Projections of Forest and Rangeland Condition Indicators for a National Assessment

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ABSTRACT / This paper discusses projections of emerging geographic areas of concern with regard to forest and rangeland condition, as indicated by a model based on a set of independent econometric production functions for condition indicators at the national scale. These production functions reflect two special characteristics: (1) the independence of ecological systems from human control, and (2) the broad scale spatial nature of environmental and ecological processes. The emphasis in this paper is the model projections themselves, which are presented and discussed using national-scale maps.

This paper summarizes an analysis carried out as part of the 1999 Assessment of the Renewable Resource Situation in the United States as mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974 (Hof and others 1999). This analysis focuses on the interaction between natural resource use and forest and rangeland condition indicators at the national scale.

The production processes for environmental outputs measured by these condition indicators are obviously different than those for traditional economic outputs. The ecosystems that "produce" environmental outputs on forest and rangelands are 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 very 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 utilized 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.

Production Structure

We define three vectors of variables: $\tilde{X}$ 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; $\tilde{Y}$ is a vector of harvested outputs such as timber, livestock grazing, and mining activity; and $\tilde{Z}$ is a vector of forest and rangeland condition indicators that serve as our environmental outputs. The traditional economic analysis would treat the $\tilde{Y}$ vector as the outputs, produced from the $\tilde{X}$ vector, with the $\tilde{Z}$ vector left largely unaccounted for. Our focus here is the $\tilde{Z}$ vector, so we will treat it as the output vector with the $\tilde{X}$ and $\tilde{Y}$ vectors as inputs. The textbook treatment of joint production would use an implicit-form production function as:

$$O = f(\tilde{X}, \tilde{Y}, \tilde{Z}) \qquad (1)$$

to relate these three variable vectors. 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). 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. Mittelhammer and others (1981) show that such a property is not obtainable with equation 1. A production structure that has this property would be:

$$Z_i = g_i(\tilde{X}, \tilde{Y}) \quad \forall\, i \qquad (2)$$

which also has the convenient property of being estimable econometrically. Note that equation 2 is not a simultaneous system, but is potentially a set of seemingly unrelated regressions (which we will investigate empirically below). Equation 2 is still a joint production

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structure, because the $\tilde{Z}$ is 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, reflecting the autonomy of the ecosystem, as desired.

Spatial Considerations

Because the problem defined for this paper is very broad-scale and because the process of producing environmental outputs takes place over very large landscapes, the desired sampling scheme would yield observations that spatially represent the ecological systems included. Unfortunately, broad-scale data are not typically available on this basis. At this scale, data are available in many different formats, from micro data with many sample points to county-level numbers that are highly reliable but are also highly aggregated. One approach is to simply aggregate all micro data into county averages and treat the county as the fundamental observation definition. This approach is typical in broad-scale statistical modeling (see Cressie 1991, p. 383), but differential county size results in inequitable sampling of ecological systems across the coterminous United States. We adopted a ''GRID'' approach, where we start with the data in its most disaggregated (and nonhomogeneously defined) format, and then use kriging to spatially interpolate observations onto a uniform grid across the country. The reader is referred to Cressie (1991) for a detailed discussion of kriging and geostatistical techniques in general and to Hof and others (1999) for more specific documentation of our procedures. Using this intermediate step increases the possibility of information loss from smoothing or averaging in the interpolation process, but approximates the more equitable sampling scheme that would have been desirable in the first place.

Database Development

Because of data availability, only the coterminous United States was included. The GRID data file was constructed to match the number of observations in the county data as closely as possible; thus, there are 3280 observations (cells) in the GRID data file. The indicators of forest and rangeland condition (dependent variables) chosen were those that are most likely to be affected by human activity on forest and rangelands and are of interest to policy-makers (including an emphasis on wildlife and threatened and endangered species).

The following dependent variables (Z_i) were included as measures of forest and rangeland condition (with sources as cited):

SED, sediment discharge, tons/day (Hydrodata 1992)
STR, streamflow, cfs (Hydrodata 1992)
PLA, Threatened and endangered plants, *N*/acre (BioData 1990, US Department of Commerce, Bureau of Census 1980a)
ANI, threatened and endangered animals, *N*/acre (BioData 1990, US Department of Commerce, Bureau of Census 1980a)
HAB, habitat structure index, ratio (US Department of Interior, Geological Survey 1990a)
BIR, native breeding birds, *N* species (US Department of Interior, National Biological Survey 1990, Peterjohn and Sauer 1993)
EXO, exotic breeding birds, ratio (US Department of Interior, National Biological Survey 1990, Peterjohn and Sauer 1993)

The following independent variables ($\tilde{X}$) that account for natural and management inputs were included:

URB, Urban land use and land cover, % (US Department of Interior, Geological Survey 1990a)
AGR, agricultural land use and land cover, % (US Department of Interior, Geological Survey 1990a)
RNG, rangeland use and land cover, % (US Department of Interior, Geological Survey 1990a)
FOR, Forest land use and land cover, % (US Department of Interior, Geological Survey 1990a)
WAT, water use and cover, % (US Department of Interior, Geological Survey 1990a)
WET, Wetlands use and cover, % (US Department of Interior, Geological Survey 1990a)
FED, land area in federal ownership, % (US Department of Agriculture, Soil Conservation Service 1987, US Department of Commerce, Bureau of Census 1980a)
PVT, land area in private ownership, % (US Department of Agriculture, Soil Conservation Service 1987, US Department of Commerce, Bureau of Census 1980a)
EVA, evaporation, inches/day (Climatedata 1990)
PRC, rainfall, inches/yr (Climatedata 1990)
SNO, snowfall, inches/yr (Climatedata 1990)
TMX, maximum temperature, °F (Climatedata 1990)
TMN, minimum temperature, °F (Climatedata 1990)
ELV, elevation, m (US Department of Interior, Geological Survey 1990b)
ELS, elevation, standard deviation (US Department of Interior, Geological Survey 1990b)
POP, population, *N*/acre (US Department of Commerce, Bureau of Census 1980b and 1990)
CRP, land area in conservation reserve program, % (US Department of Commerce, Bureau of Census 1987)
IRR, land area irrigated, % (US Department of Commerce, Bureau of Census 1987)
CRU, land area unlikely to be converted to cropland, % (US Department of Agriculture, Soil Conservation Service 1987)

CRM, Land area with medium potential to be converted to cropland, % (US Department of Agriculture, Soil Conservation Service 1987)
CRH, land area with high potential to be converted to cropland, % (US Department of Agriculture, Soil Conservation Service 1987)
DIV, economic diversity, index (US Department of Agriculture, Forest Service 1985a)

The following independent variables ($\tilde{Y}$) that measure removals from forest and rangeland were included:
TBR, stumpage value, $/acre (US Department of Agriculture, Forest Service, 1985b)
BFC, beefcows, N/acre (US Department of Commerce, Bureau of Census 1987)
MIN, minesites, N/acre (US Department of Interior, Bureau of Mines 1992)
HWY, land area in highways and interstates, % (GEOECOLOGY 1979)
RDS, land area in dirt, gravel, and paved local roads, % (GEOECOLOGY 1979)
See Hof and others (1999) for more detailed information regarding the data set development.

Model Estimation

We tested a variety of functional forms for the model and settled on the ‘‘translog’’ form because its interaction terms were indicated to be important and the adjusted R^2's (ranging from .4120 to .9679) indicated superior fit. 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 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 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 (1979) tests for heteroskedasticity, and all of the models were indicated to be 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 utilize the OLS estimates. We thus applied 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 estimation. The similarity of the *t* tests and White's tests probably results 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 quite 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 (0.0122 to 0.0239), suggesting that the seven equations do not exhibit contemporaneous correlations among the residuals. See Hof and others (1999) for more discussion of the equation estimation and for the complete equation estimations.

Projection of Independent Variables

Projections to the year 2020 for 11 independent variables were developed: URB, AGR, RNG, FOR, WAT, WET, POP, IRR, TBR, BFC, and MIN. These are the variables from our set that reflect human use and management intensity of natural resources. The remainder of the independent variables were held constant during the projection period.

County-level projections for population (POP) were obtained from Woods & Poole Economics, Inc. (CEDDS 1997). These county population projections were georeferenced to the county centroids and kriged to develop indexed population projections for the GRID. Based on the assumption that urban (URB) and agricultural (AGR) land use and mining activity (MIN) 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 (Flather and Hoekstra 1989, Department of Agriculture, Forest Service 1989a–c, 1994, Guldin 1989, Joyce 1989). We then multiplied each observation in the GRID data set by the appropriate index to obtain projections for the GRID observations.

After multiplying each observation by the appropriate projection indexes, the land use/cover projections for the GRID observations did not sum to the known land-base totals (that is, total acres in each region). We adjusted the projected GRID observations to be consistent with the known totals by using a procedure called *iterative proportional fitting* (Bousfield 1977). For a detailed discussion of the independent variable projections, the reader is referred to Hof and others (1999).

Projection of Forest and Rangeland Condition Indicators

The projection analysis requires a comparison of the projected value of each dependent variable (environmental condition indicator) for each GRID observation in the year 2020 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 with means of the independent variables inserted. The projected values of the dependent variables are derived by applying the coefficients from the translog equations to the projected independent variables. The ratio and the absolute difference between the projected and current values are calculated for each GRID point observation in each equation. We created maps to display areas of potentially significant change in forest and rangeland condition indicated by this analysis, which we label as hotspots. These were determined using the criteria specified in Prendergast and others (1993), namely the upper or lower 5% of the projections, whichever would typically indicate a degradation in environmental conditions. In the case of streamflow (STR), either extreme may indicate a degradation, so we split the hotspots into upper and lower classes of 2.5% of the observations each. The hotspots discussed should be regarded as candidates for further study—our analysis is suggestive, not definitive in projecting trends.

Threatened and Endangered Plants (PLA, Figure 1)

Our data base included 274 plant species that are listed as threatened or endangered under the US Endangered Species Act (ESA, P.L. 93-205). These species are currently concentrated in peninsular Florida, the southern Appalachian Mountains and piedmont, and the Mediterranean climate region of the central California coast (Figure 1a). Projected hotspots of increasing plant endangerment (Figure 1b, c) indicate that the southern desertic basins, plateaus, and plains region of western and central Texas have the potential to become an important area for resource conflicts, resulting in new concentrations of threatened and endangered plants. New concentrations of endangered plants are also projected to occur in the central desertic basin and range region of southern Nevada and western California, and along the southern California Coast Range and valleys. All other prominent projected hotspots tend to emphasize areas with current concentrations of endangered plants. These areas include the southern Appalachians, southern piedmont, and peninsular Florida. Because these latter areas already support a high density of endangered plants, they only become apparent when examining absolute trend projections (Figure 1c).

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

Threatened and Endangered Animals (ANI, Figure 2)

A total of 357 animal species in our database were listed as threatened and endangered under the ESA. These species are currently concentrated in the southeastern United States, the central California coast, and the Washington/Oregon border (Figure 2a). Areas predicted to show elevated numbers of threatened and endangered animals are concentrated in states along the Pacific coast (Figure 2b, c). Both the east and west slope of the northwest mountains, the central California Coast Range, and interior valleys indicate a geographic extension of the areas currently supporting a high number of threatened and endangered animals.

The hotspots identified in the model projections appear to result because of the combination of all the independent variables. In particular, land use intensification stemming from population increases, irrigated agriculture, and grazing of beef cows appear to be associated with elevated levels of threatened and 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)

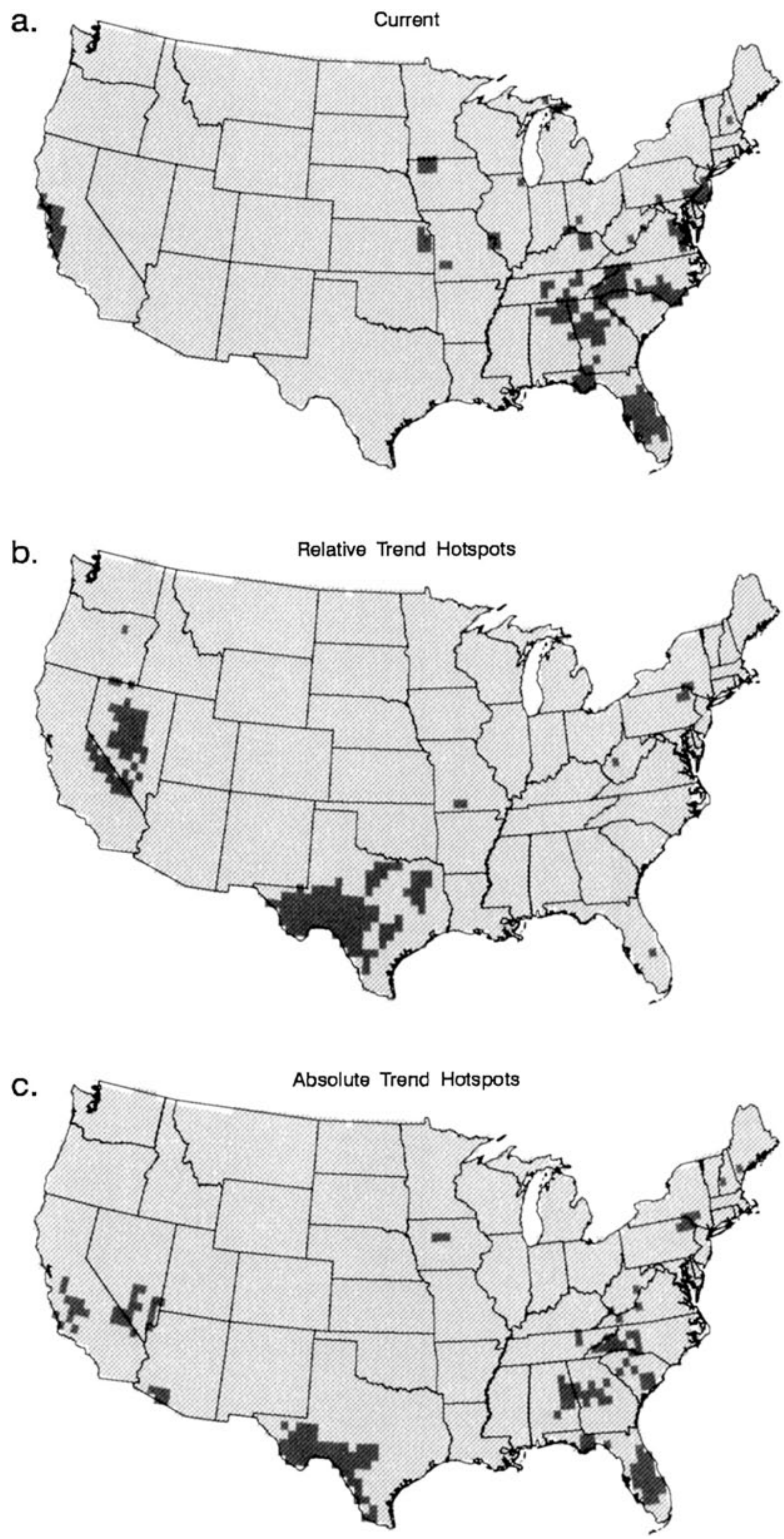

Figure 1. Locations of the upper 5% of occurrences of threatened and endangered plant species in current values (a), projected relative trends (b), and projected absolute trends (c).

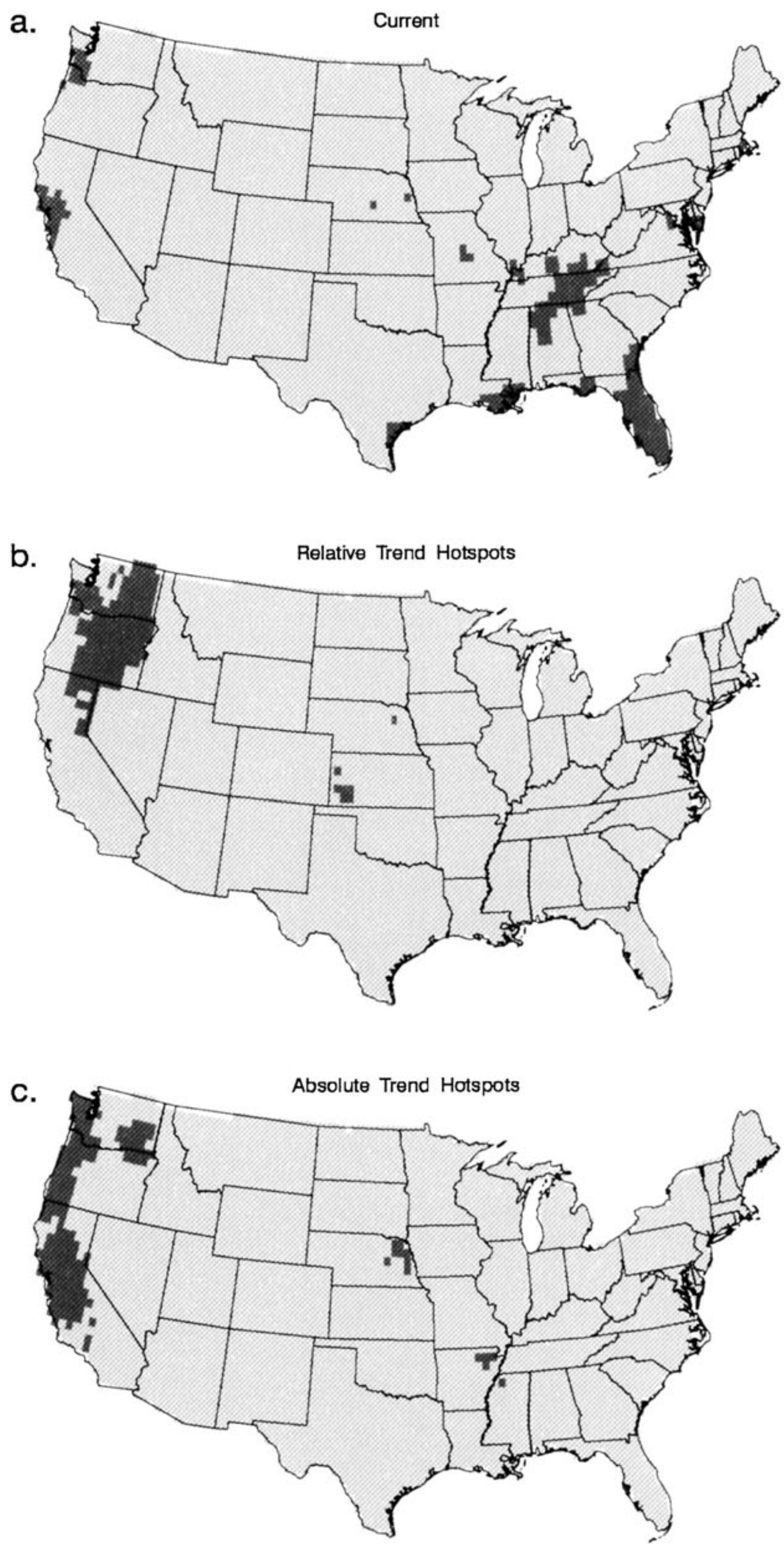

Figure 2. Locations of the upper 5% of occurrences of threatened and endangered animal species in current values (a), projected relative trends (b), and projected absolute trends (c).

are substantiated by the hotspots in those regions identified by our model.

Streamflow (STR, Figure 3)

Both high (increased flooding) and low (water diversion or aquifer drawdown) streamflow could indicate ecosystem degradation. Therefore, we examined both the upper and lower 2.5% of the streamflow frequency distribution to identify hotspots. Because current streamflow patterns (Figure 3a) are closely tied to precipitation, current streamflow hotspots are found in both mesic (namely the southern Appalachian and northern Pacific coast regions) and arid (namely the Southwest) ecosystems. Projected hotspots of streamflow are found in the southeastern United States and the Pacific coast states (Figure 3b, c). High streamflow hotspots are concentrated in the southeast and include peninsular Florida, the southern Appalachians, the east Texas coastal plain, and the southern desertic basins of west Texas. Low streamflow hotspots are primarily concentrated in the western United States. The west slope of the northwest mountains and the northern California mountains both have high current streamflow but are projected to lose flow under our future land use scenario. The southern California mountains, which currently have low streamflow, are projected to lose more flow in the future with important implications to aquatic ecosystems. The one eastern low streamflow hotspot projected to occur is in the Allegheny plateau and Catskill Mountains region.

The increasing streamflow hotspots identified in the model projections appear to result primarily because of projected decreases in forest land cover (FOR) along with the confluence of all the other independent variables. The decreasing STR hotspots in the far west appear to result from the decreases in timber harvesting (TBR) projected for that region.

Agricultural and urban development have historically 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 Cascade Mountains in the Pacific Northwest and in southern California may be reflected in the hotspots in and around those regions.

Sediment Discharge (SED, Figure 4)

High sediment discharge is currently found in areas of intensive agricultural activities (e.g., Mississippi basin, south-central California), intensive timber harvesting (e.g., Pacific northwest), or in areas with highly erosive soils (e.g., coastal southern California) (Figure 4a). Like the streamflow indicator, areas where sediment discharge is projected to increase occur in the southeast and Pacific coast states (Figure 4b, c). The projected hotspots in peninsular Florida and the southern desertic basins of west Texas are notable because they do not currently have high sediment discharge levels. The projected hotspots in the Pacific coast states, on the other hand, indicate areas where stream sediments are already high and are likely to get higher.

Sediment discharge hotspots identified in the model projections appear to result primarily from projected increases in grazing (BFC) and in mining activity (MIN). In the southeastern United States, projected increases in AGR also appears to be contributing to the hotspots observed in this region.

Habitat Structure (HAB, Figure 5)

The habitat structure indicator, which is measured as the ratio of area in natural vegetation (forest, range, wetland) to area in intensively used land (agriculture, urban), identifies those regions that have undergone extensive development to support human populations. Regions that are currently characterized by low habitat structure include the corn-belt and northern plains regions of the central United States (Figure 5a). For the most part, projected hotspots for the habitat structure indicators show little overlap with current hotspots. This is not too surprising because once land comes under agricultural or urban development there is little that can be done to further reduce our measure of habitat structure. For this reason, the relative and absolute trend hotspots are nearly identical (Figure 5b, c). New hotspots indicative of habitat structure degradation are projected to occur in the southern coastal plain, the Allegheny plateau and Catskill Mountains, the southwest desertic basin and range, and the east and west slopes of the northwest mountains.

The HAB hotspots identified in the model projections appear to result primarily because of the projected decreases in forest land cover (FOR), rangeland cover (RNG), and the ancillary increases in the more developed land uses. This finding is corroborated by Klopatek and others (1979) in the South, and by Spies and Franklin (1988) and Ripple and others (1991) in northern California and southern Oregon.

Native Breeding Birds (BIR, Figure 6)

The number of different bird species observed at a given location appears to be related to primary productivity. The diversity of birds, as measured by the count of unique species, reaches its highest levels in the eastern United States and the more mesic areas of the West (see

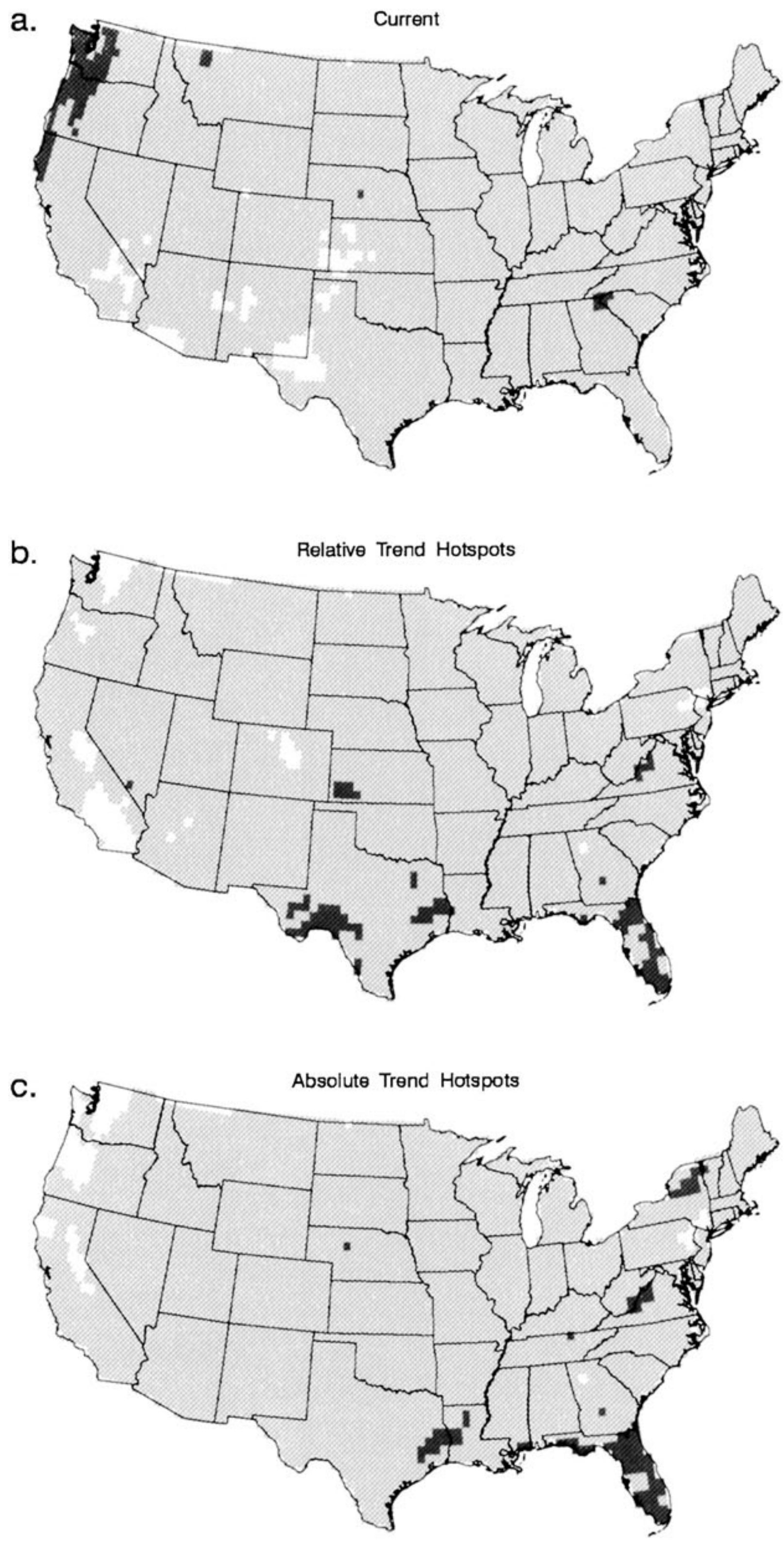

Figure 3. Locations of the upper 2.5% and lower 2.5% of streamflow in current values (a), projected relative trends (b), and projected absolute trends (c).

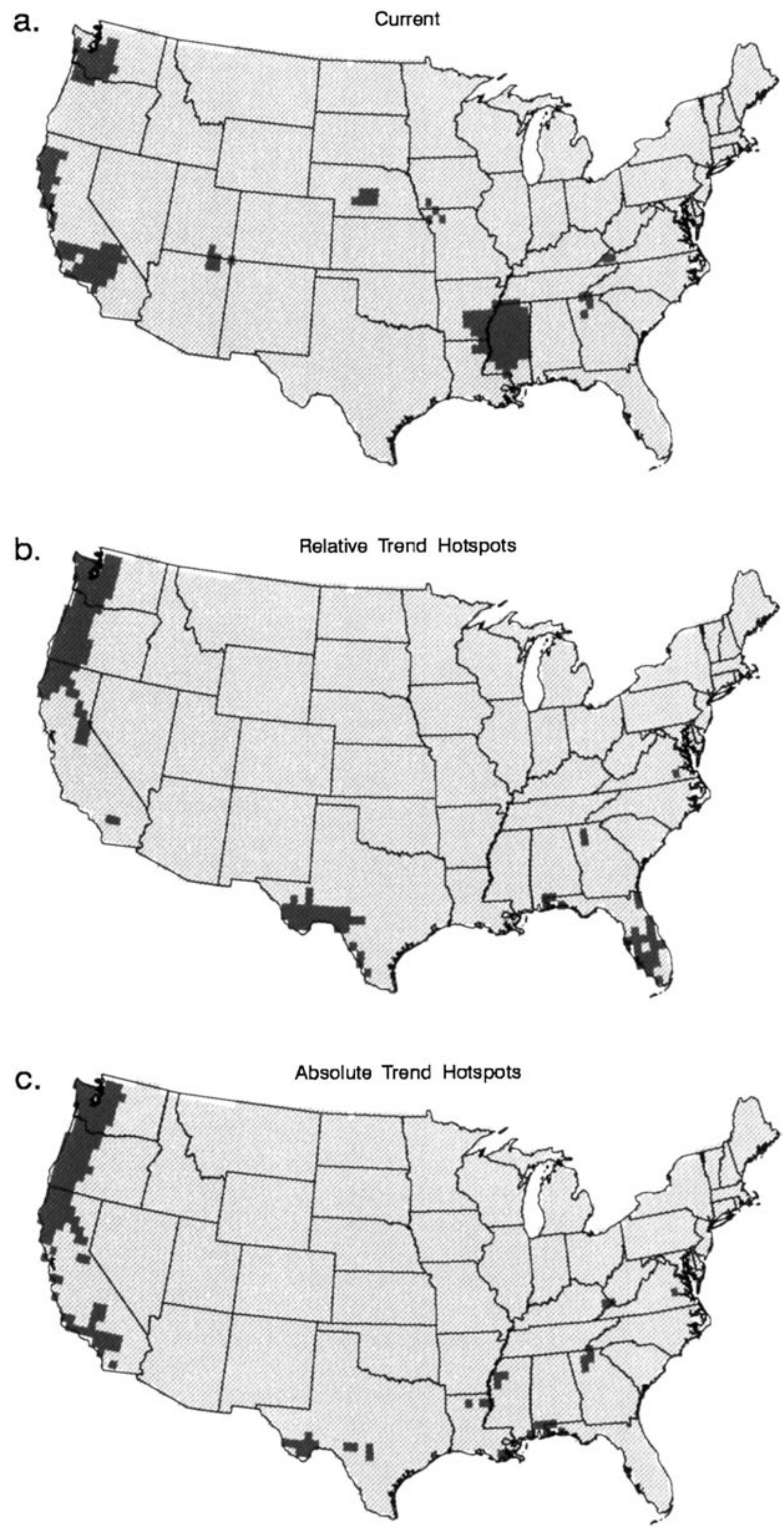

Figure 4. Locations of the upper 5% of sediment discharge in current values (a), projected relative trends (b), and projected absolute trends (c).

Hof and others 1999). A notable exception to this pattern is the high diversity of birds in the arid southwest, particularly southern Arizona, where some of the highest number of bird species are observed (Currie 1991). Areas that have particularly depauperate bird communities are found in the more arid interior west (Figure 6a). One of the most widespread signs of ecosystem distress is a reduction in species diversity

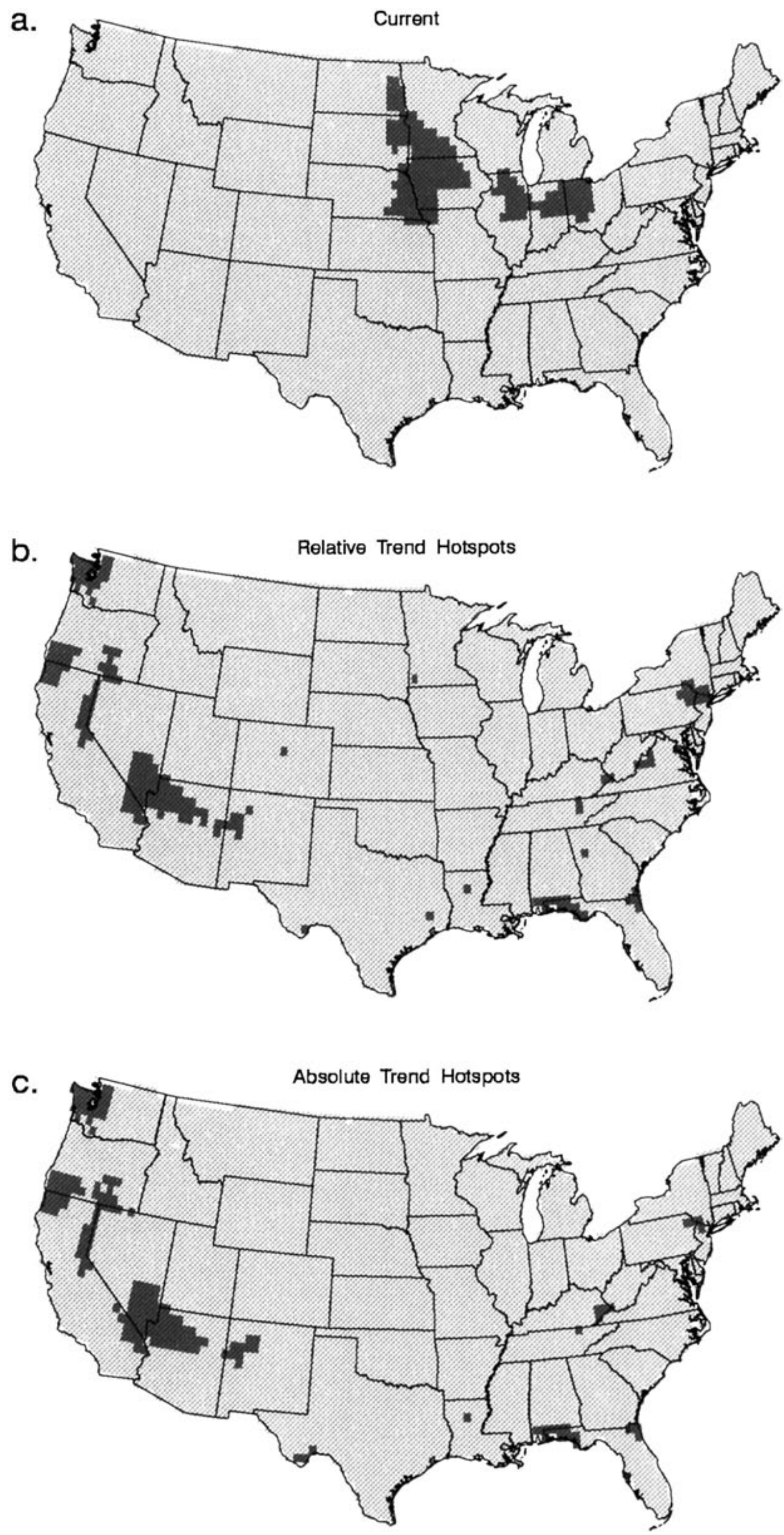

Figure 5. Locations of the lower 5% of the habitat structure index in current values (a), projected relative trends (b), and projected absolute trends (c).

(Rapport and others 1985). The majority of projected breeding bird hotspots occur in areas that currently support high numbers of breeding bird species (Figure 6b, c). Areas that are projected to lose breeding bird diversity under our future land-use scenario include the central till plains region, the Laurentian mixed forest region of coastal Maine, the southern Appalachians, and the southern Mississippi Valley alluvium. The east-

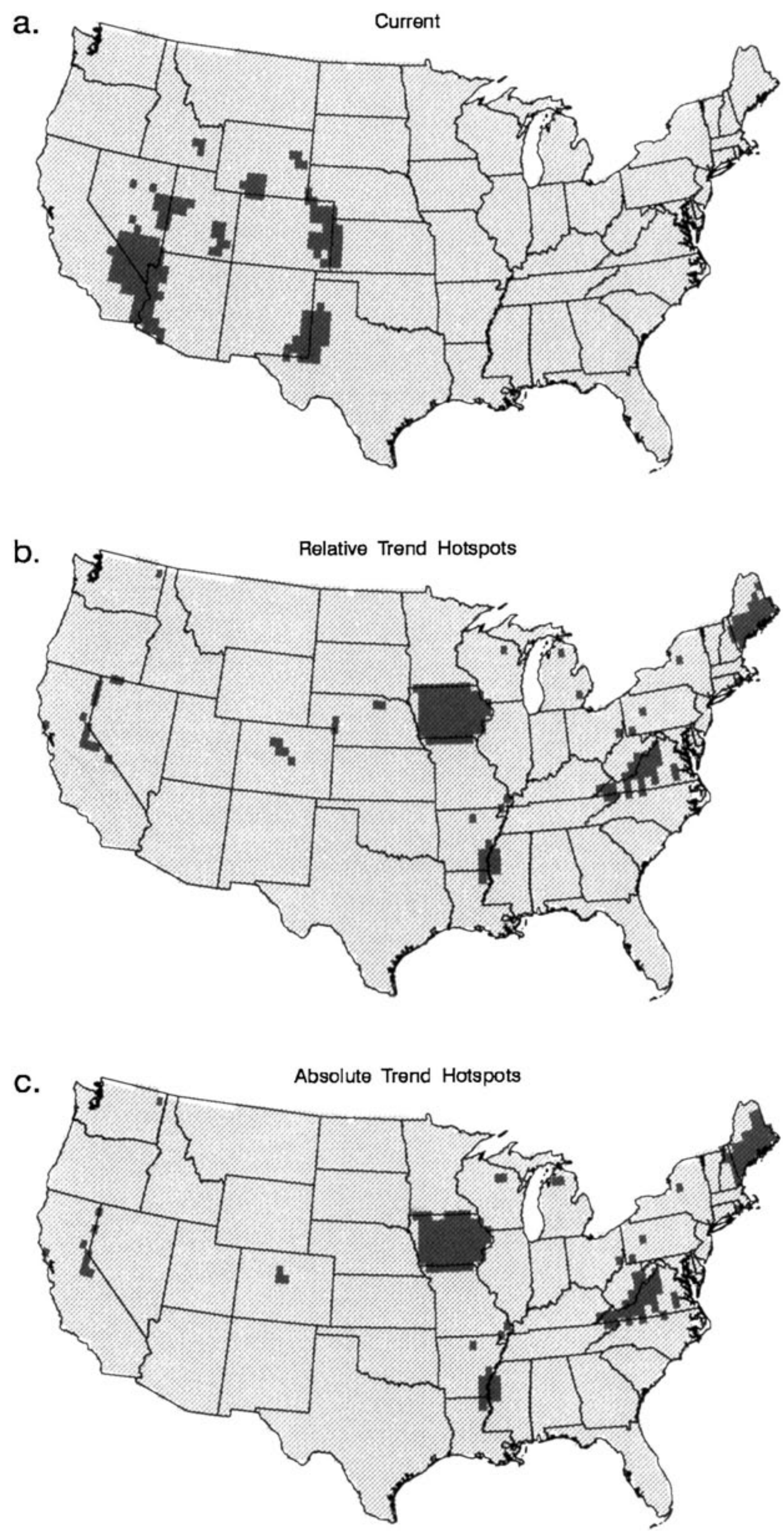

Figure 6. Locations of the lower 5% of occurrences of native breeding bird species in current values (a), projected relative trends (b), and projected absolute trends (c).

ern slope of the northwest mountains, an area currently characterized by low numbers of breeding birds, is also projected to lose bird diversity.

The BIR 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 eastern forested regions (Askins and others 1990) and northern

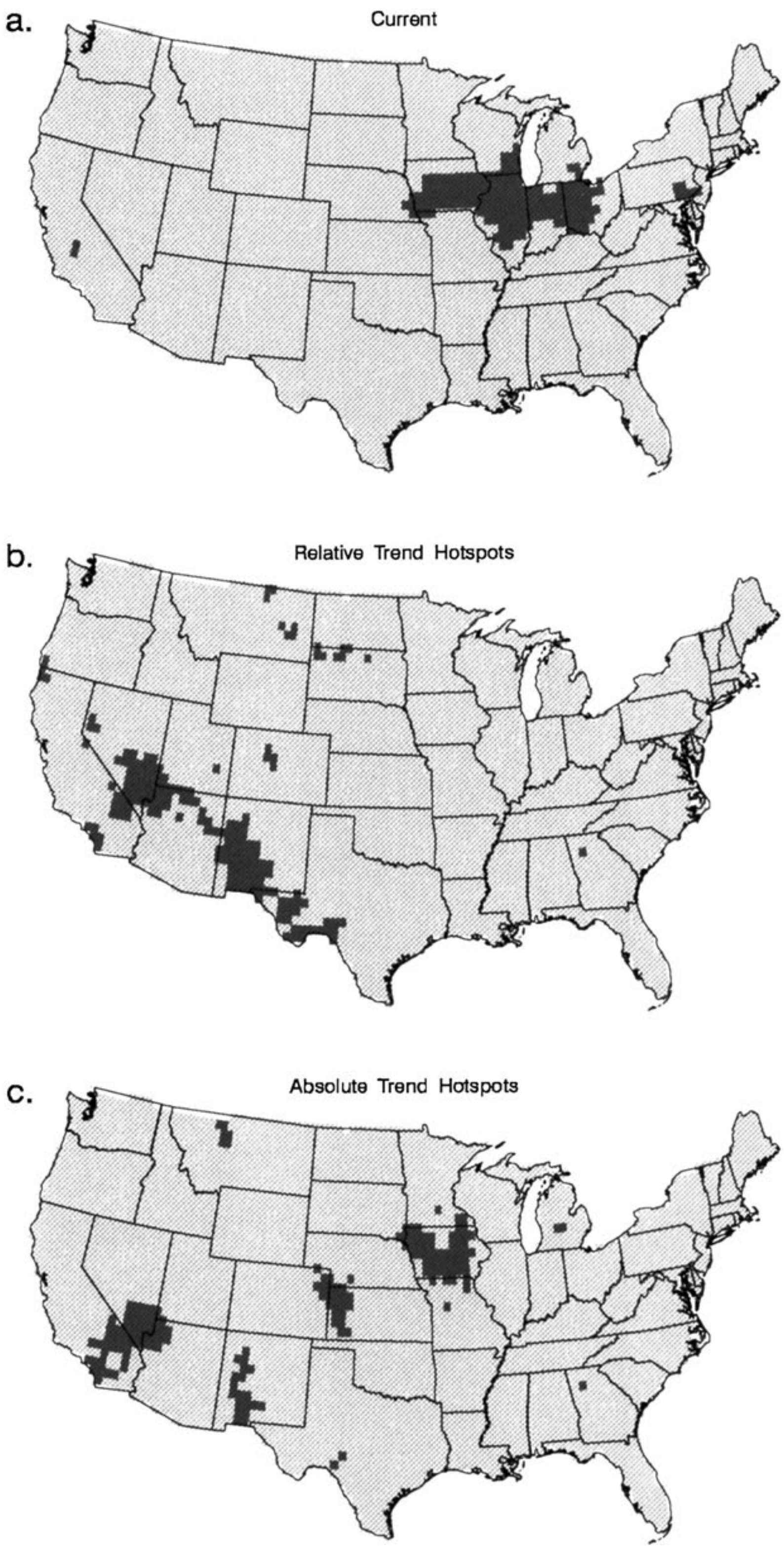

Figure 7. Locations of the upper 5% of occurrences of exotic breeding bird species in current values (a), projected relative trends (b), and projected absolute trends (c).

great plains grassland breeding birds (Knopf 1995) are supported by the projected hotspots in those areas. In eastern forests 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, subsequent afforestation, and the absence of disturbance to reestablish younger forest age classes (Welsh and Healy 1993).

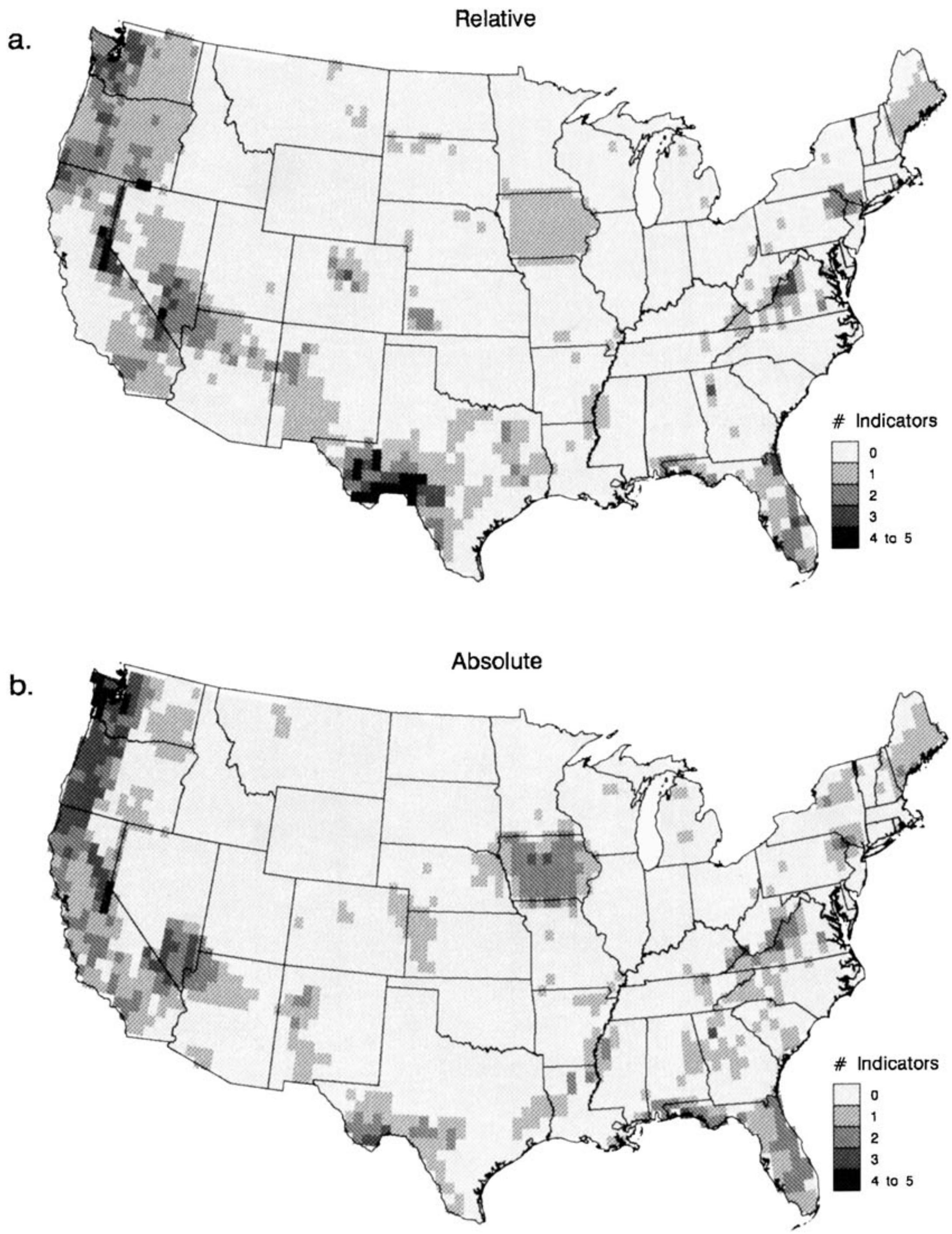

Figure 8. Overlay of relative and absolute trend hotspots from Figures 1 to 7.

Exotic Breeding Birds (EXO, Figure 7)

When species richness declines in response to some environmental disturbance, there is often an accompanying pattern of increasing numbers of exotic species that are more opportunistic and able to adapt to the disruption of native habitats (Rapport and others 1985). The current geographic pattern of exotic bird species, as measured by the proportion of individual birds observed that are not native to a given region, is correlated with intensive land-use patterns. Areas where intensive agriculture (e.g., the corn-belt region of the Midwest) and urban development (e.g., the Mid-Atlantic coast) dominate the landscape are also characterized by bird communities with high proportions of exotic species (Figure 7a). Projected hotspots all occur in more arid, less forested environments. The central till plains of Iowa and the central high plains of western Kansas are projected to observe greater proportions of exotic species under the land-use scenario we examined. Similarly, the southwest and southern desertic basin regions are also projected to undergo shifts toward more exotics in the local avifauna.

The exotic bird hotspots identified in the model projections appear to result primarily because of the projected increases in population (POP) in southern California, southern Nevada, Arizona, New Mexico and west Texas. In the till plains and prairie areas, the hotspots identified appear to reflect projected land-use intensification from timbering (TBR) and agricultural activities (AGR). The native grassland areas of the northcentral prairie ecosystem have experienced intensive land-use activities for many decades (Samson and Knopf 1994) and such disturbance can predispose animal communities to invasion by exotic species (Smallwood 1994). The conversion of natural vegetation to intensive agriculture and urban land uses (Klopatek and others 1979) and the known decline in grassland breeding birds in that region (Knopf 1995) are consistent with the pattern of increasing exotic birds projected by the model.

Summary and Conclusion

If we assume that coincidence of hotspots identifies those geographic areas that will be subject to high levels of land-use stress, then this modeling approach can offer natural resource planners a tool that allows them to anticipate where resource conflicts are likely to be the most problematic in the future. Overlaying the projections for the seven indicators of ecosystem degradation does identify several areas where concurrence is particularly high (Figure 8). In particular, the west slope of the northwest mountains, portions of California, the desertic basin regions of west Texas and southern Nevada, the central till prairie, peninsular Florida, and the southern Appalachians all show overlap with three or more indicators based on either the relative or absolute trend criterion.

We have avoided any interpretations that suggest actual causation because the econometric methods used only identify patterns of correlation between dependent and independent variables (including interactions terms). Thus, these potential hotspots should be viewed only as candidates for areas of concern. We do note, however, that areas of concern identified in our analysis have some correspondence in the literature. In addition to the previous citations, a recent World Wildlife Fund study (Ricketts and others 1999) also identified geographic areas that warrant conservation focus, based primarily on biodiversity attributes. Their map of areas requiring immediate protection of remaining habitat and extensive restoration (which they call "class 1" regions; Ricketts and others 1999) is remarkably similar to our maps depicted in Figure 8. Both indicate the west coast, west Texas, the central till prairie around Iowa, portions of Florida, and the southern Appalachians as areas of concern. Our study indicates a few areas in addition to the World Wildlife Fund study, including the desertic basin and range region of southern Nevada. Nonetheless, the similarity between these study results, which are based on very different methodologies, is noteworthy and suggests that the areas highlighted are not simply an artifact of a particular data source or analysis.

This analysis is clearly exploratory in nature and all results reported are tentative. Hopefully, the results will serve to focus additional attention in high priority areas, both in terms of research and management direction. Further research also is clearly 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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