY

1979) for the conterminous United States compiled by the Environmental Sciences Division of Oak Ridge National Laboratory. The data were aggregated and converted to proportion of county. This COUNTY data set was georeferenced to the county centroids and kriged to develop the GRID data.

Full Translog COUNTY Data Set

After the data for each variable listed in tables 1 and 2 were calculated at the COUNTY level, the variables were combined into one full COUNTY data set. Table 3 lists the minimum, maximum, mean, standard deviation, and smallest nonzero value for each variable in this data set. The desired functional form for the environmental output production model (translog) required the log transformation of each variable in the data set. We handled zero observations in the log transformations by substituting an arbitrarily small constant (less than one-fourth the smallest nonzero observation, to make sure that the adjustment was not disproportionate). The procedure we used was to scale the data by multiplying each observation by a power of 10 and then add the constant 1 to each observation (to avoid taking the log of zero in the log transformations). The magnitude of the smallest nonzero observation thus determined the (power of 10) scaling factor. Another purpose of scaling was to convert proportions to percentages. Table 3 includes the scaling factor we used to adjust each variable. Finally, the full translog COUNTY data set was completed by cross-multiplying the 27 log-transformed independent COUNTY variables to create the interactions terms. This resulted in a full translog data set of 405 variables.

Full Translog GRID Data Set

After the data for each variable listed in tables 1 and 2 were calculated at the GRID level, the full translog GRID data set was developed by using the same procedures as those for the full translog COUNTY data set (that is, scaling, log transformation, and translog calculations). Table 4 lists the summary statistics for each variable from the original GRID data set.

Model Estimation

Functional form posed a problem for this study because there is little previous research at this scale and with this orientation to give guidelines about appropriate forms. The linear form was theoretically the least attractive, as its assumption of fixed absolute changes across observations did not accommodate diminishing returns or other varying responses or interactions across levels of observations. Moreover, exotic forms such as the Box-Cox transformation would have added considerable estimation and interpretation difficulties but not really expanded the choice of forms. The Cobb-Douglas and translog forms thus appeared to be the most logical choices. The translog is obviously an umbrella for the Cobb-Douglas and quadratic forms, so we were able to test whether those functions were more appropriate for this data set than the more general translog form itself. Initial results indicated that many interaction terms were significant, so the translog appeared to be superior to either of the functional forms that excluded the interaction terms. Also, the adjusted R^2s were higher for the translog model than the Cobb-Douglas counterparts by at least 10 percentage points, and there was clear theoretical appeal to including interaction terms.

As pointed out in the previous section, the full translog equations have 405 variables included. To pare down this variable set and eliminate insignificant variables to avoid overspecification, we adopted the conventional approach that excludes insignificant

Table 3—Summary statistics for original county data

Variable	Mean	Std. dev.[a]	Minimum	Maximum	Smallest nonzero	Scaling factor
PLA	7.3961951E-7	2.1216662E-6	0	0.000028246	1.52E-7	8
ANI	3.1495845E-6	5.0844491E-6	0	.000097870	1.49E-7	8
STR	1.039678000	.792168100	.057990000	9.523200000		
SED	1.775236800	2.311145800	.345170000	50.221090000		
HAB	.487394800	.302170500	0	.998397100	1.93E-4	5
BIR	48.765113200	9.161018600	15.937270000	71.458150000		
EXO	.123343200	.088929200	.003620000	.440190000		2
URB	.039929900	.083841300	0	.981370000	4.0E-5	5
AGR	.438541000	.309940000	0	.994650000	4.0E-5	5
RNG	.116892200	.230195300	0	.996140000	1.0E-5	6
FOR	.340483500	.294398800	0	.979690000	2.0E-5	6
WAT	.022296900	.052229500	0	.683820000	1.0E-5	6
WET	.030019200	.073207000	0	.694910000	1.0E-5	6
FED	.104944900	.193518700	0	.986692100	2.88E-6	7
PVT	.769696800	.230101300	0	.995611900	2.8E-3	4
EVA	.204155100	.051903200	.129840000	.483910000		
PRC	37.543267800	14.374863100	2.820780000	119.529480000		
SNO	29.532040300	32.777466300	.313660000	216.765590000		
TMX	65.326792100	8.650085700	35.661720000	88.559040000		
TMN	42.085226500	8.478676900	18.251300000	64.870870000		
ELV	438.868433400	510.254356000	0	3486.800000000	.15	2
ELS	65.206455600	108.922072900	0	1258.650000000	.38	2
POP	.238370700	1.669937500	.000228527	67.636138800		
CRP	.007161700	.014413200	0	.285516400	6.61E-6	6
IRR	.024354400	.062503000	0	.966028700	4.25E-6	6
CRU	.213095100	.160989600	0	.905210000	3.7E-4	5
CRM	.083104300	.077710100	0	.586710000	1.0E-4	5
CRH	.027624800	.035712400	0	.336380000	5.0E-5	5
DIV	.543024000	.061299700	.036600000	.770500000		2
TBR	5.047690700	14.943677700	0	329.566479600	2.06E-6	7
BFC	.022365000	.021424400	0	.221395700	3.21E-5	6
MIN	.000102944	.000235098	0	.005472300	6.06E-7	7
HWY	.004892800	.004335200	0	.085656400	4.8E-5	5
RDS	.012173300	.006940600	0	.089804200	1.1E-4	5

[a] Std. dev. = standard deviation.

Table 4—Summary statistics for original grid data

Variable	Mean	Std. dev.[a]	Minimum	Maximum	Smallest nonzero	Scaling factor
PLA	4.8514177E-7	9.4730149E-7	0	0.000013825	1.9E-8	9
ANI	2.4977762E-6	2.7378339E-6	0	.000027683	4.5E-8	8
STR	.8521283	.9260413	.05646	11.334560000		
SED	1.7323450	2.6015327	.33713	60.698120000		
HAB	.6034115	.2813122	.00721	.980310000		2
BIR	44.6398614	11.0758308	12.88230	71.596870000		
EXO	.0977762	.0772250	.00092	.440110000		2
URB	.0290335	.0476536	.00058	.619830000		2
AGR	.3335224	.2845407	0.00455	.979190000		2
RNG	.2696109	.2877459	0	.974980000	1.0E-5	6
FOR	.3106129	.2546800	0	.949440000	1.0E-5	6
WAT	.0178499	.0276778	.00013	.415640000		2
WET	.0244898	.0582046	0	.578500000	1.0E-5	6
FED	.2087884	.2392800	.00009	.932280000		2
PVT	.6617233	.2552390	.03788	.981570000		2
EVA	.2292083	.0592729	.13060	.467110000		
PRC	28.7868871	16.8183088	2.86850	122.744600000		
SNO	36.4373888	36.8110583	.31603	325.543810000		
TMX	64.2356442	9.1939126	40.68432	89.981270000		
TMN	38.9936986	9.2799329	17.30041	65.305470000		
ELV	1034.4700000	911.7383057	1.16477	4104.360000000		
ELS	144.7240721	150.4672063	1.28944	769.719140000		
POP	.1262457	.3752798	.00185	14.493240000		
CRP	.0062995	.0088680	0	.072120000	1.0E-4	6
IRR	.0288693	.0450679	.00005	.391820000		2
CRU	.2077090	.1080167	.02723	.699920000		2
CRM	.0685167	.0475782	.00083	.334020000		2
CRH	.0210058	.0187188	0	.170060000	2.0E-5	6
DIV	.5346884	.0398070	.40069	.656400000		2
TBR	5.0918491	10.7152946	.47656	124.520880000		
BFC	.0170072	.0152274	.00023	.110370000		
MIN	.0120913	.0156037	0	.154560000	1.0E-5	6
HWY	.0036837	.0024410	.00057	.027220000		2
RDS	.0100859	.0055473	.00155	.026010000		2

[a] Std. dev. = standard deviation.

variables. In econometrics, it is common to run the full model and then drop insignificant variables, but it is common in biometrics to use a forward stepwise algorithm. Our problem has elements of both disciplines, but we chose a forward stepwise approach to obtain a "parsimonious specification." Through this approach, we could control the significance level of the retained variables and also obtain the fewest number of significant variables. We relied on the large sample size to stabilize the individual variable significance tests given the inevitable multicollinearity in a data set such as ours.

With aggregated cross-sectional data, heteroskedasticity is expected. We performed the Breush-Pagan (Breush and Pagan 1979) tests for heteroskedasticity for the COUNTY and GRID models. All are quite heteroskedastic. We were not able to find a generalized least squares model that could purge the coefficient estimates of the effects of heteroskedasticity, so we were forced to use the ordinary least squares estimates. We thus applied the White's corrected chi-square tests (White 1980) for hypothesis testing in all equations. Significance tests had only slightly different results with this test than with the original t-tests used in the stepwise estimation. The similarity of the t-tests and White's tests probably resulted from the large sample size. The R^2 is potentially biased by the inefficiency of the coefficient estimates in the presence of heteroskedasticity. The extent of the efficiency loss is likely to be small, however, given the large sample and the similarity of the corrected and uncorrected significance tests. It was not possible to subdivide the country into "ecoregions" because of this heteroskedasticity—the large sample size of the national data set was needed to compensate for the estimation inefficiency. We thus relied on the set of independent variables to account for regional differences.

We also tested for the equations being "seemingly unrelated" (Zellner 1962). We regressed each equation's residuals against the residuals from all of the other six equations. The R^2 statistics from those regressions are quite low, thereby suggesting that the seven equations do not exhibit contemporaneous correlations among the residuals. We thus accept the independent estimations as tenable. See Hof and others (1998) for more discussion of the equation estimation.

In tables 5-19, we present the translog equations for each COUNTY and GRID model. Table 5 lists the R^2 values and number of significant variables in each model, and tables 6-12 and tables 13-19 present the equations for the COUNTY and GRID models, respectively. Note that the naming convention for the interactions terms is the two interacting variable names connected with an underscore.

Projection of Independent Variables

Using the estimated equations to project changes in forest and rangeland condition indicators over time (see discussion below) required the projection of selected independent variables (the measures of human activities). Because improved explanatory power seems to result from "kriging" the data into a uniform grid of observations, as opposed to aggregating the data into the lowest common administrative unit (see Hof and others 1998), we determined that the GRID approach would be the most appropriate for the projection analysis; thus, projections were developed only at the GRID level.

Text continued on page 30.

Table 5—The R^2 values and number of significant variables for all equations

Equation	R^2 (adjusted) COUNTY	R^2 (adjusted) GRID	Number of significant variables ($\alpha = 0.05$) COUNTY	Number of significant variables ($\alpha = 0.05$) GRID
PLA	.1286	.5772	24	96
ANI	.2908	.4120	25	13
STR	.9040	.9032	75	60
SED	.4330	.6869	74	115
HAB	.9480	.9679	93	31
BIR	.7981	.8929	71	114
EXO	.7773	.8408	52	120

Table 6—Threatened and endangered plants equations with the county approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
RDS	-2.4443** (.3126)	PRC_SNO	-0.2744** (.0714)
URB_SNO	.1437** (.0331)	PRC_TMN	-.6129** (.1073)
URB_POP	.0822** (.0241)	PRC_IRR	.0168** (.0054)
AGR_SNO	.0621** (.0158)	PRC_RDS	.4823** (.0719)
AGR_POP	.0559** (.0103)	SNO_ELV	-.1019** (.0168)
RNG_RNG	-.0086* (.0033)	SNO_POP	-.2065** (.0324)
RNG_SNO	-.0308** (.0052)	SNO_DIV	-.2741** (.1055)
RNG_BFC	.0181** (.0037)	SNO_RDS	.1109** (.0358)
WET_CRH	-.0039** (.0012)	TMX_POP	-.3123** (.0672)
FED_FED	.0060** (.0011)	ELS_POP	.0435* (.0213)
FED_POP	.0172** (.0049)	ELS_RDS	.0616** (.0108)
PVT_BFC	-.0144** (.0043)	POP_POP	-.0477* (.0224)

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 7—Threatened and endangered animals equations with the county approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
AGR_AGR	0.0287** (.0051)	PRC_SNO	0.2795** (.0549)
AGR_IRR	.0363** (.0087)	PRC_POP	-.0925** (.0312)
FOR_WET	.0073** (.0011)	SNO_ELV	.1124** (.0247)
FOR_IRR	-.0255** (.0046)	SNO_ELS	-.0698* (.0287)
FOR_RDS	.0520** (.0072)	TMX_ELV	.0991** (.0387)
WAT_WAT	.0360** (.0042)	TMX_DIV	.3244** (.0907)
WAT_BFC	-.0333** (.0059)	TMN_RDS	-.1062** (.0292)
FED_FED	.0174** (.0024)	ELV_POP	-.0357** (.0124)
FED_ELS	-.0133** (.0041)	ELS_BFC	.0824** (.0078)
FED_TBR	-.0025** (.0009)	POP_IRR	.0662** (.0121)
PVT_PVT	.1125** (.0172)	MIN_CRH	.0078** (.0022)
PVT_ELV	-.1354** (.0209)	IRR_IRR	.0135** (.0050)
EVA_SNO	.8872** (.1167)		

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 8—Streamflow equations with the county approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
URB	-0.3256** (.0759)	RNG_SNO	0.0057** (.0013)	WET_EVA	0.0440** (.0113)	SNO_TMN	0.1904** (.0420)
EVA	14.1437** (1.4716)	RNG_ELV	-.0070** (.0018)	WET_PRC	.0301** (.0060)	SNO_POP	-.0152** (.0035)
SNO	-.7809** (.1737)	RNG_ELS	.0102** (.0019)	WET_BFC	-.0031** (.0010)	SNO_BFC	.0204** (.0041)
TMN	2.9704** (.6975)	RNG_BFC	.0075** (.0015)	WET_MIN	-.0015 (.0007)	SNO_MIN	-.0188* (.0024)
ELV	-.4174** (.0634)	RNG_MIN	-.0019* (.0008)	PVT_TMN	.0608** (.0133)	SNO_RDS	-.0148* (.0059)
MIN	.2390** (.0507)	RNG_IRR	.0023** (.0007)	PVT_ELS	-.0331** (.0056)	TMX_TMN	-.9995** (.1474)
URB_URB	.0169** (.0041)	RNG_CRM	.0021** (.0005)	EVA_SNO	-.5051** (.0396)	ELS_ELS	.0217** (.0023)
URB_EVA	-.1706** (.0317)	RNG_HWY	-.0045* (.0012)	EVA_TMX	-2.8012** (.3342)	ELS_BFC	-.0199** (.0039)
URB_PRC	-.0545* (.0176)	FOR_PRC	.0594** (.0081)	EVA_CRP	-.0614** (.0095)	ELS_IRR	.0102** (.0021)
URB_POP	-.0290** (.0041)	FOR_SNO	-.0117** (.0024)	EVA_IRR	-.1250** (.0196)	TBR_TBR	.0006* (.0003)
URB_BFC	-.0106** (.0039)	FOR_TMX	-.1121** (.0100)	PRC_PRC	.3281** (.0271)	BFC_MIN	-.0166** (.0029)
AGR_RNG	-.0066** (.0016)	FOR_ELS	.0271** (.0031)	PRC_SNO	-.1219** (.0190)	MIN_MIN	.0034** (.0010)
AGR_PRC	-.0318** (.0087)	FOR_TBR	.0015** (.0004)	PRC_ELV	.1500** (.0179)	MIN_CRU	-.0031** (.0010)
AGR_SNO	-.0279** (.0046)	FOR_RDS	.0147** (.0023)	PRC_ELS	-.1909** (.0143)	MIN_RDS	.0158** (.0045)
AGR_ELS	.0220** (.0049)	WAT_EVA	.0477** (.0099)	PRC_TBR	-.0108** (.0020)	CRP_DIV	-.0261** (.0040)
AGR_POP	.0230** (.0028)	WAT_ELV	-.0124** (.0032)	PRC_BFC	.0685** (.0109)	IRR_IRR	.0040** (.0008)
AGR_MIN	.0140** (.0029)	WAT_ELS	.0256** (.0037)	PRC_MIN	-.0750** (.0110)	IRR_RDS	-.0204** (.0037)
AGR_IRR	.0046* (.0019)	WAT_POP	.0070** (.0022)	PRC_IRR	-.0654** (.0095)	RDS_RDS	-.0105** (.0034)
RNG_RNG	-.0030** (.0006)	WAT_TBR	.0016** (.0005)	SNO_SNO	.0303** (.0045)		

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 9—Sediment discharge equations with the county approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
WET	-0.1849** (.0455)	RNG_EVA	-0.1108** (.0174)	EVA_PRC	-1.8541** (.1728)	SNO_IRR	0.0122** (.0035)
PVT	-.2250** (.0655)	RNG_PRC	-.0858** (.0075)	EVA_SNO	-.4528** (.0674)	SNO_CRU	.0210** (.0052)
EVA	7.9488** (1.0856)	RNG_SNO	-.0068** (.0019)	EVA_ELS	-.1465* (.0580)	TMN_TMN	-1.2050** (.2688)
PRC	-5.5173** (.7420)	RNG_ELS	.0208** (.0021)	EVA_POP	.2064** (.0307)	TMN_ELV	-.3119** (.0420)
TMN	12.2903** (2.1030)	RNG_MIN	.0029* (.0013)	EVA_BFC	.4825** (.0751)	TMN_ELS	-.0992** (.0287)
TBR	.1291** (.0255)	FOR_WET	-.0031** (.0010)	EVA_CRP	.0883** (.0169)	TMN_CRP	.1532** (.0263)
MIN	.8353** (.1158)	FOR_SNO	.0110** (.0029)	EVA_RDS	-.3111** (.0951)	ELV_ELS	.0170** (.0035)
CRP	-.2877* (.1079)	WAT_SNO	-.0041* (.0020)	PRC_SNO	-.3544** (.0331)	ELV_BFC	-.0178** (.0047)
IRR	-.1556** (.0500)	WET_WET	-.0021* (.0009)	PRC_ELV	.3232** (.0417)	ELS_POP	.0206** (.0046)
URB_WET	-.0063** (.0022)	WET_FED	.0010** (.0003)	PRC_BFC	.2025** (.0340)	POP_MIN	.0502** (.0069)
URB_SNO	.0363** (.0097)	WET_EVA	-.0505* (.0206)	PRC_MIN	-.0944** (.0175)	TBR_TBR	.0013** (.0005)
URB_POP	.0107* (.0046)	WET_PRC	.0442** (.0119)	PRC_IRR	.0602** (.0139)	TBR_IRR	-.0033** (.0009)
URB_TBR	-.0062** (.0016)	WET_ELS	.0130** (.0027)	PRC_RDS	-.0949 (.0427)	TBR_CRU	-.0050** (.0011)
URB_MIN	-.0228** (.0063)	WET_HWY	-.0101** (.0028)	SNO_SNO	-.0630** (.0066)	TBR_HWY	.0052** (.0015)
URB_CRM	.0097** (.0028)	PVT_TBR	-.0112** (.0028)	SNO_ELV	.0191 (.0094)	BFC_MIN	-.0143* (.0048)
AGR_SNO	-.0231** (.0059)	PVT_BFC	.0311** (.0070)	SNO_ELS	-.0714** (.0106)	MIN_IRR	-.0111** (.0021)
AGR_TBR	.0043** (.0012)	PVT_MIN	.0307** (.0105)	SNO_POP	-.0553** (.0096)	MIN_RDS	-.0343** (.0075)
RNG_FOR	-.0019** (.0008)	PVT_CRP	-.0187** (.0066)	SNO_BFC	.0574** (.0077)		
RNG_FED	-.0012** (.0004)	PVT_CRM	-.0103** (.0025)	SNO_CRP	.0166** (.0036)		

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 10—Habitat structure index equations with the county approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
FOR	-0.6197** (.0964)	RNG_FOR	-0.0334** (.0009)	FOR_DIV	-0.0835** (.0161)	EVA_ELV	0.0890** (.0290)	ELS_CRU	-0.0253** (.0037)
WET	.2594** (.0525)	RNG_WAT	-.0017** (.0005)	FOR_RDS	-.0102* (.0029)	PRC_PRC	.0991** (.0243)	ELS_CRM	.0141** (.0024)
TBR	.1315** (.0213)	RNG_WET	-.0022** (.0004)	WAT_WET	-.0027** (.0007)	PRC_ELV	-.1088** (.0184)	POP_BFC	-.0141** (.0025)
URB_FOR	-.0060** (.0016)	RNG_PVT	.0201** (.0031)	WET_WET	.0061** (.0005)	PRC_ELS	.0623** (.0167)	POP_CRP	.0051** (.0012)
URB_WET	-.0045** (.0012)	RNG_PRC	.0185** (.0062)	WET_FED	-.0005* (.0002)	PRC_TBR	-.0196** (.0035)	POP_CRU	.0194** (.0034)
URB_TBR	.0047** (.0012)	RNG_TMX	.0280** (.0078)	WET_PVT	-.0348** (.0036)	PRC_MIN	-.0268* (.0098)	POP_DIV	-.0536** (.0127)
AGR_AGR	-.0259** (.0023)	RNG_ELV	.0076** (.0010)	WET_EVA	-.0309** (.0099)	SNO_TBR	-.0046** (.0011)	TBR_MIN	-.0045** (.0005)
AGR_RNG	-.0127** (.0017)	RNG_BFC	-.0083** (.0012)	WET_ELS	-.0119** (.0016)	SNO_MIN	-.0103** (.0024)	TBR_CRU	-.0022 (.0010)
AGR_FOR	.0074** (.0019)	RNG_CRP	.0022** (.0004)	WET_CRU	-.0061** (.0013)	SNO_CRP	.0029** (.0011)	MIN_CRM	-.0043* (.0015)
AGR_WAT	.0028** (.0005)	RNG_CRU	.0095** (.0013)	WET_DIV	.0635** (.0115)	SNO_CRU	.0135** (.0038)	MIN_DIV	.1189** (.0174)
AGR_WET	.0036* (.0015)	FOR_FOR	.0186** (.0007)	WET_RDS	-.0072** (.0023)	SNO_RDS	-.0193** (.0058)	MIN_RDS	.0183** (.0043)
AGR_PVT	.0203** (.0065)	FOR_WET	-.0052** (.0006)	FED_POP	-.0022** (.0005)	TMX_ELV	.1608** (.0144)	CRU_CRU	.0054* (.0018)
AGR_PRC	-.0477** (.0099)	FOR_PVT	.0417** (.0049)	PVT_EVA	-.1942** (.0503)	TMX_MIN	-.0803** (.0159)	CRU_CRM	-.0061 (.0024)
AGR_SNO	-.0225** (.0040)	FOR_EVA	-.0928** (.0124)	PVT_SNO	.0382** (.0068)	TMX_CRM	-.0630** (.0102)	CRU_RDS	.0231** (.0061)
AGR_ELS	.0364** (.0040)	FOR_PRC	.0678** (.0107)	PVT_ELV	-.1108** (.0071)	ELV_ELV	.0194** (.0039)	CRM_RDS	.0204** (.0043)
AGR_POP	-.0164** (.0035)	FOR_ELV	.0635** (.0035)	PVT_CRM	.0129* (.0054)	ELV_ELS	-.0189** (.0042)	DIV_DIV	-.2673** (.0420)
AGR_CRU	.0114** (.0033)	FOR_ELS	-.0167* (.0040)	PVT_DIV	.1266** (.0270)	ELV_POP	.0155** (.0029)	DIV_RDS	.1029** (.0183)
AGR_RDS	-.0225* (.0065)	FOR_POP	.0138** (.0021)	PVT_RDS	-.0576** (.0097)	ELV_TBR	-.0038* (.0012)		
RNG_RNG	.0143** (.0006)	FOR_MIN	.0072** (.0011)	EVA_TMX	.4264** (.0895)	ELV_MIN	-.0122** (.0027)		

** = significant with α = 0.01.
* = significant with α = 0.05.
All others significant with α = 0.10.

Table 11—Native breeding birds equations with the county approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
RNG	0.0676** (.0158)	RNG_HWY	-0.0018** (.0005)	PRC_SNO	0.0252** (.0037)
FOR	-.2428** (.0254)	FOR_FOR	.0016** (.0002)	PRC_TMN	.2133** (.0204)
WET	.1529** (.0301)	FOR_WET	.0007** (.0002)	PRC_ELS	-.0431** (.0053)
TMN	-3.8720** (.3655)	FOR_TMX	.0358** (.0056)	PRC_CRH	.0074** (.0018)
URB_WAT	-.0026** (.0004)	FOR_ELV	.0113** (.0007)	SNO_ELS	-.0071** (.0012)
URB_PVT	.0073** (.0013)	FOR_BFC	-.0013* (.0005)	SNO_HWY	.0055** (.0016)
URB_SNO	-.0054** (.0012)	FOR_HWY	-.0024** (.0005)	TMX_TMN	.3318** (.0471)
URB_ELV	-.0055** (.0013)	WAT_WAT	.0007** (.0002)	TMX_ELV	-.1829** (.0151)
URB_BFC	.0074** (.0011)	WAT_SNO	.0042** (.0006)	TMX_ELS	.0446** (.0066)
URB_RDS	-.0072** (.0011)	WET_FED	-.0002** (.0001)	TMN_ELV	.1606** (.0168)
AGR_SNO	.0071** (.0012)	WET_PVT	.0022* (.0009)	ELV_POP	.0090** (.0011)
AGR_ELV	-.0074** (.0012)	WET_PRC	-.0087** (.0018)	ELS_ELS	-.0032** (.0006)
AGR_ELS	.0061** (.0015)	WET_SNO	-.0016** (.0005)	ELS_CRM	-.0027** (.0005)
RNG_RNG	-.0009** (.0002)	WET_TMX	-.0322** (.0059)	POP_BFC	-.0080** (.0013)
RNG_FOR	-.0016** (.0002)	WET_ELV	-.0038** (.0006)	POP_IRR	-.0012 (.0006)
RNG_WAT	.0004* (.0002)	WET_BFC	-.0010* (.0004)	BFC_BFC	.0011 (.0005)
RNG_FED	.0002** (.0001)	WET_IRR	-.0006** (.0002)	IRR_HWY	.0042** (.0008)
RNG_PVT	.0049** (.0007)	WET_DIV	.0120** (.0026)	IRR_RDS	-.0035** (.0007)
RNG_EVA	.0320** (.0034)	PVT_SNO	-.0113** (.0022)	CRU_CRU	.0011* (.0004)
RNG_PRC	.0140** (.0024)	PVT_BFC	-.0066** (.0012)	CRU_DIV	-.0115** (.0019)
RNG_SNO	-.0015** (.0005)	EVA_EVA	.1406* (.0513)	CRU_RDS	.0056** (.0011)
RNG_TMN	-.0139** (.0037)	EVA_PRC	.2945** (.0372)	CRM_CRM	.0010** (.0003)
RNG_ELV	.0009* (.0004)	EVA_ELV	-.0957** (.0084)	CRM_RDS	.0020* (.0007)
RNG_BFC	-.0032** (.0004)	EVA_CRH	.0149** (.0039)		

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 12—Exotic breeding birds equations with the county approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
AGR	-0.7233** (.1861)	RNG_TMN	-0.0389** (.0065)	EVA_PRC	0.2080** (.0451)
FOR	.8330** (.0750)	RNG_TBR	.0006* (.0002)	EVA_IRR	.0242 (.0098)
SNO	-2.5448** (.2981)	RNG_BFC	.0071** (.0015)	EVA_CRM	-.0649** (.0182)
TMN	15.5791** (1.4976)	RNG_IRR	.0024** (.0008)	PRC_SNO	.2611** (.0152)
CRM	-.2523* (.0799)	RNG_CRU	.0082** (.0014)	SNO_SNO	.0140* (.0056)
URB_RNG	-.0062** (.0012)	RNG_CRH	.0014** (.0004)	SNO_TMX	.4050** (.0657)
URB_ELV	.0114** (.0012)	FOR_WET	-.0022** (.0005)	SNO_ELV	-.0409** (.0045)
URB_CRP	-.0046** (.0017)	FOR_PRC	-.0463** (.0065)	SNO_CRP	.0102** (.0017)
AGR_AGR	.0210** (.0022)	FOR_TMX	-.1517** (.0162)	SNO_RDS	.0188** (.0059)
AGR_RNG	-.0038* (.0015)	FOR_CRP	.0027* (.0013)	TMN_TMN	-2.3774** (.2128)
AGR_FOR	-.0114** (.0020)	WAT_PRC	.0139** (.0041)	TMN_CRM	.0635* (.0211)
AGR_FED	.0027** (.0007)	WAT_CRM	-.0050* (.0017)	ELS_IRR	.0129** (.0023)
AGR_SNO	.0483** (.0073)	WET_SNO	-.0048** (.0013)	BFC_CRM	-.0063** (.0013)
AGR_TMN	.1621** (.0461)	WET_POP	.0084** (.0010)	CRP_CRU	.0075** (.0020)
AGR_ELS	-.0103** (.0022)	WET_CRM	.0058** (.0008)	CRP_DIV	-.0216** (.0065)
RNG_FOR	.0022* (.0009)	FED_ELV	-.0031** (.0008)	IRR_RDS	-.0109** (.0020)
RNG_PVT	-.0139** (.0027)	PVT_PVT	.0106** (.0027)	CRU_CRU	-.0058** (.0009)
RNG_EVA	-.0814** (.0093)	PVT_SNO	-.0373** (.0092)	CRM_CRM	-.0033* (.0012)

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 13—Threatened and endangered plants equations with the grid approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
PRC	28.134** (3.7335)	FOR_DIV	0.1908** (.0805)	EVA_CRP	0.7509** (.1163)	ELS_CRU	-0.6220** (.1281)
TBR	-31.117** (4.1475)	WAT_WAT	-.1411** (.0339)	EVA_CRU	-1.9490** (.3509)	ELS_CRM	-.8133** (.1483)
URB_FED	.1720** (.0296)	WAT_WET	-.0787** (.0218)	PRC_SNO	.2049** (.0856)	ELS_DIV	1.2936** (.3008)
URB_POP	-.1829** (.0427)	WAT_EVA	-.6743** (.2700)	PRC_TMX	-5.3065** (.6258)	ELS_RDS	1.1783** (.1444)
URB_HWY	.7171** (.1505)	WAT_SNO	.0990* (.0398)	PRC_ELS	.6970** (.1681)	POP_HWY	-.3481** (.1408)
URB_RDS	.6954** (.2142)	WAT_ELV	-.2900** (.0691)	PRC_CRU	-.9015** (.2772)	POP_RDS	-1.1529** (.2284)
AGR_PRC	.8286** (.1029)	WAT_CRP	.1767** (.0212)	PRC_HWY	.9928** (.3225)	TBR_BFC	-.3771** (.0555)
AGR_SNO	.1671** (.0562)	WAT_DIV	-.6947** (.1725)	SNO_TBR	-.1694** (.0570)	TBR_CRP	-.2396** (.0270)
AGR_ELV	-.3788** (.0632)	WET_PRC	-.4669** (.0721)	SNO_MIN	-.0661 (.0288)	TBR_IRR	-.2117** (.0334)
AGR_POP	.6130** (.0845)	WET_SNO	.0950** (.0220)	SNO_IRR	-.0954** (.0268)	TBR_CRM	.5156** (.0873)
AGR_CRU	-.6261** (.1087)	WET_TMX	.6651** (.1114)	SNO_DIV	.5954** (.1591)	TBR_DIV	3.8315** (.7362)
AGR_HWY	-1.8771** (.1735)	WET_TMN	-.2030** (.0773)	SNO_HWY	-.4705** (.0820)	TBR_HWY	-.9893** (.1426)
RNG_RNG	-.0235** (.0047)	WET_ELV	-.1525** (.0387)	TMX_ELV	-.8505** (.2088)	BFC_IRR	-.1777** (.0291)

Table 13—Threatened and endangered plants equations with the grid approach (continued)

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
RNG_WAT	.0761** (.0127)	WET_MIN	.0320* (.0127)	TMX_TBR	1.9717** (.5767)	MIN_CRH	.0593** (.0107)
RNG_PVT	-.1637** (.0528)	WET_HWY	.1161* (.0450)	TMX_CRU	4.9020** (.5120)	CRP_CRP	.0211** (.0071)
RNG_TMX	.2056** (.0607)	FED_TBR	-.1625** (.0363)	TMN_HWY	-1.5803** (.3455)	CRP_IRR	-.0731** (.0138)
RNG_BFC	.0391** (.0107)	FED_IRR	.0704** (.0188)	TMN_RDS	-1.6513** (.1990)	CRP_RDS	.1600** (.0528)
RNG_CRM	.0774** (.0213)	FED_RDS	.2776** (.0752)	ELV_ELV	.4406** (.0933)	IRR_CRU	.3928** (.0486)
RNG_HWY	-.1029** (.0338)	PVT_SNO	-.6250** (.1144)	ELV_ELS	-.4341** (.1308)	CRU_CRU	.6739** (.1329)
FOR_WAT	.1509** (.0259)	PVT_ELS	.3350* (.1526)	ELV_TBR	.5073** (.1019)	CRU_DIV	-4.7183** (.5105)
FOR_PRC	-.3228** (.0954)	PVT_POP	-.4193** (.0733)	ELV_CRM	.9336** (.1339)	CRU_HWY	1.3193** (.2315)
FOR_SNO	-.1156** (.0312)	PVT_TBR	1.2559** (.1761)	ELS_TBR	-.5162** (.0894)	CRM_CRM	.2510** (.0619)
FOR_TBR	.1818** (.0547)	PVT_CRM	-1.1215** (.1282)	ELS_MIN	-.1744** (.0379)	CRH_HWY	.5495** (.0697)
FOR_CRP	.0988** (.0153)	EVA_TBR	1.1744** (.2927)	ELS_IRR	-.2045** (.0368)	HWY_RDS	2.8262** (.3419)

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 14—Threatened and endangered animals equations with the grid approach

Variable	Coefficient (std. error)
AGR_IRR	0.0727** (.0064)
RNG_WET	-.0056** (.0007)
FOR_TMN	.0331** (.0035)
WET_ELS	.0264** (.0027)
FED_BFC	-.0418** (.0029)
FED_IRR	-.0347** (.0057)
SNO_IRR	.0479** (.0067)
ELV_BFC	.1356** (.0070)
ELS_BFC	-.0635** (.0088)
POP_IRR	.0732** (.0089)
TBR_CRM	-.0834** (.0101)
CRP_CRU	-.0173** (.0029)
CRM_RDS	.1853** (.0223)

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 15—Streamflow equations with the grid approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
AGR	-2.0221** (.1559)	FOR_POP	0.0351** (.0057)	SNO_HWY	0.0325** (.0103)
FOR	-.5936** (.0902)	FOR_TBR	.0195** (.0077)	TMX_TMX	-.8382** (.0745)
PVT	-3.3462** (.6329)	WAT_WAT	.0128** (.0044)	TMN_TBR	.0583** (.0238)
SNO	.7928** (.0503)	WAT_EVA	.1605** (.0431)	ELV_IRR	-.0180** (.0052)
POP	-.6381** (.0962)	WAT_PRC	-.0522** (.0173)	ELV_RDS	-.0630** (.0169)
BFC	1.2914** (.1464)	WAT_ELS	.0339** (.0077)	ELS_POP	-.0581** (.0091)
URB_WAT	.0314** (.0059)	WAT_MIN	.0196** (.0052)	ELS_TBR	.0598** (.0091)
AGR_AGR	.0802** (.0113)	WET_TBR	-.0124** (.0035)	ELS_MIN	.0380** (.0077)
AGR_FOR	.0332** (.0063)	FED_FED	.0066** (.0026)	ELS_IRR	.0380** (.0081)
AGR_BFC	-.0957** (.0166)	FED_RDS	-.0237** (.0116)	ELS_DIV	-.1227** (.0225)
AGR_MIN	.0766** (.0092)	PVT_TMX	1.1253** (.1486)	POP_POP	-.0235** (.0045)
AGR_CRP	.0072** (.0019)	PVT_POP	.0923** (.0142)	TBR_MIN	-.0556** (.0077)
AGR_HWY	-.0451** (.0103)	PVT_MIN	-.1191** (.0114)	BFC_BFC	.0587** (.0097)
AGR_RDS	-.1391** (.0203)	EVA_TMN	-.1095** (.0179)	BFC_MIN	-.0747** (.0075)
RNG_WET	.0023** (.0005)	PRC_PRC	.0934** (.0262)	BFC_RDS	.0685** (.0223)
RNG_ELS	-.0089** (.0013)	PRC_TMX	.4245** (.0468)	MIN_RDS	.0823** (.0155)
FOR_FOR	.0045* (.0017)	PRC_ELS	-.3688** (.0229)	IRR_IRR	.0135** (.0024)
FOR_WAT	.0124* (.0048)	SNO_SNO	.0359** (.0034)	IRR_RDS	-.0593** (.0130)
FOR_PRC	.0468* (.0217)	SNO_BFC	.0514** (.0071)	CRU_RDS	.0780** (.0239)
FOR_ELS	.1167** (.0097)	SNO_MIN	-.0658** (.0049)	HWY_HWY	-.0598** (.0129)

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 16—Sediment discharge equations with the grid approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
AGR	3.3460**	AGR_CRU	-0.1090**	WET_MIN	-0.0430**	EVA_IRR	0.3568**	ELS_CRP	0.1289**
	(.7586)		(.0266)		(.0027)		(.0491)		(.0112)
WAT	.7669**	AGR_DIV	-.4298*	WET_IRR	-.0265**	EVA_CRU	-.3623*	ELS_IRR	.1225**
	(.1814)		(.1844)		(.0032)		(.1486)		(.0143)
FED	-3.4335**	RNG_FOR	-.0149**	WET_CRU	.0386**	EVA_HWY	1.1683**	ELS_CRM	.0546*
	(.4444)		(.0021)		(.0072)		(.1491)		(.0194)
TBR	3.0224**	RNG_SNO	-.0093**	FED_PVT	.3367**	EVA_RDS	-1.1532**	POP_RDS	-.1706**
	(.6540)		(.0021)		(.0431)		(.1600)		(.0357)
BFC	4.1282**	RNG_ELV	.0454**	FED_SNO	-.0219**	PRC_PRC	.1199*	TBR_BFC	.0899**
	(.5079)		(.0035)		(.0052)		(.0474)		(.0137)
CRM	-8.1380**	RNG_CRU	-.0243**	FED_TMN	-.2549**	PRC_CRP	.0876**	TBR_CRU	-.1137**
	(.9391)		(.0055)		(.0329)		(.0169)		(.0227)
URB_TMN	-.1250**	RNG_CRM	.0451**	FED_MIN	-.0108*	PRC_IRR	.1425**	TBR_DIV	-.8756**
	(.0239)		(.0054)		(.0043)		(.0240)		(.1505)
URB_ELS	.1917**	RNG_HWY	.0114*	FED_CRU	.0375**	PRC_CRU	-.5802**	TBR_HWY	.1003**
	(.0126)		(.0052)		(.0124)		(.0721)		(.0262)
URB_MIN	-.0290**	RNG_RDS	-.0482**	FED_DIV	.7312**	PRC_CRM	.3145**	BFC_MIN	-.1123**
	(.0073)		(.0094)		(.0933)		(.0436)		(.0097)
URB_CRP	-.0216**	FOR_PVT	-.3154**	FED_HWY	.0403**	PRC_DIV	-.6642**	BFC_CRP	-.0279**
	(.0059)		(.0271)		(.0135)		(.0765)		(.0067)
URB_IRR	.0218**	FOR_TMX	.2729**	PVT_PRC	.7973**	PRC_HWY	.4631**	BFC_CRM	.1195**
	(.0085)		(.0283)		(.0863)		(.0650)		(.0209)
URB_CRU	.0495**	FOR_ELS	-.0358**	PVT_ELV	.3731**	PRC_RDS	-.4096**	BFC_DIV	-.3575**
	(.0203)		(.0115)		(.0252)		(.0682)		(.1181)
URB_RDS	.3340**	FOR_POP	-.0329**	PVT_POP	.1658**	SNO_SNO	-.0345**	MIN_CRP	.0339**
	(.0393)		(.0074)		(.0214)		(.0042)		(.0047)
AGR_AGR	.1598**	FOR_BFC	-.0746**	PVT_TBR	.4739**	SNO_IRR	.0556**	MIN_IRR	-.0243**
	(.0197)		(.0105)		(.0514)		(.0060)		(.0047)
AGR_RNG	-.0136**	WAT_WAT	.0180**	PVT_CRP	-.0383**	SNO_CRU	.1048**	MIN_RDS	-.0348*
	(.0046)		(.0064)		(.0154)		(.0088)		(.0176)
AGR_FOR	.0396**	WAT_WET	-.0181**	PVT_IRR	.2013**	TMX_ELS	-.3026**	IRR_CRM	-.1012**
	(.0089)		(.0048)		(.0261)		(.0434)		(.0113)
AGR_PVT	-.3693**	WAT_PVT	-.1115**	PVT_CRU	.2801**	ELV_ELS	-.1400**	IRR_HWY	-.0825**
	(.0428)		(.0286)		(.0595)		(.0205)		(.0156)
AGR_PRC	-.4118**	WAT_EVA	-.1521**	PVT_DIV	-.5238**	ELV_TBR	-.0818**	IRR_RDS	.1089**
	(.0472)		(.0486)		(.1150)		(.0135)		(.0213)
AGR_ELS	-.1178**	WAT_ELS	-.0617**	EVA_PRC	-.8208**	ELV_MIN	-.0559**	CRM_CRM	-.0870**
	(.0220)		(.0121)		(.1477)		(.0076)		(.0137)
AGR_TBR	-.1735**	WAT_CRP	-.0183**	EVA_TMX	1.0616**	ELV_CRP	-.1244**	CRM_DIV	1.8066**
	(.0210)		(.0055)		(.1725)		(.0102)		(.2346)
AGR_BFC	-.1143**	WAT_IRR	.0266**	EVA_ELS	-.2412**	ELV_IRR	-.1072**	CRM_RDS	.2087**
	(.0192)		(.0076)		(.0736)		(.0143)		(.0400)
AGR_CRP	.0705**	WET_TMN	.0521**	EVA_POP	.2049**	ELS_ELS	.1327**	CRH_RDS	-.1154**
	(.0097)		(.0078)		(.0522)		(.0201)		(.0164)
AGR_IRR	-.0836**	WET_TBR	.0487**	EVA_CRP	.2979**	ELS_BFC	-.0800**	RDS_RDS	-.2048**
	(.0140)		(.0059)		(.0384)		(.0153)		(.0394)

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 17—Habitat structure index equations with the grid approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
RNG	0.6991** (.0244)	FOR_POP	0.0280** (.0021)
FOR	.6115** (.0167)	FOR_IRR	-.0026** (.0008)
URB_URB	-.0162** (.0018)	WET_WET	.0076** (.0004)
AGR_AGR	-.1060** (.0032)	WET_SNO	-.0035** (.0003)
AGR_RNG	-.0145** (.0008)	WET_IRR	-.0056** (.0009)
AGR_FOR	.0135** (.0015)	WET_CRU	-.0222** (.0019)
AGR_IRR	.0197** (.0019)	FED_RDS	.0156* (.0042)
AGR_CRU	.1258** (.0072)	SNO_RDS	-.0316** (.0038)
RNG_RNG	.0055** (.0003)	ELS_RDS	.0796** (.0081)
RNG_FOR	-.0471** (.0010)	POP_DIV	-.0882** (.0063)
RNG_WET	-.0037** (.0003)	BFC_CRH	-.0040** (.0004)
RNG_FED	.0018** (.0003)	CRP_RDS	-.0073** (.0027)
RNG_ELS	.0061** (.0006)	CRU_CRU	-.0611** (.0048)
RNG_CRU	.0339** (.0015)	CRU_RDS	.2236** (.0158)
RNG_DIV	-.0487** (.0054)	DIV_RDS	-.2349** (.0163)
FOR_FOR	.0047** (.0005)		

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Table 18—Native breeding birds equations with the grid approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
AGR	-0.9144** (.1267)	RNG_TBR	-0.0037** (.0007)	WET_IRR	-0.0062** (.0007)	PRC_MIN	-0.0525** (.0066)	POP_MIN	-0.0056** (.0019)
WAT	.4920** (.0669)	RNG_CRM	-.0060** (.0008)	WET_CRU	-.0115** (.0023)	PRC_IRR	.0201** (.0043)	POP_CRU	-.0363** (.0057)
SNO	-.8618** (.1018)	FOR_FOR	.0018** (.0005)	FED_FED	.0022** (.0008)	PRC_CRU	.0663** (.0117)	POP_HWY	-.0445** (.0053)
ELV	-.3271** (.0489)	FOR_EVA	-.0650** (.0078)	FED_EVA	.0310** (.0109)	PRC_CRM	.0293** (.0102)	POP_RDS	-.0388** (.0072)
TBR	-1.0625** (.1580)	FOR_SNO	.0058** (.0016)	FED_PRC	-.0125* (.0054)	PRC_HWY	.0947** (.0161)	TBR_TBR	-.0252** (.0023)
IRR	-.0384* (.0181)	FOR_ELV	.0236** (.0024)	FED_SNO	-.0048** (.0013)	PRC_RDS	-.0816** (.0160)	TBR_BFC	-.0118** (.0037)
URB_AGR	.0109** (.0039)	FOR_TBR	.0136** (.0028)	FED_ELS	.0048** (.0016)	SNO_TMN	.0483** (.0097)	TBR_CRH	.0182** (.0035)
URB_PVT	.0481** (.0099)	FOR_IRR	.0036** (.0012)	FED_IRR	-.0039** (.0010)	SNO_TBR	-.0143** (.0021)	TBR_DIV	.3461** (.0379)
URB_TMX	.0697** (.0183)	FOR_DIV	-.0672** (.0048)	PVT_SNO	-.0242** (.0051)	SNO_IRR	-.0028** (.0010)	TBR_HWY	-.0183** (.0058)
URB_POP	.0130** (.0021)	FOR_RDS	-.0139** (.0038)	PVT_POP	-.0360** (.0078)	SNO_CRH	.0090** (.0022)	TBR_RDS	.0655** (.0071)
URB_BFC	.0231** (.0033)	WAT_WAT	.0076** (.0015)	PVT_MIN	-.0372** (.0045)	SNO_DIV	.1700** (.0207)	BFC_MIN	-.0057** (.0018)
URB_IRR	.0062** (.0016)	WAT_WET	-.0046** (.0012)	PVT_CRU	-.0911** (.0124)	SNO_RDS	.0452** (.0049)	BFC_CRU	-.0154** (.0046)
URB_DIV	-.1013** (.0186)	WAT_PRC	-.0207** (.0063)	PVT_CRH	.0496** (.0051)	TMN_POP	.0365** (.0093)	MIN_HWY	.0271** (.0043)
AGR_WAT	.0124** (.0027)	WAT_SNO	-.0061** (.0021)	PVT_HWY	-.1101** (.0126)	TMN_MIN	.0620** (.0062)	IRR_CRU	-.0125** (.0035)
AGR_FED	.0222** (.0021)	WAT_TMN	-.1238** (.0146)	PVT_RDS	.1382** (.0134)	TMN_CRM	.1778** (.0179)	IRR_CRM	.0085** (.0026)
AGR_TMN	-.0471** (.0139)	WAT_ELS	-.0154** (.0029)	EVA_TMX	.2249** (.0267)	TMN_CRH	-.0411** (.0084)	IRR_RDS	-.0248** (.0040)
AGR_TBR	-.0558** (.0044)	WAT_POP	-.0097** (.0023)	EVA_TBR	.1639** (.0165)	TMN_DIV	-.1222** (.0192)	CRU_CRM	-.0408** (.0060)
AGR_BFC	-.0201** (.0025)	WAT_BFC	-.0136** (.0031)	EVA_MIN	-.0663** (.0105)	ELV_ELV	-.0113** (.0019)	CRU_HWY	-.0297** (.0113)
AGR_CRU	.0528** (.0059)	WAT_CRU	.0185** (.0044)	EVA_CRM	.0956** (.0216)	ELV_CRH	.0119** (.0037)	CRM_DIV	-.1109** (.0173)
AGR_DIV	.2071** (.0290)	WET_WET	.0022** (.0003)	PRC_TMX	.0715** (.0128)	ELV_RDS	-.0405** (.0069)	CRH_CRH	-.0046** (.0009)
RNG_WAT	-.0019** (.0007)	WET_TMN	.0066** (.0022)	PRC_ELS	.0779** (.0073)	ELS_BFC	.0268** (.0028)	CRH_RDS	-.0153** (.0047)
RNG_WET	.0012** (.0002)	WET_TBR	.0055** (.0012)	PRC_POP	.0353** (.0065)	ELS_CRH	-.0202** (.0031)	RDS_RDS	.0274* (.0109)
RNG_ELS	.0020** (.0006)	WET_BFC	.0085** (.0012)	PRC_TBR	-.0560** (.0069)	ELS_HWY	-.0234** (.0061)		

** = significant with α = 0.01.
* = significant with α = 0.05.
All others significant with α = 0.10.

Table 19—Exotic breeding birds equations with the grid approach

Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)	Variable	Coefficient (std. error)
URB	0.5414** (.1240)	FOR_CRM	-0.0675** (.0064)	EVA_ELV	0.3658** (.0589)	ELV_CRU	0.0524** (.0159)
SNO	-2.2421** (.3331)	FOR_RDS	-.0390** (.0114)	EVA_BFC	.2366** (.0721)	ELV_RDS	.1733** (.0249)
ELS	-1.1668** (.3133)	WAT_ELV	-.0650** (.0075)	EVA_CRU	-.2585** (.1022)	ELS_POP	-.0495** (.0119)
URB_WET	.0193** (.0043)	WAT_POP	-.0392** (.0076)	EVA_CRM	-.6396** (.0962)	ELS_BFC	.0608** (.0138)
URB_MIN	-.0345** (.0063)	WAT_MIN	.0356** (.0042)	PRC_PRC	-.1234** (.0376)	ELS_CRM	.0698** (.0151)
URB_IRR	-.0419** (.0069)	WAT_IRR	-.0382** (.0050)	PRC_TMX	-.5864** (.0687)	ELS_DIV	.6489** (.0605)
URB_CRH	-.0450** (.0104)	WET_POP	.0182** (.0035)	PRC_ELV	.3209** (.0273)	POP_TBR	-.0470** (.0095)
URB_RDS	.0910** (.0244)	WET_TBR	.0124** (.0050)	PRC_POP	.3281** (.0239)	POP_CRU	-.1116** (.0186)
AGR_AGR	.0629** (.0085)	WET_IRR	.0090** (.0018)	PRC_TBR	-.1714** (.0243)	POP_CRM	-.0625** (.0158)
AGR_SNO	.0978** (.0122)	FED_BFC	-.0249** (.0050)	PRC_BFC	-.2042** (.0353)	TBR_BFC	.0311** (.0109)
AGR_ELV	-.1647** (.0179)	FED_MIN	-.0100** (.0026)	PRC_CRM	.4408** (.0465)	TBR_MIN	.0235** (.0070)
AGR_ELS	.1486** (.0224)	FED_HWY	.0399** (.0102)	PRC_CRH	-.1013** (.0167)	TBR_CRH	.0426** (.0133)
AGR_TBR	-.0911** (.0167)	PVT_EVA	.4640** (.1174)	SNO_TMX	.2896** (.0697)	TBR_RDS	.0700** (.0260)
AGR_CRM	.1792** (.0200)	PVT_PRC	.2534** (.0533)	SNO_TMN	.1138** (.0253)	BFC_BFC	-.0244** (.0080)
RNG_RNG	-.0021** (.0008)	PVT_TMX	.3478** (.0545)	SNO_ELV	-.0358** (.0078)	CRP_HWY	.0277** (.0046)
RNG_WET	.0041** (.0011)	PVT_ELS	-.4714** (.0359)	SNO_BFC	.0712** (.0096)	IRR_HWY	.0817** (.0118)
RNG_ELS	.0223** (.0031)	PVT_POP	-.2748** (.0252)	SNO_CRP	.0071** (.0022)	CRU_CRH	.0922** (.0167)
RNG_POP	.0229** (.0033)	PVT_TBR	.3740** (.0399)	SNO_IRR	-.0081* (.0036)	CRU_DIV	-.7406** (.0755)
RNG_TBR	.0098** (.0027)	PVT_BFC	.1060** (.0249)	SNO_CRM	-.1637** (.0128)	CRM_CRM	-.1000** (.0127)
RNG_BFC	.0153** (.0025)	PVT_CRU	.2546** (.0489)	SNO_CRH	.0343** (.0072)	CRH_RDS	-.0499** (.0124)
RNG_HWY	-.0285** (.0052)	PVT_CRM	-.4874** (.0372)	SNO_RDS	-.0547** (.0183)	HWY_RDS	-.1327** (.0467)
RNG_RDS	-.0352** (.0063)	EVA_PRC	-.2753* (.1174)	TMX_POP	.1450** (.0305)		
FOR_SNO	.0323** (.0041)	EVA_SNO	-.2580** (.0398)	TMX_TBR	-.3333** (.0466)		

** = significant with $\alpha = 0.01$.
* = significant with $\alpha = 0.05$.
All others significant with $\alpha = 0.10$.

Projections to 2020 for 11 independent variables were developed (see table 20). For each of these variables, we developed a set of GRID projection indexes that represent the ratio of projected value to current value. The ownership variables were held constant because recent RPA assessments concluded that ownership patterns for forest and rangeland are expected to change little over the projection period (USDA Forest Service 1989b). The rest of the independent variables (for example, the climate variables) were held constant because they did not reflect human activity, and it is assumed that they will not change during the projection period.

County-level projections for population were obtained from Woods and Poole Economics, Inc., an independent corporation that specializes in long-term county economic and demographic projections. Woods and Poole's database contains population projections for every county in the United States through 2020 (CEDDS 1997). These county population projections were georeferenced to the county centroids and kriged to develop population projections at the GRID level. Projections for the other variables were either unavailable or available only at broader (regional or national) scales. Based on the assumption that urban and agricultural land use and mining activity are directly related to local population growth, we developed a unique projection index for each grid cell (observation) for those three variables. For the remaining seven variables, we developed a set of regional indexes based on projections from recent USDA Forest Service assessments. Table 20 lists these indexes by variable (plus means for POP, URB, AGR, and MIN) and USDA Forest Service assessment region. We then multiplied

Table 20—Regional projection indexes to 2020 for independent variables

	Region[b]			
Variable[a]	NO	SO	RM	PC
URB[c]	1.21012	1.30840	1.40253	1.61983
AGR[c]	.84674	.81924	.78135	.63412
RNG	.46948	1.11443	1.05951	1.00529
FOR	.97901	.95830	.96957	.97209
WAT	1.06255	1.06234	1.06263	1.06284
WET	.96523	.96051	.97667	.97031
POP[c]	1.21012	1.30840	1.40253	1.61983
IRR	1.12424	1.12441	1.12445	1.12445
TBR	1.58491	1.44293	1.27245	.69118
BFC	1.13712	1.40809	1.46758	2.32813
MIN[c]	1.97344	2.13372	2.28722	2.64159

[a] Refer to table 2 for the list of independent variables.
[b] Regions are as follows: NO = Northern Region, SO = Southern Region, RM = Rocky Mountain Region, and PC = Pacific Coast region.
[c] Means across all grid cells.

each observation in the GRID data set by the appropriate index to obtain projections for the GRID observations. A brief description of the data sources for and development of the projection indexes follows.

Urban land use projections were not available. We assumed a direct relation between urban land use and population and calculated urban land use projection indexes by taking the ratio of projected population to current population. Although agricultural lands are projected to decrease (Flather and Hoekstra 1989), projections were available only at the national level. Because it is also projected that there will be an increase in agricultural lands resulting from the conversion of forest lands and rangelands (USDA Forest Service 1989c), we assumed that the projected net decrease in agricultural land is the result of urban growth. Thus, we treated decreases in agricultural land as inversely proportional to the projected increases in population and calculated the AGR projection indexes by taking the ratio of current population to projected population.

Projections for the number of mine sites were not available. Current and projected demands for minerals were available at the national level (USDA Forest Service 1989b). We assumed that sand and gravel operations could be a proxy for all mineral mining activity because it accounts for the vast majority of mineral mining. We assumed further that supply and demand are in equilibrium and are closely related to urban growth and that per capita consumption is the same across the entire United States. We thus used the current and projected population data at the GRID level and current and projected national demand for sand and gravel to calculate the MIN projection indexes based on a ratio of the projected per capita consumption to current per capita consumption.

Regional projections (and the current regional distribution) of rangelands were available from Flather and Hoekstra (1989) and USDA Forest Service (1989a). Regional projections (and the current regional distribution) of forest lands were available from USDA Forest Service (1989a). National projections (and the current regional distribution) of water cover were available from USDA Forest Service (1989a). We assumed the projections maintained the same regional proportion as the current situation. National projections to 2000 and current national area of wetlands (WET) were available from Flather and Hoekstra (1989). We used a simple regression to extrapolate the projection of wetland loss to 2020. Regional data on both total non-Federal wetlands and non-Federal wetlands with potential for conversion to cropland also were available (Flather and Hoekstra 1989). The difference between the national level data on current wetlands and the total of regional non-Federal wetlands was assumed to be Federal wetlands and divided among the regions by the proportion of Federal land comprising each region. The national projection of wetland loss was divided among the regions by the same proportion as the potential for conversion to cropland. This information was used to calculate a regional WET projection index. Regional projections (and the current regional distribution) of irrigated land area were available from Guldin (1989). Regional projections (and the current regional distribution) of timber harvests were available from USDA Forest Service (1995). Regional projections (and the current regional distribution) of beef cow numbers were available from Joyce (1989).

After multiplying each observation in the land use-cover GRID data sets by the appropriate projection indexes, the land use and cover projections for the GRID observations did not sum to the known land base totals (that is, total acres in each region). Nor did the projected acres for each GRID observation under each land use and cover type sum to the corresponding known land use and cover projection totals. We adjusted the projected GRID observations to be consistent with the known totals by using a procedure called iterative proportional fitting. Iterative proportional fitting has been used in demographic studies (Bousfield 1977) requiring sample data to be adjusted for consistency with data obtained from other sources or with the constraints of established theory. It is a procedure by which approximate table values can be adjusted so the marginal totals (across rows and columns) of the adjusted table are nearly equal to the known values of the marginal totals. The particular method we used is called raking (Deming and Stephan 1940).

Projection of Forest and Rangeland Condition Indicators

The purpose of this analysis is to identify long-term trends in the condition of forest and rangelands based on anticipated changes in human activities. The analysis uses the estimated equations, which identify broad-scale relations among natural characteristics, human activities, and indicators of environmental conditions.

The projection analysis requires a comparison of the projected value of each dependent variable (environmental condition indicator) for each grid observation in 2020, given the projected independent variables for that observation, with the current value of each dependent variable. The current values of the dependent variables for this analysis are the predicted values from the estimated translog equations for each dependent variable. The projected values of the dependent variables are derived by applying the coefficients from the translog equations to the projected independent variables. The ratio of the antilog of the projected value to the antilog of the current value and the absolute difference between the antilogs of the projected and current values are calculated for each grid point observation in each equation. These ratios and absolute differences indicate the trends in environmental condition indicators over the projection period. We decided to use both of these approaches because the ratio approach captures changes relative to current conditions, whereas the absolute-difference approach reflects the magnitude of the change.

We created maps to display the ratios and absolute differences, the current condition of each dependent variable, and areas of potentially significant changes in forest and rangeland condition, or what we call trend hotspots.

The current condition map, the ratio and absolute difference (trend) maps, and the hotspot maps are displayed for each dependent variable in figures 1-7. The USDA Forest Service assessment regions (Northern, Southern, Rocky Mountain, and Pacific Coast) are highlighted in these maps. The current condition maps are the current values predicted by the regression equations with current means of the independent variables inserted. The current condition maps portray values that are not scaled or transformed and include five data classes, each containing 20 percent of the observations, except in the case of threatened and endangered plants where a value of zero accounts for more than 20 percent of the observations and the remaining observations are proportioned equally to the other four classes. The classes depicted in the trend maps each contain 20 percent of the observations, as in the current situation maps, except a class break is made where the ratio is 1.0, or the absolute difference is zero, to demarcate increasing and decreasing trends in the condition indicators.

Text continued on page 41.

Key to the Figures

—The Current map indicates the current values of the given indicator predicted by the model with current levels of the independent variables inserted. Each of the five classes contains 20 percent of the observations (except in fig. 1, which is proportioned to account for the high occurrence of zero observations).

—The Trend maps indicate either the ratio of or the absolute difference between the predicted (year 2020) values of the given indicator and the current values (given in the Current map). Each of the five classes contains 20 percent of the predicted observations (except that a class break is made where the ratio is 1.0 or the absolute difference is zero). In figure 1, darker colored areas are indicated to have more threatened and endangered plant species. In figure 2, darker colored areas are indicated to have more threatened and endangered animal species. In figure 3, the lighter areas are indicated to have less streamflow and the darker areas are indicated to have more streamflow. Large increases and large decreases in streamflow are both considered to be indicators of potential concern. In figure 4, darker colored areas are indicated to have more sediment discharge. In figure 5, lighter areas are indicated to have less habitat structure (caused by more human impact). In figure 6, lighter areas are indicated to have fewer native breeding birds. In figure 7, darker areas are indicated to have more exotic breeding birds.

—The Hotspot maps indicate the upper or lower (indicated in the legend) 5 percent of the predicted trends (in either ratio or absolute terms) to highlight areas of the greatest concern with regard to potential future degradation. In the case of streamflow, either upper or lower extremes in predicted trends may indicate areas of concern, so the hotspots are defined as the upper and lower 2.5 percent of the predicted observations. Figure 8 summarizes the hotspots.

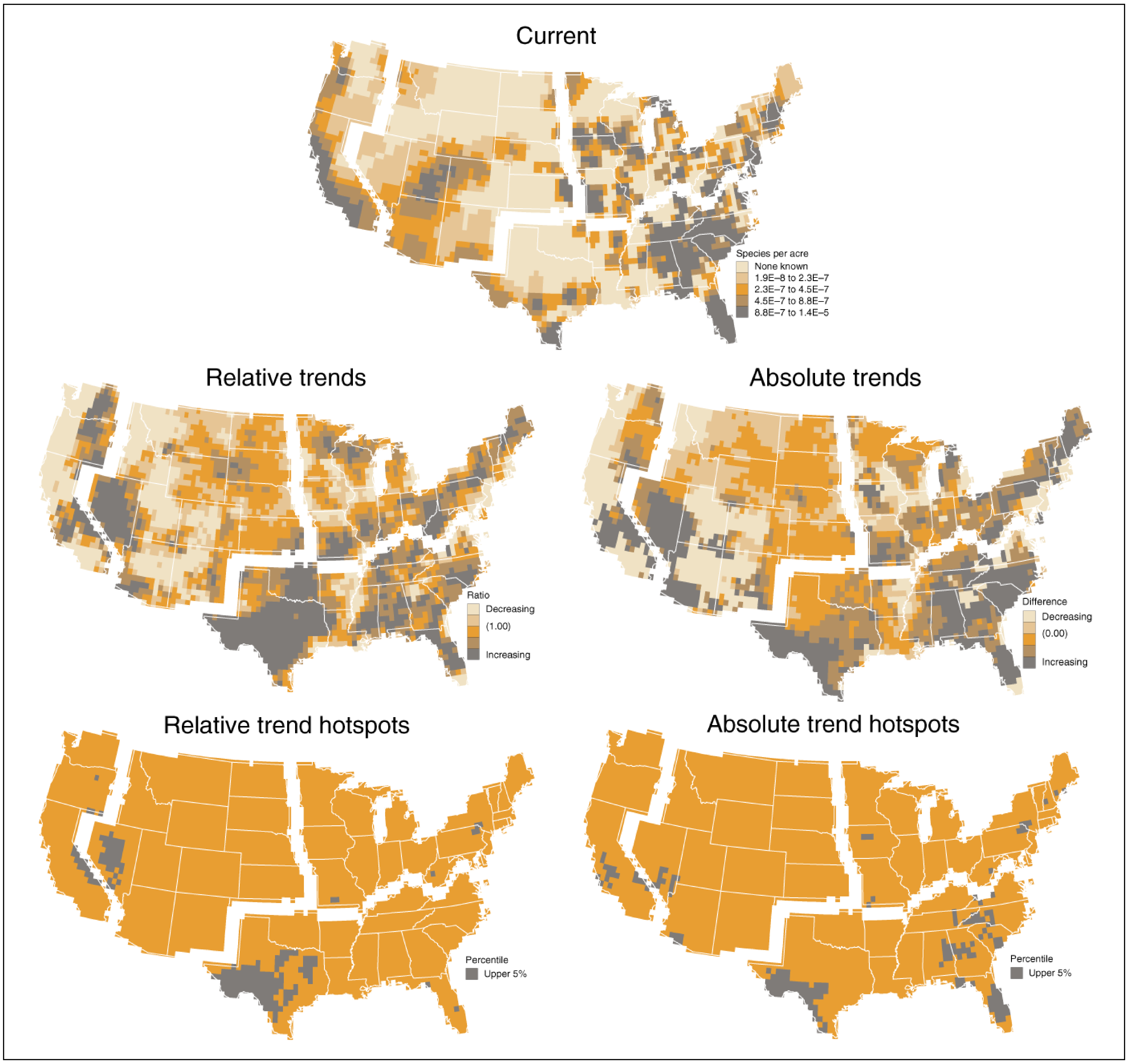

Figure 1—Threatened and endangered plants condition indicator: current, trends, and hotspots.

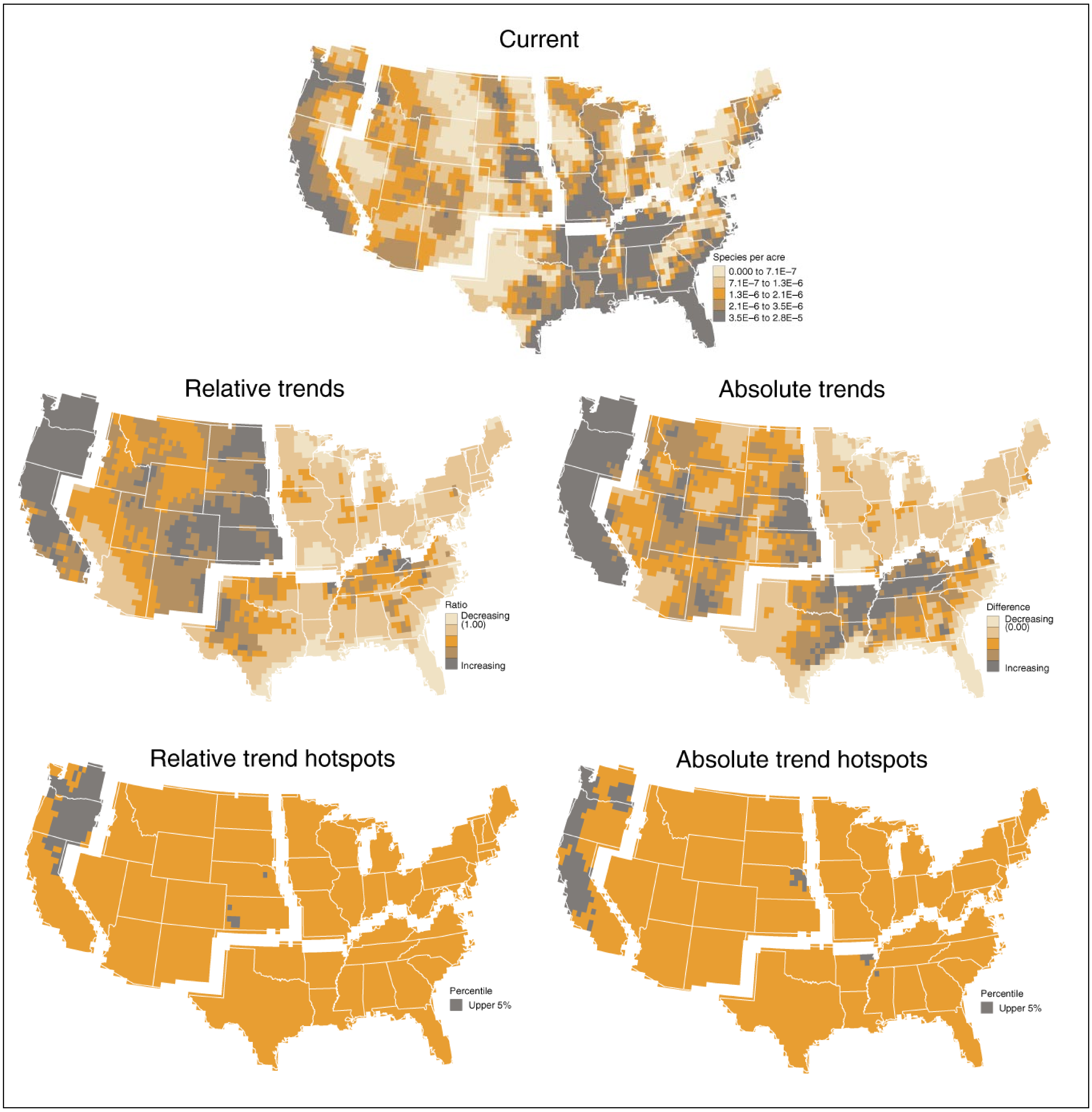

Figure 2—Threatened and endangered animals condition indicator: current, trends, and hotspots.

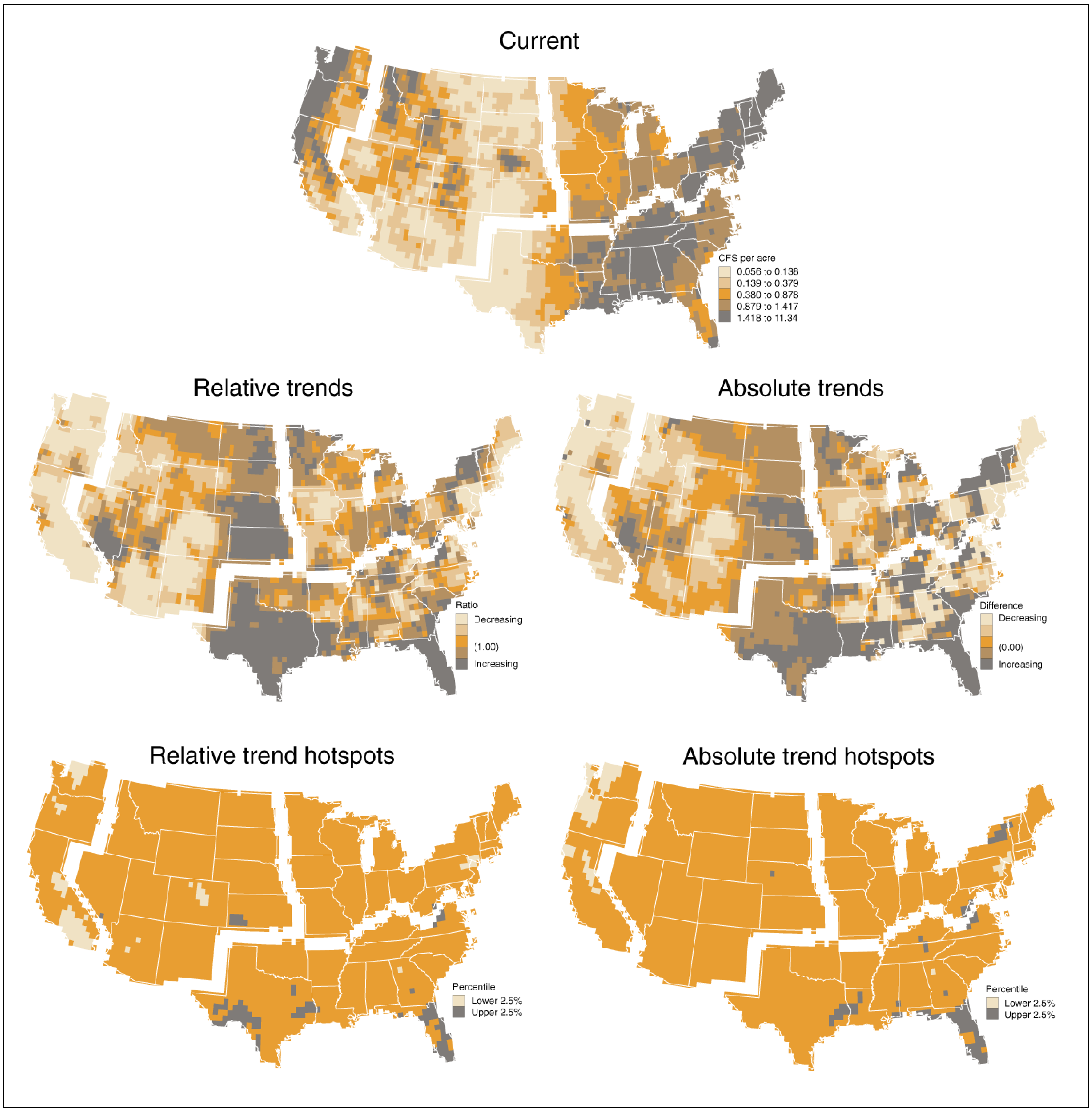

Figure 3—Streamflow condition indicator: current, trends, and hotspots.

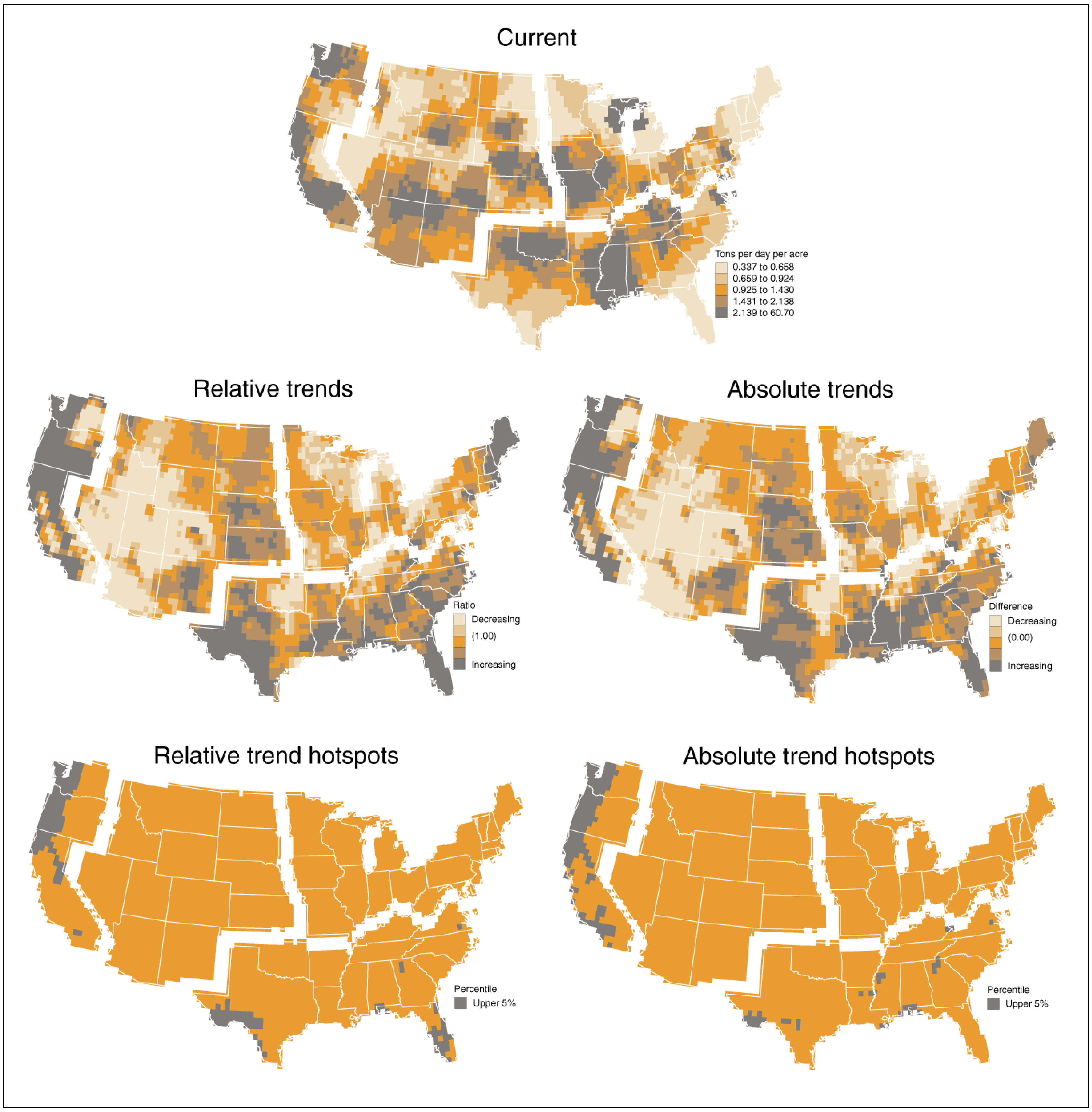

Figure 4—Sediment discharge condition indicator: current, trends, and hotspots.

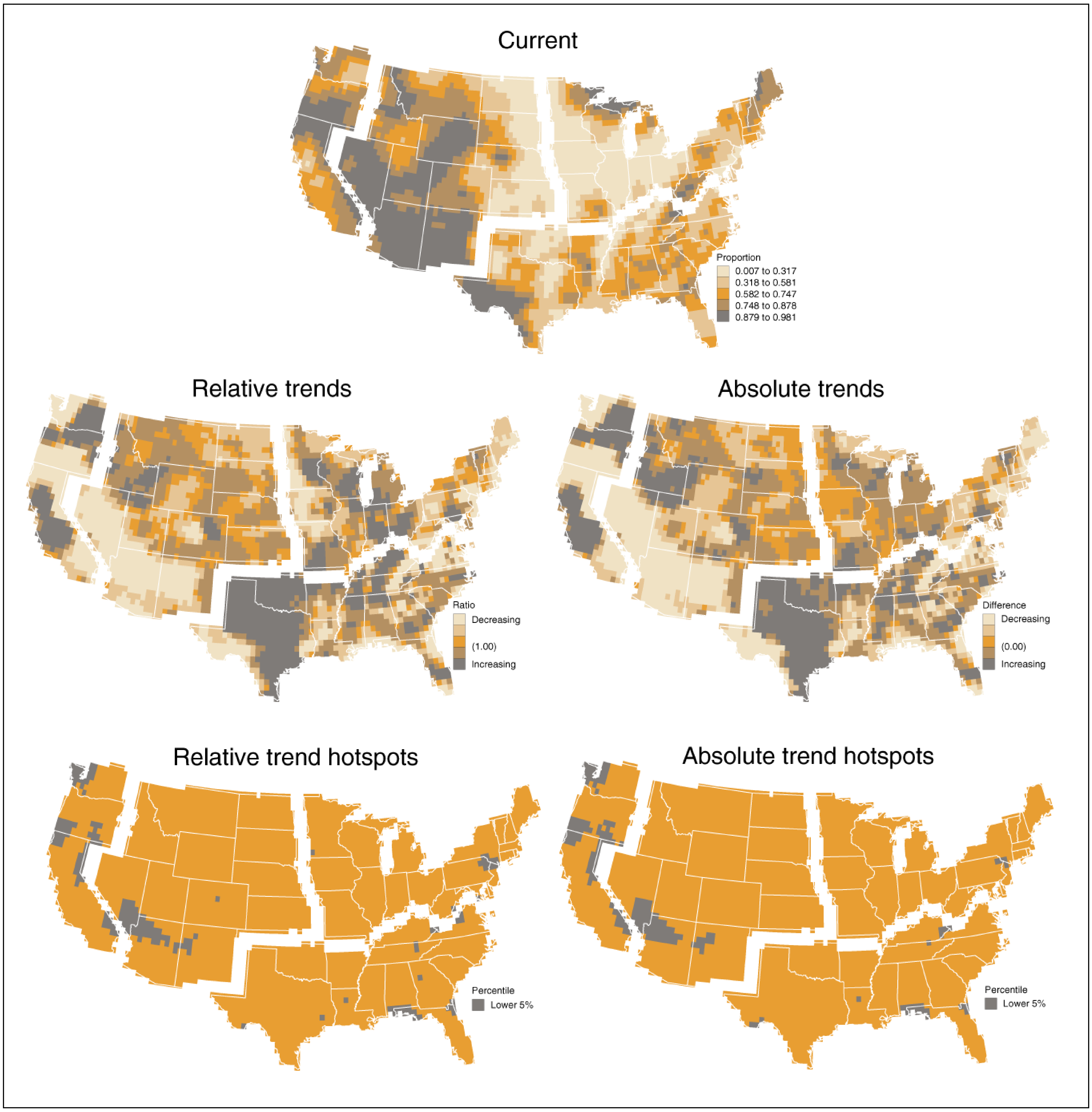

Figure 5—Habitat structure condition indicator: current, trends, and hotspots.

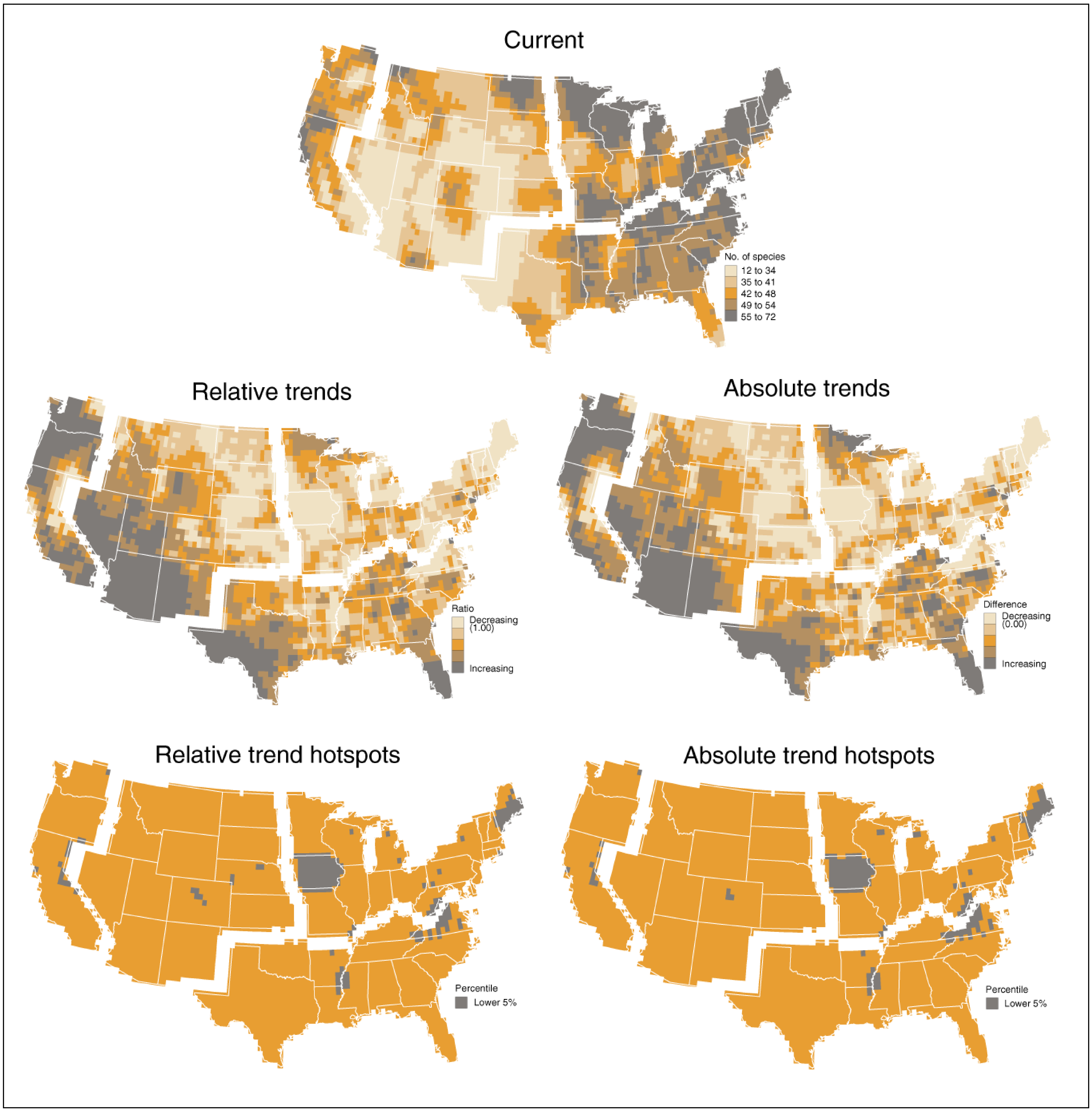

Figure 6—Native breeding birds condition indicator: current, trends, and hotspots.

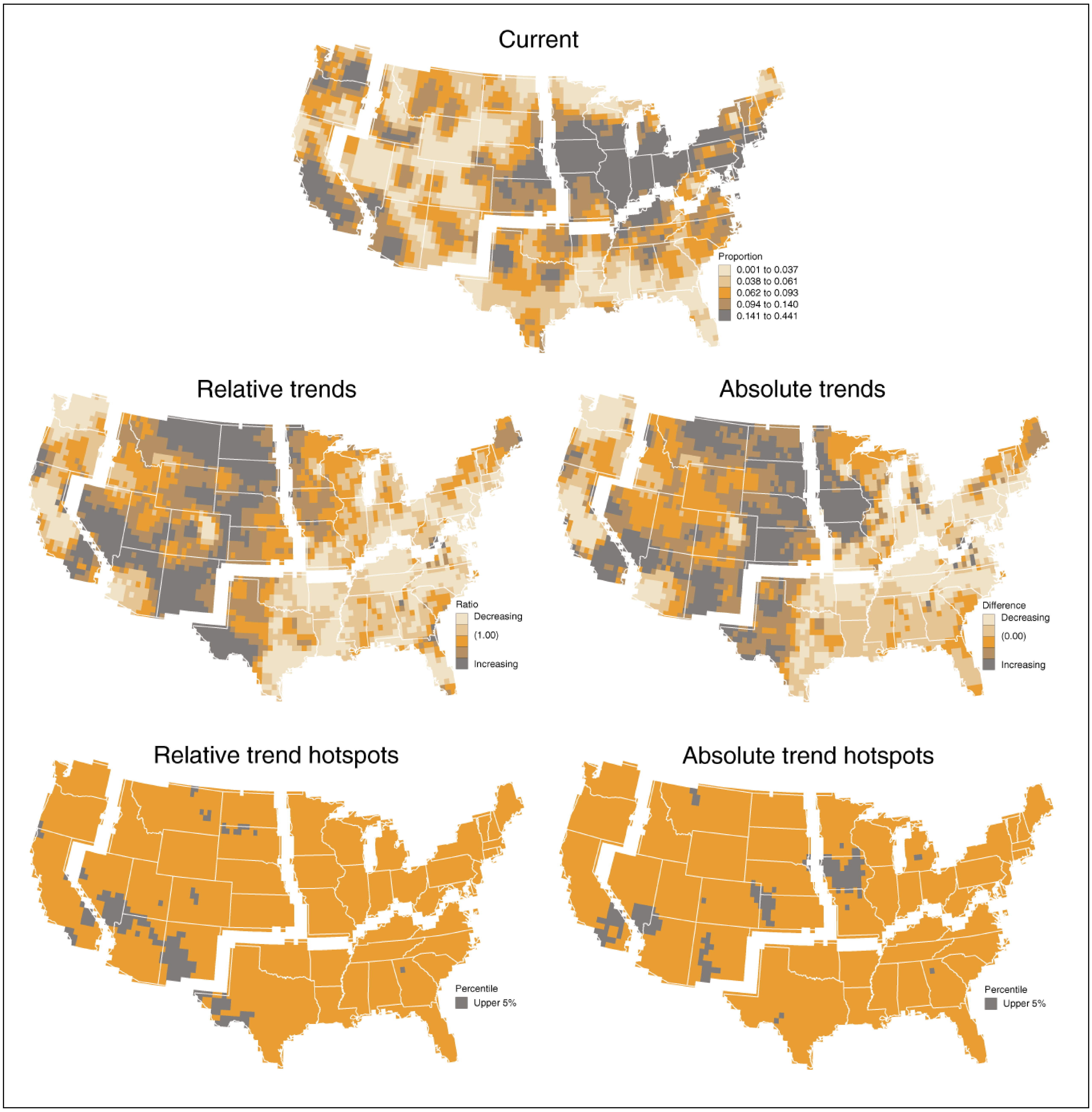

Figure 7—Exotic breeding birds condition indicator: current, trends, and hotspots.

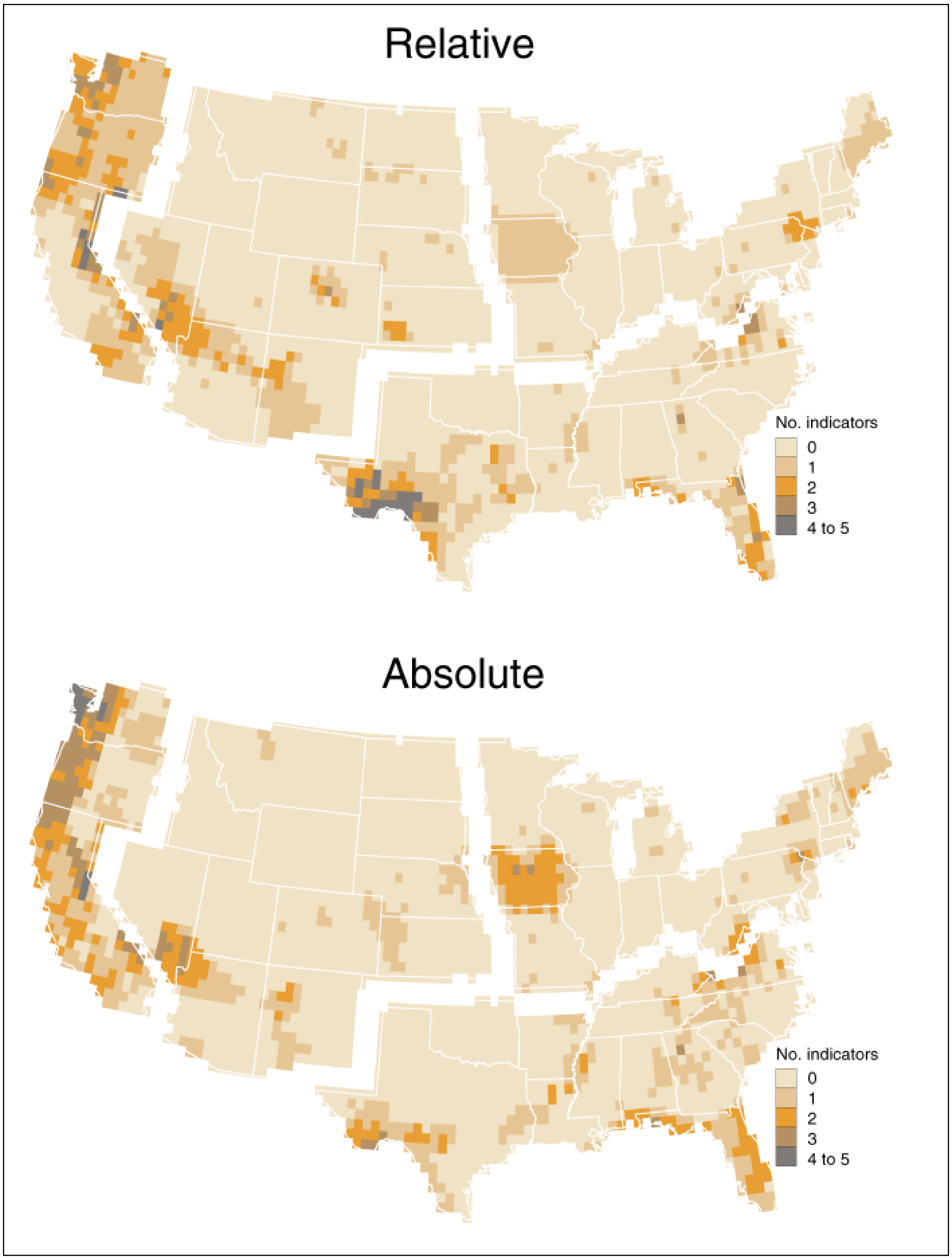

Figure 8—Coincidence of hotspot condition indicators.

Geographic areas where system degradation is of concern, also called hotspots, were determined by using the criteria specified in Prendergast and others (1993)—namely the upper or lower 5 percent of the observations from the trend maps, whichever would typically indicate a degradation in environmental conditions. In the case of streamflow, either extreme may indicate a degradation, so we split the hotspots into upper and lower classes of 2.5 percent of the observations each.

The following discussion of the results depicted in these maps is organized by condition indicator. To establish a context for the projected hotspots, we initiate each discussion by describing the current situation and overall trends in terms of the locations of the different condition classes. We close the results section with a summary of the coincidence and spatial extent of hotspot occurrence. The hotspots discussed should be regarded as candidates for further study; that is, our analysis is suggestive, not definitive in projecting trends.

Threatened and Endangered Plants

Current conditions—Concentrations of threatened and endangered plants (fig. 1) are distributed throughout the Northern Region with pockets of high density occurring in many physiographic regions. Conversely, all other RPA regions showed distinct geographic concentrations of threatened and endangered plants. In the South, endangered plants are largely clustered in the coastal plain, piedmont, and mountain regions. Concentrations also occurred in the subtropical regions of the Florida peninsula and in the prairie and plateau areas of southern Texas. The Rocky Mountain Region sees the highest concentrations in the plateau and mountain areas of the southwest. In the Pacific Coast Region, the highest levels are found all along the California coast and in the central Cascade mountain and valley region.

Trends—In the Northern Region, the higher trend classes dominate from New England to the Ozark Highlands. Increases also are indicated around the upper Great Lakes and in the central prairie region. Decreases are less evident but extend from the Mississippi valley into the southern Great Lakes region and also are found along the upper Atlantic coastal plain. In the Southern Region, increases dominate in the east and west with a much smaller area of decreases indicated along the lower Mississippi basin. Small areas of decreases also are found along the Appalachian Mountains, the coastal plain and in the Florida Everglades. Large areas of both increasing and decreasing classes are found in the southwestern desert and mountain areas of the Rocky Mountain Region. There is also a large area of decreases extending up into the northern Rocky Mountains. In the Pacific Coast Region, the highest increasing trend class dominates from the coast to the Sierra Nevada in central California and east of the Cascade Range in Oregon and Washington. The lowest decreasing class dominates everywhere else in the Pacific Coast Region.

Hotspots—The Northern Region does not have any extensive hotspots, but the largest, in the Catskill Mountains region, currently displays the highest occurrence class. The hotspots are much larger in the Southern Region with the largest located in the desert, plains, and plateaus of southwest Texas and on the Florida peninsula. Smaller areas are found in the coastal plain, piedmont, and southern Appalachians in the east and in the prairie parkland region of east Texas. As in the Northern Region, most of these hotspots are found in areas currently having high levels. In the Rocky

Mountain Region, a large hotspot conspicuously dominates the basin and range region of Nevada. This area currently displays a low occurrence class. The only other hotspot in this region is a small area of the Sonoran Desert of southwest Arizona. Two significant hotspots are found in the Pacific Coast Region, both in California. One extends from the Sierra Nevada into the basin and range region along the Nevada border, and the other straddles the southern central valley and coastal mountains. The former occurs in areas currently displaying lower occurrences, whereas the latter are in areas that currently have high levels.

The hotspots identified in the model projections seem to result primarily from projected increases in population, reductions in agricultural and range land uses, reductions in water area, and the associated increases in urban land uses in the affected areas. It is important to note that the reduction in agricultural land use is projected with an increase in irrigation, thereby suggesting an intensification of the remaining agricultural activities. Noss and Peters (1995) corroborate the hotspot in Florida, and cite increases in land use intensity (associated with population increases) and fire suppression as the causes. The U.S. Fish and Wildlife Service (1993) corroborates the hotspot in southern Arizona and cites urban development and incompatible land management strategies as the key factors in species endangerment.

Threatened and Endangered Animals

Current conditions—In the Northern Region, a large area of high threatened and endangered animals (fig. 2) concentrations currently covers the Ozark Highlands of southern Missouri and extends up the Mississippi River valley. Other smaller areas are found along the coast, in the central Appalachians, and along the lower Ohio River valley. High concentrations dominate the central portion of the Southern Region and also cover Florida and extend north up the Atlantic coastal plain. The higher concentrations are less extensive in the Rocky Mountain Region, but a large area does occur in the Great Plains from eastern Nebraska to North Dakota. Other areas are found scattered throughout the Rocky Mountains and in the desert of southern Arizona. In the Pacific Coast Region, high levels dominate in California, especially along the coast. High levels also dominate west of the Cascade Range and extend along the Columbia basin to the Blue Mountains and Palouse regions.

Trends—The Northern region is stable in terms of the threatened and endangered animals indicator. In the Southern Region, a significant increase is projected to occur from the prairie and high plains regions of Texas and Oklahoma to the southern Appalachian Mountains. Stability in this region is indicated for the Atlantic coast and the Florida peninsula. Increases dominate in the Rocky Mountain Region, especially the Great Plains, but there are also extensive areas throughout the mountain and intermountain regions. The highest trend class blankets nearly the entire Pacific Coast Region.

Hotspots—There are no hotspots indicated in the Northern Region and remarkably few in the Southern and Rocky Mountain Regions. These are confined to small areas in the Mississippi basin and the central Great Plains. In contrast, the Pacific Coast Region is dominated by a hotspot that extends from central California and west of the Cascade Range into eastern Oregon and Washington. A significant portion of this hotspot covers areas that currently exhibit high levels.

The hotspots identified in the model projections seem to result because of the combination of all the independent variable projections. In particular, land use intensification stemming from population increases, irrigated agriculture, and grazing of beef cows seem to be associated with elevated levels of threatened and endangered animals. The hotspots shown in figure 2 occur in regions currently supporting residual populations of threatened and endangered animals. The projected hotspots thus emphasize areas where animal endangerment is currently a problem and do not indicate the emergence of new concentrations of endangered animals.

Declining insect diversity in California driven by land use and development pressures (Hafernik 1992) and the continuing decline in salmon runs in the Pacific Northwest because of development in the Columbia River basin (Nehlsen and others 1991) are substantiated by the hotspots in those regions identified by our model. The decline in mollusks and fishes in the southern Appalachian region due to river basin developments and mining activities (Lydeard and Mayden 1995) is consistent with our trend maps. Of particular note are areas of decreasing threatened and endangered animals along the gulf coast in the trend maps, which may reflect the loss of species (that is, extinction) in those areas due to coastal development pressures (Flather and others 1998). This pattern raises an important issue concerning the interpretation of the trend maps in figures 1 and 2. A projected decline in the number of threatened and endangered species could result from either species population recovery or species extinction. Consequently, declining trends in endangered species also may indicate further environmental degradation.

Streamflow

Current conditions—In the Northern Region, the highest streamflow (fig. 3) conditions are found in New England and gradually decrease toward the western portion of the region. The lowest class is absent from this region. In the Southern Region, the highest class occurs from the southern Appalachian Mountains, piedmont, and interior plateaus to the gulf coast. Streamflow drops quickly to the lowest level in western Texas. The Florida peninsula, except for the Everglades, displays a midlevel range. Except for areas in the high Rocky Mountains from Colorado to Montana and Idaho, and an area along the Platte River in central Nebraska, the Rocky Mountain Region exhibits the aridity of the lower classes. In the Pacific Coast Region, the highest levels are found west of the Cascade Range and down the spine of the Sierra Nevada. The lowest levels dominate in southern California.

Trends—Extremes dominate the trends in New England where the interior mountains and plateaus exhibit the highest increasing class, whereas the area from Maine down to the coastal piedmont and plain exhibits the lowest decreasing class. This level of decrease also dominates in the Allegheny plateau of the Northern Region but abruptly changes to the highest level of increase in the till plains of Ohio and Indiana and in the central Appalachian Mountains. Other areas with high levels of increasing streamflow are found in the upper Great Lakes, whereas another area of the greatest decrease is found in Iowa. In the Southern Region, increasing trends dominate from Texas to Florida. As in the Northern Region, the rest of this region shows a mixture of the highest and lowest trend classes. In the Rocky Mountain Region, increasing trends dominate in the Great Plains, especially in the south. The southwest is dominated by the lowest decreasing class except for areas in southern Nevada and the canyon lands of southern Utah that exhibit the highest increasing trend class. The Pacific Coast Region is dominated by the lowest level.

Hotspots—Hotspots of increasing streamflow in the Northern Region are found in the Adirondack Mountains of New York and the Appalachian Mountains in West Virginia. An area extending from the Allegheny plateau in northeastern Pennsylvania through the mountains to the upper Atlantic coastal plain displays a hotspot of decreasing streamflow. All these hotspots occur in areas where streamflow is currently at the highest level. Hotspots of increases are found along the southern tier of the Southern Region, especially in Florida. A small hotspot also appears in the mountains of Virginia. Hotspots of decreasing streamflow are not indicated in this region. The hotspot of increases in southwest Texas is notable because this is a desert region with the lowest level of current streamflow. Hotspots are minimal in the Rocky Mountain Region. A hotspot of decreases is found along the Front Range in Colorado, and a hotspot of increases is located in the plains of southwestern Kansas. This latter hotspot occurs in an area of currently low streamflow. The Pacific Coast Region exhibits extensive hotspots of decreases. These encompass the coastal range and desert areas of southern California into the Sierra Nevadas and from the Cascade Range to the coast in Oregon and Washington. The Cascade and Sierra hotspots occur in areas currently exhibiting the highest level of streamflow, whereas the southern California area currently has the lowest levels.

The increasing hotspots identified in the model projections (in the Eastern United States) seem to result primarily from projected decreases in forest land cover along with the confluence of all the other independent variables. The decreasing hotspots in the far west seem to result from the decreases in timber harvesting projected for that region.

Agricultural and urban development historically have resulted in extensive streamflow impacts and water quality degradation throughout the contiguous United States (Benke 1990, Turner and Rabalais 1991). Continuing intensive development in such areas as along the Front Range in Colorado, the Cascade Range in the Pacific Northwest, and in southern California may be reflected in the hotspots in and around those regions. Similarly, the conversion of bottom-land hardwood forest to agricultural use in the lower Mississippi basin may be reflected in the increases projected there.

Sediment Discharge

Current conditions—In the Northern Region, the upper Great lakes currently exhibit a large area of the highest class of sediment discharge (fig. 4) surrounded by an equally large area of the lowest level. The till plains in the western portion of the region are dominated by the higher classes, except for Minnesota where the lower classes dominate. The lowest class also covers most of New England. In the Southern Region, the higher classes extend from the Mississippi delta up through the southern Great Plains to the west and to the southern Appalachian Mountains in the east. The lowest class covers the Florida peninsula and also is found in the Rio Grande plain of southern Texas. The highest classes currently dominate in the southwest of the Rocky Mountain Region, especially the Four Corners area, and also in the southern Great Plains. The central basin in Wyoming also has high levels. The lowest levels currently cover much of the northern plains and extend from the basin and range country of Nevada into the northern Rocky Mountains. Another area of low levels sits conspicuously astride the Nebraska and Wyoming border. In the Pacific Coast Region, high levels dominate in southern California and that State's northern redwoods region. High levels also currently extend from the Cascade Range to the coast in Washington. The lowest class occurs in the Sierra Nevadas and the high plateaus of southeastern Oregon.

Trends—In the Northern Region, the higher trends occur in northern New England, the Allegheny plateau in West Virginia, and the till plains in the west. Decreasing trends are found around the Great Lakes, along the lower Ohio River valley, and into the Ozark Highlands of Missouri. Increasing trends are more pronounced in the Southern Region, especially the plains and desert regions of western Texas, from the gulf coast to the southern Appalachian Mountains, and the Florida peninsula. A smaller area from the interior plateaus of Kentucky to the prairie of Oklahoma exhibits a decreasing trend. In the Rocky Mountain Region, decreasing trends cover the desert in the southwest and extend through the intermountain basin, range, and canyon lands into the Rocky Mountains. Increasing trends dominate in the Great Plains, especially to the south, and extend into the southern Rocky Mountains in New Mexico. The Pacific Coast Region is largely covered by the highest increasing trend class, which extends from the desert of southern California all the way to the northern Cascade Range of Washington. The areas not in this highest class are for the most part in the lowest decreasing trend class. These include the east side of the Cascade Range in the north, parts of California's central valley and Coast Range, and much of the Mojave and Sonoran Deserts to the south.

Hotspots—No hotspots of sediment discharge appear in the Northern or Rocky Mountain Regions. In the Southern Region, the main hotspots are located in the desert areas of southwest Texas and on the Florida peninsula. Both of these occur in areas currently having the lowest levels of sediment discharge. Smaller hotspots are scattered from the central gulf coast and Mississippi basin to the southern Appalachians and occur in areas of currently high levels. In the Pacific Coast Region, there is a large hotspot from the Cascade Range to the Pacific Coast and from the redwoods of northern California to northern Washington. This hotspot also extends into the northern Sierra Nevadas. A smaller hotspot is found along the southern California coastal range extending into the southern desert.

The hotspots identified in the model projections seem to result primarily from projected increases in grazing and in mining activity. In the Southern Region, projected increases in agricultural land use also seem to be contributing to scattered hotspots. Turner and Rabalais (1991) discuss increasing sedimentation in the lower Mississippi basin from conversion of bottom-land hardwood forest to agriculture use, corroborating this projection.

Habitat Structure

Current conditions—Extensive areas of low habitat structure (fig. 5) conditions are associated with areas where agricultural land uses dominate—the western low plateau and till plain regions in the Northern Region, the Great Plains region of the Rocky Mountains, and along the Mississippi alluvium in the Southern Region. Conversely, high levels are associated with regions where climate, physiography, or land ownership patterns preclude intensive agriculture—the upper Great Lakes, northern New England, the central Appalachian Mountains, the arid Southwest, the Pacific Northwest, and the northern, central, and southern Rocky Mountains. Of particular note is the absence of low habitat structure conditions in the Pacific Coast Region with the exception of the California central valley.

Trends—In the Northern Region, decreases are projected from Maine down the Atlantic coast into Virginia. A substantial area of the till plains in the West as well as smaller areas of the central Appalachian Mountains, Allegheny plateau, and upper Great Lakes also are trending toward a decrease. Increasing trends are found from the lake plains of Minnesota to the till plains of Indiana and Ohio. Other areas of increase are located in the Ozark Highlands, the northern Appalachian Mountains, and the Green Mountains of New England. A large area from the Texas plateaus and plains regions to the Ozark mountains is trending toward an increase. Other areas in the Southern Region where the habitat structure is projected to increase are found in the interior plateau region, the southern Appalachian piedmont, the central coastal plain, and southern Florida. A large area in the southwestern Texas desert is decreasing as are areas of the gulf coastal plain, the southern Appalachian Mountains into the northern piedmont and coastal plain, and north Florida. In the Rocky Mountain Region, most of the desert southwest displays the lowest decreasing trend class. Another area of conspicuous decreases is in the central mountains of Colorado. A large area around the Snake River plains of Idaho is showing an increasing trend. Smaller areas of increase are located in the San Juans of Colorado, the high plains of northeastern Colorado, and the Black Hills region of South Dakota. Trends in the Pacific Coast Region are generally in either the highest increasing or lowest decreasing classes. Increasing trends dominate in central California from the coast through the central valley and also covers all of northern Oregon extending into the highlands of northeastern Washington. The lowest trend class covers the Puget Sound and Olympic Peninsula region of Washington and all of southern Oregon into Northern California and down the spine of the Sierra Nevada into southern California.

Hotspots—The only outstanding hotspot in the Northern Region extends from the Allegheny plateau in northeastern Pennsylvania east to the Atlantic through the coastal plain and piedmont regions. This hotspot occurs in an area already at low levels. The largest hotspot in the Southern Region is found along the gulf coast in the panhandle of Florida and into Alabama. Smaller areas are located on the Atlantic coast in northern Florida, in the central Appalachian Mountains, and in the Big Bend country of southwest Texas. These latter areas generally have high current levels. In the Rocky Mountain Region, a large hotspot extends from the basin and range country of southern Nevada through the canyon lands and mountains of northern Arizona into New Mexico. This region is currently at high levels. In the Pacific Coast Region, hotspots are located in the Sonoran Desert of southern California, from the basin and range region of southeastern Oregon into the southern Cascade Range and northern Sierra Nevada of California, the Klamath Mountains straddling Oregon and California, and the Puget Sound and Olympic Peninsula regions of northwestern Washington.

The hotspots identified in the model projections seem to result primarily from the projected decreases in forest land cover, range land cover, and the ancillary increases in the more developed land uses. This finding is corroborated by Klopatek and others (1979) in the Southern United States, and by Spies and Franklin (1988) and Ripple and others (1991) in northern California and southern Oregon.

Native Breeding Birds

Current conditions—The Northern Region is currently dominated by the highest classes of native breeding bird (fig. 6) occurrence. The exception is through the western till plains section, but even here the lowest classes do not dominate. The Southern Region also is dominated by the higher classes, but the areas of exception here are larger and include the Mississippi basin and almost the entire states of Florida and Texas, where a large area of the lowest class extends from the southwestern desert region through the panhandle. In contrast, the lower levels currently dominate in the Rocky Mountain Region, especially in the desert southwest and high plains. A large island is found in the northeastern Great Plains along with smaller ones in the northern Rocky Mountains and the basin, range, and desert regions of southeastern Arizona. The highest level in the Pacific Coast Region is found in the coastal redwoods region of northern California extending into the southern Cascade Range. A smaller area of high levels is located in the highlands of northeastern Washington. The lowest level is found in the Columbia basin and in the southern central valley and southern deserts of California.

Trends—In the Northern Region, large areas of decline are found in New England, the lower Great Lakes, the Allegheny plateau and mountains, and the western till plains. Increasing trends are mostly confined to smaller areas around Lake Superior and the Allegheny plateau in northeastern Pennsylvania. These trends are projected in areas of currently high levels. In the Southern Region, large areas of increases cover Texas and the Florida peninsula, with smaller areas scattered through the coastal plain, piedmont, and interior plateau regions. The increasing trends in Texas and Florida are occurring in areas at currently lower levels. Areas of decreasing BIR are found in the Mississippi basin and the Appalachian Mountains. In the Rocky Mountain Region, increasing trends dominate in the southwest, whereas large areas of decreases are found in the Great Plains. There are also notable areas of decline in the central and northern Rocky Mountains. The Pacific Coast Region is dominated by increasing trends except for an area of decrease extending from the Sierra Nevada to the southern Cascade Range and into the basin and range region of eastern Oregon and some smaller areas in the Coast Range north of San Francisco Bay and the highlands of northeastern Washington.

Hotspots—In the Northern Region, two large hotspots are located in the coastal lowlands and foothills of southern Maine and the western till plains encompassed by the State of Iowa. Another notable hotspot is found in the mountains of West Virginia. The Maine and West Virginia hotspots occur in areas of currently high levels, whereas the hotspot to the west is in an area already at the lower levels. Hotspots in the Southern Region are found in the Appalachian Mountains and in the Mississippi basin. Hotspots are minimal in the Rocky Mountain Region, the most notable being a small area in the mountains in central Colorado. Hotspots in the Pacific Coast Region are confined mainly to the Sierra Nevadas and Modoc plateau.

The hotspots identified in the model projections appear to result because of the combination of all the independent variable projections. Well-known declines in Neotropical migrant breeding bird species in forested regions in the Eastern United States (Askins and others 1990) are supported by projected hotspots in those areas. In New England, there are indications that breeding birds dependent on early successional stages are at risk because of the increase in mature classes that results from abandonment of agricultural land and subsequent afforestation (Welsh and Healy 1993). In coastal plain and piedmont areas of the Southern Region, however, fragmentation and urban development are affecting breeding bird populations (Flather and others 1992), and this is indicated in the hotspots in those regions. The known decline in northern Great Plains grassland breeding birds (Knopf 1995) is reflected in the trends maps in figure 6.

Exotic Breeding Birds

Current conditions—Intensive land use activities (for example, agriculture and urban development) are associated with bird communities dominated by nonnative species. It is thus not surprising that the Corn Belt of the Northern Region is dominated by the highest class of exotic breeding birds (fig. 7). Similarly, low levels are found in those areas retaining much of their natural vegetation—the northern mixed forests in the Great Lakes region and a few smaller areas in northern Maine, the Adirondacks, and the mountains of West Virginia. In the Southern Region, the lowest class covers the southern tier from east Texas to the Florida peninsula. Areas of high levels are found in the high plains and prairie regions in northern Texas, the Ozark Highlands, the interior plateaus of Kentucky, and the southern Appalachian Mountains. In the Rocky Mountain Region, extensive areas of the lowest class are found from the northern Great Plains through the Rocky Mountains and into the southwest basin, range, and canyon lands. The higher classes dominate in the southern plains with smaller areas in the desert southwest and the Snake River plain in Idaho. The higher classes dominate in central and southern California and in the Columbia River basin in the Pacific Coast Region. The lower classes are less extensive and are found in the redwoods region in northern California and east of the Cascade Range in Oregon.

Trends—Decreasing trends dominate along the southern tier of the Northern Region from the Ozark Highlands of southern Missouri to southern New England, notably in areas that currently have high levels. The highest increasing class dominates in the till plains region in the western part of New England. Except for the high plains and deserts of western Texas where increasing trends are found, the Southern Region is dominated by decreasing trends, especially the northern tier where the lowest class predominates. This lowest class of decrease also tends to occur in areas of currently high levels. Exotic bird occurrence is projected to increase almost everywhere in the Rocky Mountain Region, most extensively in the Great Plains. Two small areas of decreasing trends are located along the northern Front Range in Colorado and in the southwest Arizona desert. Both of these areas currently experience the higher classes. In the Pacific Coast Region, the trend class of greatest decreases occurs in central California from the coast to the Sierra Nevadas and most of the State of Washington. Increases dominate in southern California and the Coast Ranges of northern California and southern Oregon.

Hotspots—In the Northern Region, one large hotspot covers the center of the western till plains region, an area already experiencing a high occurrence. An area of the southwestern Texas desert is the only notable hotspot in the Southern Region. An extensive hotspot covers much of the basins, ranges, canyon lands, and deserts of the southwest in the Rocky Mountain Region. Other hotspots are found in the southern and northern plains. In the southern plains and in the basin and range region of southern Nevada, the hotspots occur in areas where exotic bird occurrence is already high. In the Pacific Coast Region, the hotspots are confined mainly to southern California in areas with currently high levels. Another small but notable hotspot occurs in the redwoods region.

The hotspots identified in the model projections seem to result primarily from projected increases in population in southern California, southern Nevada, Arizona, New Mexico, and western Texas. In the till plains and prairie areas, the hotspots identified seem to reflect projected increases in timbering and agricultural land use. The central till plains and prairie areas of the Northern and Rocky Mountain Regions have been experiencing intensive land use activities (Klopatek and others 1979, Samson and Knopf 1994) and such disturbance can predispose a bird (or mammal) community to invasion by exotic species (Smallwood 1994). Such a situation is perhaps indicated by the hotspots in that region. These hotspots also may be related to the conversion of natural vegetation to intensive land uses (Klopatek and others 1979) and the known decline in grassland breeding birds in that region (Knopf 1995).

Hotspot Summary

Tables 21 and 22 summarize the occurrence of relative and absolute indicator hotspots, respectively, in terms of percentage of region (the variable names are defined in tables 1 and 2). As much as 24.6 percent of the contiguous United States is associated with at least one indicator hotspot. The Pacific Coast displays the most, as much as 79.8 percent of the region, whereas the Rocky Mountain Region displays the least, as little as 9.9 percent. The highest concentrations of indicator hotspots seem to be threatened and endangered animals (43.9 percent), streamflow (17.7 percent), sediment discharge (29.0 percent), and habitat structure (19.6 percent) in the Pacific Coast; exotic breeding birds (8.9 percent) in the Rocky Mountains; native breeding birds (14.3 percent) in the Northern Region; and threatened and endangered plants (12.5 percent) in the Southern Region. The lowest concentrations of threatened and endangered plants (0.9 percent) and habitat structure (0.5 percent) occur in the Northern Region and the lowest streamflow concentration (0.1 percent) and native breeding birds concentration (0.2 percent) occur in the Rocky Mountain Region. No threatened and endangered animals or sediment discharge hotspots are found in the Northern Region. Sediment discharge hotspots also are absent from the Rocky Mountain Region, and there are no relative exotic breeding birds hotspots in the Northern Region. The lowest concentration of absolute exotic breeding birds hotspots (0.4 percent) is in the Southern Region.

Figure 8 graphically reflects the lesser coincidence of hotspots in the Northern and Rocky Mountain Regions and the greater extent of coincidence in the Southern and Pacific Coast Regions. In the Northern Region, the few pockets of higher coincidence are found in the north-central glaciated till plains region, in the northern Allegheny plateau region, and in the central Appalachian ridge and valley region. These primarily represent the native breeding birds, exotic breeding birds, and the threatened and

Table 21—Summary of occurrence of relative hotspot condition indicators (percentage of region)

	Region[b]				
Indicator[a]	PC	RM	NO	SO	US
PLA	5.0	2.7	0.9	12.5	5.0
ANI	43.9	.5	.0	.0	5.0
STR	17.7	1.5	1.1	8.9	5.0
SED	29.0	.0	.0	7.2	5.0
HAB	19.6	4.1	1.8	3.1	5.0
BIR	3.9	.7	14.3	3.9	5.0
EXO	5.2	8.9	.0	3.5	5.0
ALL	79.8	14.0	16.6	24.5	24.6

[a] Refer to table 1 for the list of indicators.
[b] Regions are as follows: PC = Pacific Coast region, RM = Rocky Mountain Region, NO = Northern Region, SO = Southern Region, and US = the total United States.

Table 22—Summary of occurrence of absolute hotspot condition indicators (percentage of region)

	Region[b]				
Indicator[a]	PC	RM	NO	SO	US
PLA	4.7	1.3	2.0	13.8	5.0
ANI	41.7	.8	.0	.6	5.0
STR	20.4	.1	3.0	8.1	5.0
SED	36.2	.0	.0	4.1	5.0
HAB	22.4	4.4	.5	2.6	5.0
BIR	2.5	.2	15.4	4.2	5.0
EXO	6.9	6.3	7.4	.4	5.0
ALL	70.4	9.9	20.4	25.8	23.1

[a] Refer to table 1 for the list of indicators.
[b] Regions are as follows: PC = Pacific Coast region, RM = Rocky Mountain Region, NO = Northern Region, SO = Southern Region, and US = the total United States.

endangered plants condition indicators. In the Southern Region, a large area of higher coincidence is found in the desert region of southwestern Texas. A few pockets also are found in the coastal lowlands of Florida, in the southern Appalachian piedmont, and in the central Appalachian Mountains adjoining the pocket of higher coincidence in the Northern Region. These primarily represent the native breeding birds, streamflow, sediment, and threatened and endangered plants condition indicators. The greatest concentrations in the Rocky Mountain Region are found in the intermountain desert region of southern Nevada. A pocket also is located in the central mountains of Colorado. These primarily represent the exotic breeding birds, habitat structure, streamflow, and threatened and endangered plants condition indicators. The Pacific Coast Region has the most extensive concentrations of hotspot coincidence. High coincidence covers much of the western slope of the Cascade Range and the valleys and Coast Ranges to the west, especially in the Puget trough and on the Olympic Peninsula. This high coincidence extends down into the Klamath Mountains, northern California coast, southern Cascade Range and Sierra Nevada foothills and mountains. There is also an area of higher hotspot coincidence in the Mojave Desert of southern California. These represent all of the condition indicators, but especially the habitat structure, sediment, streamflow, and threatened and endangered animals condition indicators.

A recent World Wildlife Fund study (Ricketts and others, in press) identifies classes of regions in terms of “biological distinctiveness and conservation status.” The “Class I” areas are defined as,

> Globally outstanding ecoregions requiring immediate protection of remaining habitat and extensive restoration. These ecoregions contain elements of biodiversity that are of extraordinary global value or rarity and are under extreme threat.

Their map of the Class I regions (Fig. 5-2, p. 93) is remarkably similar to the maps in figure 8. Both indicate the west coast; southern Arizona, New Mexico, and Texas; the area around Iowa; Florida; and the large area around the southern Appalachian Mountains as areas of concern. Our study indicates a few areas in addition to the World Wildlife Fund study, including the area around Las Vegas, Nevada; the area in and around Maine; and some areas in the Great Plains. Nonetheless, the similarities between these study results, which are based on much different methods, are noteworthy.

Conclusion

We identified potential hotspots in seven condition indicators for forest and rangelands based on projected changes in 11 independent variables related to human activities (table 20). We avoided any interpretations that suggest actual causation because the econometric methods used only identify patterns of correlation between dependent and independent variables (including interaction terms). Thus, these potential hotspots should be viewed only as candidates for areas of significant change. We also pointed out results from this analysis that are consistent with other empirical studies, especially the World Wildlife Fund study, which suggests that further investigation into these and other hotspots may be warranted. The hotspots indicated in this study raise many questions that may help in focusing future research. Some of the more surprising and interesting unanswered questions provoked by this projection analysis include the following:

- The BIR hotspot located in the western till plains area of the Northern Region is notably large and conspicuously bounded by the Iowa State borders. Is this suggestive that land use intensification and conversion to crop and urban land in the till plains of Iowa, where there is very little natural vegetation left (< 8 percent; Klopatek and others 1979), could lead to a loss of remanent native breeding bird populations?
- The projection analysis has identified large ANI hotspots covering most of Oregon and Washington, areas not currently delineated as high endangerment regions (except for fish species in the Columbia River basin). What is the nature of the human activities in this region that would result in such a change of conditions?
- What is causing the increasing STR hotspots in the Southern and Northern Regions, given that these regions are different ecologically, climatically and in human use conditions (especially the Florida peninsula and the Adirondack region)?
- Sediment discharge appears to be a major concern in the Cascade Range, western valleys, and coast ranges of the Pacific Northwest but increased streamflow, typically associated with sedimentation problems, is not indicated as a hotspot. In fact, hotspots of reduced streamflow are indicated. How can this situation be explained? On the other hand, increasing streamflow and sediment discharge are both projected as hotspots in the desert region of southwestern Texas. Are they related?
- Habitat structure in the Florida peninsula is projected to increase, yet plant endangerment there also is increasing. How can that be explained?
- Habitat structure from the southern Nevada desert through northern Arizona and New Mexico is projected as a hotspot of decline, yet the trends in native breeding birds indicate an increase in native species richness. Are there factors other than habitat that explain this apparent contradiction?
- In the discussion of overall trends in the condition indicators, we also pointed out areas that appeared to be experiencing some improvement in conditions. For example, areas in southern Florida and western Texas currently experiencing the lower habitat structure conditions are projected to have the greatest increases in that indicator. Similarly, areas along the southern tier of the Northern Region that have the highest class of current exotic breeding birds are projected to experience the greatest decreases. Would it be worthwhile to focus analysis on such regions for information that might assist in mitigating the conditions that seem to be associated with hotspots?

The questions outlined above are just a few of the more obvious that this study raises. These questions reflect the purpose of this analysis, which was to identify broad-scale (national) relations among natural characteristics, human activities, and ecosystem condition. This analysis is exploratory, and all results reported are tentative. It is intended that the results serve to focus additional attention in high-priority areas, both in terms of research and management direction. Also, further research is needed in developing the methods for studies such as this one, which can serve the purpose of triage in large-scale planning efforts.

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