Developing Land Cover Scenarios in Metropolitan and Non-Metropolitan Michigan, USA: A Stochastic Simulation Approach

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Abstract

We proposed to develop a stochastic LCLUC modeling approach and apply it to both metropolitan and non-metropolitan counties in Michigan. During the past year we have made substantial progress in developing the multi-temporal Landsat TM/ETM+ data set required for the empirical work as well as significant progress in developing and implementing the proposed methodology. We have refined the methodology and presented results from a demonstration project. On completion of the land cover dataset in the coming year, we will pursue the empirical analysis of land cover changes across time and space and begin implementing the simulation approach to develop projections and evaluate the methodology.

Keywords

Research Field Keywords: Land Use Modeling, Urbanization, Change Detection

Geographic Area Keywords: North America, Temperate Forest

Remote Sensing Keywords: Landsat, Aerial Photography

Methods/Scales Keywords: GIS, Stochastic Processes

NASA ESE Scientific Questions

The work we are doing attempts to address each of the following NASA ESE research questions:
a) What are the changes in land cover and/or land use (monitoring/mapping activities)? Our work addresses this question by developing rigorous descriptions of the spatial locations and patterns of change over three-year intervals between 1984 and 1999 and compares the patterns of change between metropolitan and non-metropolitan areas in the State of Michigan, USA.
b) What are the causes of LCLUC? The descriptions provide a means to evaluate where changes are more likely and thereby develop specific hypotheses about the drivers of those changes. Our comparison between Southeastern and Northern Michigan seeks to understand the role of different kinds of development (e.g., urban sprawl vs. disperse rural development) on the spatial patterns of land use change and, as a consequence, on the fragmentation of the landscape.
c) What are the consequences of LCLUC? Our aim is to produce reasonable land cover scenarios. The reason for developing scenarios is to produce baseline land cover projections that can be used in models to evaluate the potential ecological impacts of those changes.

Proportion of Themes

Social Science: We estimate this to be about 50%. We draw on social science research, have a resource economist on the team, and engage social science principles in the interpretations.
Carbon: 25%, one of the consequences of change we seek to evaluate is on carbon storage
GOFC: 50%, our methods should be directly useful to the GOFC objectives and implementation.

Project Goals

1. *Develop a spatial database to represent land use change and land cover change in metro and non-metro areas of Michigan between 1984 and 2000.*
   - This objective is about 75% complete and on target for generation of land cover change database by Q1 2003 and land use change database by Q3 2003.
   - 30 Landsat TM scenes have been acquired, georeferenced, cloud-masked, haze-corrected, and radiometrically calibrated. Next steps are classification and accuracy assessment.
2. *Estimate the future shares for sample metro and non-metro counties in each of three major land use types--agriculture, forest, and development.*
   - This objective is planned for Q4 2002 and Q1 2003.
3. *Apply generalized additive models (GAM) to generate predictions of the probabilities of land cover change based on initial pattern of land cover and several socioeconomic and biophysical predictor variables.*
   - Methodology has been demonstrated. Analyses will continue through Q3 2003.
   - In a slight modification of the approach, we have focused on generating land cover projections directly, as opposed to modeling land use first, then land cover. The original proposed approach, though theoretically interesting, is likely not very practical.
4. *Develop land cover simulations conditioned on the countywide estimates of future land cover amounts, estimated land cover transition probabilities, and spatial patterns of change.*
   - Simulation methodology is developed and a substantial amount of the necessary computer programming is complete. Graphical user interface is planned for Q3 2003.
   - Application of the methodology is planned for Year 3 of the project (Q4 2003-Q3 2004).
5. *Evaluate the predictive ability of the simulation approach, and the adequacy of the resulting uncertainty estimates.*
   - This objective is planned for Year 3 of the project (Q4 2003-Q3 2004).

Progress of the Study

We have made significant progress in the development of the methodology outlined in the proposal. We have implemented the methodology (i.e., generalized additive models and geostatistical simulation) in a demonstration project that will be published this fall. This demonstration project has permitted us to refine the methods and outline future steps for the project.

We have refined several methodological issues. First, we have implemented the generalized additive model (GAM) method of estimating transition probabilities, to our knowledge the first example of such an application of this method. There is good reason to continue to use GAMs for this purpose, because of their interpretability relative to artificial neural networks (ANNs). We will therefore focus our methodology on GAMs. Second, in discussions with our economist collaborator, we have identified a more efficient methodology for developing land cover projections that are linked to socioeconomic models. Instead of modeling land use, then estimating land cover patterns from the land use projections, we will estimate county-wide land cover proportions directly using econometric methods. The econometric methods will be calibrated using the National Land Cover Dataset (NLCD) and will use population and economic projections to estimate future land cover proportions. Third, we have decided to make our land cover classifications as comparable with the NLCD classification as possible. This, we hope, will make our results more comparable and useful nationwide.

In addition to the objectives and timeline outlined on the previous, we will pursue several topics that are important to implementation of the simulation methodology. First, the simulation methodology is implemented in a Fortran program. We will work on developing a graphical interface for the program in VisualBasic or VisualC++. Second, we have identified error propagation as an important topic for further investigation. A PhD student working on the project will work on the dissertation that seeks to develop methods for accuracy assessment of an image time series. She will evaluate the patterns of spatial, temporal, and thematic dependence of error in both land cover classifications and change detection. This evaluation should have broader impact on the LCLUC community, as researchers seek to grapple with accuracy issues in multi-temporal image data sets.

Our most significant results to date are:

- New Findings - none to date
- New Potential - our methodology for developing land cover projections is outlined in an article to appear in the October 2002 issue (special issue on Characterizing Landscape Dynamics) of *Photogrammetric Engineering and Remote Sensing*. The methodology presents an approach to developing land cover projections that are more realistic with respect to the spatial patterns they produce. This method will permit evaluations of both the future amount, likely location and fragmentation of land cover. The latter (fragmentation) has not been permitted in previously developing land cover models, because they don't pay specific attention to the patterns of change.
- New Products - We will have new data sets and software, but these are not completed yet.

Conclusion

We are making reasonable progress towards the objectives of our project. The approach and methods of the project are basically intact, though some minor modifications have been made and noted above. We anticipate producing projections of land cover patterns that reproduce spatial patterns of change better than can be produced by other state-of-the-art methods. In addition to the projects and empirical analysis comparing patterns of change in Michigan, we expect the methods and software produced will be useful to the broader community. In addition to the issues described above, the project is having a significant educational impact. We have engaged two PhD students (Amy C. Burnicki, Natural Resources and Environment, and Meng-Ying Li, Civil and Environmental Engineering) who are working exclusively on this project and learning much about the remote sensing and land cover change science. It's likely that both will complete dissertations on work related to the project. Further we have employed about 4 undergraduate students to work on the project as independent research learning opportunities.

Publications

Brown, D.G., Goovaerts, P., Burnicki, A., Li, M.Y. 2002. Stochastic simulation of land-cover change using geostatistics and generalized additive models. *Photogrammetric Engineering and Remote Sensing*, 68(10).