NASA Land Cover Land Use Change Research Program: 1998 Progress Report

CAUSES AND CONSEQUENCES OF LAND COVER CHANGE IN A GREATER ECOSYSTEM: TREND AND RISK ASSESSMENT, MONITORING, AND OUTREACH

Andrew Hansen, Alisa Gallant, Jerry Johnson, Bruce Maxwell, Ray Rasker, Jay Rotella
Montana State University, Bozeman, MT

Warren Cohen
USDA Forest Service, Forestry Sciences Laboratory, Corvallis, OR

Introduction and Objectives

The regions surrounding many nature reserves are growing rapidly in human population size. Such population increases raise question as to role of ecosystem quality in attracting new immigrants and the consequences of increasingly intense human land use on ecosystem quality. The goal of this study is to quantify changes in biodiversity, land use, and human socioeconomic performance in the Greater Yellowstone Ecosystem (GYE) over the past 23 years and to test hypotheses on interactions among these ecological and human factors.

Objectives of the study are:

1. Quantify changes in biophysical gradients, biodiversity, and land use and socioeconomic factors across the GYE from 1972-1996.
2. Test hypotheses on interactions among biophysical gradients, biodiversity, and socioeconomic patterns.
3. Assess current and future risk to ecological hot spots and potential for restoration.
4. Develop an approach to monitor ecological and human interactions.
5. Communicate results to stakeholders.

Here, we report progress from September 1997, when funding began, through April 1998. A first step was to define the study area boundaries based on ecological and socioeconomic factors. The resulting 100,000-km^2 study area includes a gradient in land use from lowland urban and agriculture to high elevation nature reserves, and includes 20 counties. We then delineated one of these counties (Gallatin) as a pilot study area where we will focus the initial trend assessment and hypothesis testing. After methods are refined in the pilot study area, analyses will be extended to the entire study area.

Objective 1: Trend Assessment

Land Cover and Use

Vegetation Classification

We have developed an automated routine for co-registering images based on spatial autocorrelation among images. Software associated with the routine will ultimately be made available on the Web.

Initial classification is being done for the Gallatin County Pilot Study Area. The pilot area was selected because it fit three important criteria: 1) high degree of land cover variability (representative of a large portion of the GYE), 2) good baseline data available for

classifying land cover as well as socioeconomic factors that are being integrated with the land cover data, and 3) easy access of the pilot area for most of the Principal Investigators.

Our cover classification scheme has six, increasingly detailed, hierarchic levels. The coarsest level is similar to an Anderson Level I scheme. The remaining five levels are comprised of a mix of discrete and continuous cover classes. Discrete classes are those that typically appear as homogeneous cover units, such as snow or bare soil. Continuous classes are those that typically appear as a mix of cover components. Examples of two continuous classes are: 1) percent cover by trees, shrubs, and herbaceous vegetation and 2) density of urban development. The use of continuous classes eliminates the label assignment problems associated with transitional areas and increases the flexibility of the results for a wider range of applications, as cover types can be re-defined based on their components.

We have acquired all imagery for the pilot area project and have ordered imagery for the TM sensor for 1990, and the TM and MSS sensors for 1985 for the study area. The georegistration routine has been completed and tested. We are now working on the Level I land cover classification for the pilot study area.

Change Detection

An important preliminary consideration for change detection analyses is that images be radiometrically matched. We are currently experimenting with several techniques to determine which best addresses this need.

We are testing an innovative method of change detection whereby we map current (1995) land cover and determine previous cover only for those areas exhibiting different spectral characteristics in past satellite data. Areas not exhibiting different spectral characteristics are assumed to have remained constant in their cover type. We are using our pilot area study to compare the results from this change detection approach with those from the more traditional approach of post-classification comparison. Our evaluation will consider the accuracy of the results, the level of effort required, and additional tradeoffs associated with each method. Preliminary steps have been completed but the bulk of the effort will follow completion of the 1995 land cover maps

Accuracy Assessment

We have refined methods for assessing cover map accuracy and acquired the necessary aerial photos for the pilot study area.

Socioeconomic Variables

Thus far we have reviewed relevant literature, identified the socioeconomic variables that will be used in the trend assessment, obtained about two-thirds of these data, and tested software for conducting multivariate analyses of these data. The 28 variables deal with population density, economic diversity, income, social cohesion, quality of live, and proximity to public lands.

Population and Rural Residential Development

Temporal trends and spatial patterns in population density in Gallatin County were quantified using data available from the Bureau of Census and state environmental agencies.

Analysis of these data indicated that there were distinct decadal trends in growth rates throughout the GYE. Between 1930 and 1970, the average rate of increase in the GYE paralleled the national average. In the 1970's, population growth rates in 15 of the 20 GYE counties increased faster than the national average. Eight of these 15 counties were in the top 25% of the fastest growing counties in the U.S. The economic recession of the 1980's produced a reduction in growth rates throughout the GYE; population trends were comparable to those between 1930 and 1970. In the 1990's, the disparity between national and GYE population trends widen. Seventeen of the 20 GYE counties have been growing faster than the national average, and 13 GYE counties are included in the top 25% of the fastest growing counties in the U.S.

Within the pilot study area, human settlement has exhibited at least two distinct spatial patterns. During the 1970's, settlement patterns were relatively uniform across the lands available for development. New development was observed in proximity to the local urban centers as well as in rural locations. In contrast, settlement patterns in the 1990's exhibited a greater degree of clustering. A greater number of home sites were selected along riparian corridors and public land boundaries, and development rates near urban locales had declined.

Objective 2: Hypothesis Testing

Hypothesis 1: Strong abiotic gradients (topography, climate, soil) cause native species abundances and richness to be high only in localized hot spots across the landscape.

The topographic complexity of the GYE causes climate to be harsh and soils to be relatively poor over much of the landscape. We speculate that the abundances and richness of native species of trees, shrubs, and birds will be high only in localized hot spots. Under other funding, we have collected data on abiotic factors, vegetation productivity and structure, and abundances of trees, shrubs, and birds across 100 plots in the northwest portion of the GYE. We have been analyzing these data under NASA funding to test Hypothesis 1. First we estimated aboveground net primary productivity (ANPP) at each plot using field data and allometric equations. We then used multiple regression to determine the amount of variation in ANPP explained by abiotic and vegetation factors and used a resulting equation to predict ANPP across the study area. Next, we quantified the amount of variance in tree, shrub, and bird species richness explained by topography, ANPP, vegetation cover type, and vegetation structure. The regression equations for "best" models were used to extrapolate species richness over the study area.

We found that elevation, cover type, and soil type explained 62% of the variation in ANPP. Elevation, ANPP, vegetation structure, and cover type explained 78% of the variation in species richness. Predicted ANPP and tree, shrub, and bird species richness were high only in localized places that cover about 4% of the study area. As hypothesized, we found that these hot spots for productivity and species diversity are primarily low in elevation, on private lands, and outside the protection of nature reserves (e.g., Yellowstone National Park).

Hypothesis 2: Human land use is correlated with environmental gradients such that land use is most intense at hot spots for biodiversity.

We speculate that abiotic factors also influence human habitat selection such that more intense land uses such as rural residential development and crop agriculture are preferentially placed near hot spots for biodiversity and productivity. We are examining this hypothesis through spatial analyses of land use and through homeowner surveys in the pilot study area. Data on home location was compiled from well records. Measures of the spatial distribution of agriculture productivity are being derived from Landsat TM imagery, soils data, and crop yield records. Initial analyses revealed that homes are located disproportionately near to hot-spot habitat types such as cottonwood, aspen, and willow stands. We speculate that hot-spot habitats are favored for home placement because of high-quality scenery, recreation opportunities, access to water, and other factors.

Household surveys are being used to quantify home placement at fine spatial scales and to query owners on the criteria important to them in selecting a home site. Pretesting of survey methods has been completed and surveys are now underway of 350 randomly-selected home sites in Gallatin County. To date, survey response rates are about 75% and the quality of the data appears to be good. Preliminary results indicate that household income is strongly correlated with home site selection criteria with wealthier home owners more likely to select home sites based on ecological amenity values.

Hypothesis 3: Counties with the greatest area of ecological hot spots have the highest socioeconomic performance.

The economy of the GYE has diversified over the last 25 years from a dependence on resource extraction towards service and professional industries. However there is variation among the counties in economic trends. We are developing a socioeconomic typology of counties. Examples of classes: “metro” or within “commuter shed ”; rural with history of resource dependence; rural with history of agricultural dependence; and rural adjacent to national park, wilderness area or other significant natural area. This typology will be used to identify variables that will be placed in predictive model of socioeconomic performance. This model will be used to test the significance of “hotspots” (i.e., high NPP and biological diversity) relative to other variables as a predictor of economic growth.

Thus far we have developed methods to address these questions at three spatial scales: Rocky Mountain States, counties in and surrounding the GYE, and subsets of counties of the GYE. We have collected much of the data needed for the analyses and tested software for conducting statistical analyses.

Hypothesis 4: Intense land use reduces the population viability of some native species.

Bird species richness is especially high in some hot-spot habitats (see above). We suspect that the high ANPP and complex vegetative structure in such sites allow birds to maximize survivorship and reproduction there. However, in areas of intense human land use, an important exception may occur. Many important nest predators and brood parasites may be found at higher densities in hot spots near or in areas of intense human land use and reduce bird survival and reproductive output in some hot spots.

Thus far, we have analyzed reproductive output data for 404 nests of 20 species of passerines in 3 habitat types (2 hot spot habitats and 1 extensive habitat). Reproductive

output varies among the habitat types for several reproductive parameters, which indicates that not all hot spots for diversity are also hot spots for population viability. Open-cup nesting species that are susceptible to brood parasites have higher nest success, lower levels of brood parasitism, and higher reproductive output in aspen stands than they do in cottonwood stands. Given these data, stochastic population models indicate that aspen stands are much more likely to operate as population source areas than are cottonwood stands. Extensive non-hot-spot habitats have only a small role in the population dynamics of many species.

Intensity of human land use is much higher in cottonwood stands than it is in other stand types. In agreement with our hypothesis, reproductive success is lower in cottonwood than it is in aspen, which is less intensely used by humans. Further support for our hypothesis comes from analyses of cottonwood stands only: intensity of land use and reproductive success are inversely related within this habitat type. We are currently conducting analyses of within aspen variation.

Risk Assessment

The results of Objectives 1 and 2 will provide a basis for identifying places in the GYE that have high biodiversity value and are at risk due to current or likely future land use. Our initial efforts have focused on developing a methodology for identifying which species in a planning area are most likely to be vulnerable to local extinction and which places in the planning area are most important to the population viability of these species.

The steps in our Dynamic Habitat and Population (DHP) Analysis are:

1. Determine which of the species in the planning area most merit field study by ranking each species' viability risk based on range-wide population status, habitat use, and threats to habitat.
2. Screen these selected species based on field study and analyses of local habitat and population factors and range-wide vulnerability scores to determine which most merit field study of local demography.
3. Obtain and use local data on reproduction, survival, and/or dispersal in key places in the landscape to parameterize population models and assess population viability of the subset of species deemed most at risk.
4. Design and evaluate alternative management strategies for the species identified as most at risk and the landscape settings most important to these species.

We applied the method in the northwest portion of the GYE and identified 25 bird species with highest risk of local extinction. A draft management plan was proposed to maintain key habitats for these species.

Future land use will be projected using our transition probability-based Land Use/Cover Change Prediction System. The model is now being recoded to use several variables to predict land use/cover change. Examples of variables used include past land use/cover, nearest neighbor land use/cover, and distance from roads. Using this new approach allows more realistic predicted maps, because spatial relationships can be included in the extra information layers. Initial tests of the new approach show a reasonable match with actual transitions in a test area in Gallatin County.

We are quantifying relationships between agricultural land use and rural residential development to better parameterize the model. Predictor variables of conversion of

agricultural lands to rural residential development include agricultural productivity, enlistment in government programs, depth to water, land-owner age, and viewshed. This work will help us to understand the mechanisms that drive agricultural land use change. The results will be incorporated in the Land Use/Cover Prediction System.

Thus far we have mapped house locations using well-permit data for three sample areas in Gallatin County for the years 1972, 1978, 1984, 1990, 1996. Agricultural land uses are now being mapped from aerial photographs for these years. Agricultural productivity is being derived using the integral of annual NDVI values for each time period. The 1990 and 1996 maps have been completed to date.

Predictions on future land use change will be used in conjunction with Dynamic Habitat and Population Analysis (described above) to identify places in the study area of high biodiversity value that are at risk of future land use intensification.

Monitoring

Current work focuses on understanding trends and interactions in ecological and socioeconomic factors across the GYE. After this work is complete, we will develop methods to monitor key response variables at regular intervals in the future.

Outreach

Beyond developing new data and knowledge, this study will make these data available to environmental decision-makers and other stakeholders. Thus far we have sent letters to major land holders/managers in the GYE and issued a press release describing the study and inviting responses from the public. Additionally, we have presented the study in various scientific forums.

Conclusion

In summary, substantial progress has been made during the first 8 months of the study and we anticipate that the project will be highly successful.

Key Publications

Clawson, M.R., and J.J. Rotella. In Press. Success of artificial nests in CRP fields, native vegetation, and field borders in southwestern Montana. J. Field Ornith. 69.

Cohen, W.B. and M. Fiorella. 1998. Comparison of methods for detecting conifer forest change with Thematic Mapper imagery. In Remote Sensing Change Detection: Environmental Monitoring Methods and Applications, Lunetta, R.S. and C.D. Elvidge, eds. Ann Arbor Press, Chelsea, MI.

Cohen, W. B., M. Fiorella, E. Helmer, J. Gray, and K. Anderson. In Press. An efficient and accurate method for mapping forest clearcuts in the Pacific Northwest using Landsat imagery, Photogrammetric Engineering & Remote Sensing.

Hansen, A.J., and J.R. Rotella. In Press. Abiotic factors and biodiversity. In M. Hunter, ed. Managing Forests for Biodiversity. Cambridge University Press.

Hansen, A.J., J.R. Rotella, A. Gallant, D. Black. In Press. Natural and human drivers of biodiversity in the Greater Yellowstone Ecosystem. Pgs xx-xx in T. Sisk (ed.) Land use history of North America: Providing a context for understanding environmental change. Biological Resources Division, U.S. Geological Survey, Washington, D.C.

Hansen, A.J., J.R. Rotella, M.L. Kraska, D. Black. In Review. Dynamic habitat and population analysis: A filtering approach to resolve the biodiversity manager's dilemma. Ecological Applications.

Hansen, A.J., J.R. Rotella. In Review. Effects of fire suppression, logging, and rural residential development on bird communities in the Rocky Mountains. For R. Knight, ed. Forest Fragmentation in the Central Rocky Mountains. Island Press.

Rotella, J.R., E.M. Madden, and A.J. Hansen. In Press. Sampling considerations for estimating abundance of passerines in grasslands. In Ecology and Conservation of Grassland Birds in the Western Hemisphere (P. Vickery and J. Herkert, eds.). Studies in Avian Biology.