# 11 Spatial decision support systems for assessing impacts of landscape change in greater ecosystems

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## Introduction

Economists consider natural landscapes in the Pacific Northwest to be more economically important in protecting water and air quality, recreational opportunities, scenic beauty, and fish and wildlife habitat than in supplying timber, food, fish, and minerals. A healthy environment is essential for a healthy economy, and the quality of the natural environment in the Pacific Northwest has tremendous economic value and is one of the driving forces behind increased employment, income, and industrial diversification (Pacific Northwest Economists 1995). Unsustainable use of natural landscapes is especially detrimental to the economies of greater ecosystems because of their heavy dependence on scenic attractions and outdoor recreation.

A major challenge facing land managers and planners in greater ecosystems is to distinguish between the impacts of natural and human-caused disturbances. Natural forces, such as fire, windstorms, avalanches, landslides, tree fall, floods, insect epidemics, and climate variability, strongly influence and shape ecological processes. Human activities have three major types of global impacts on the biological productivity and ecological integrity of landscapes: raising concentrations of carbon dioxide in the atmosphere due to the burning of fossil fuels, increasing fixation of nitrogen through the production of industrial fertilizer, and changing land use and land cover (Hansson and Wachernagel 1999). There is general agreement that human-induced land-use/cover changes have the most significant impact on ecosystems (IIASA 1998; Mac et al. 1998; Vitousek 1994). Some of the most adverse impacts of land-use changes stem from urbanization, conversion of lands to agriculture, drainage of wetlands, and fragmentation of forests (Mac et al. 1998). Specifically, changes in land use have a strong and dominant influence on spatial and temporal changes in the structure and functioning of ecosystems (Vitousek et al. 1997).

This paper discusses how geospatial analytical techniques (remote sensing, GIS, and GPS) can be used to develop a spatial decision support system (SDSS) that allows protected area managers, resource management agencies, regional planners, and stakeholders to predict regional changes in land-use/cover and landscape structure, and their impacts on ecological integrity and economic activity. The SDSS integrates three elements: a) an ecosystem-wide regional assessment of land-use/cover changes, b) a functional model that predicts regional landscape changes in response to biophysical and economic drivers, and c) regional impacts of predicted landscape changes on ecological integrity and economic activity.

## Regional land-use/cover changes

Regional assessment of landscape changes is evaluated in three steps. In the first, past and current land cover maps are generated for the entire ecosystem using Landsat TM triplicates for the 1980s, 1990s and 2001. In the second step, a land management zone map is created by combining GIS layers for hypsography, geographic features, administrative boundaries, existing road networks and land ownership, a land cover map created using the triplicate scenes, and management objectives for

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different land areas. Land management zones are the geographic units for predicting landscape changes. Three primary management objectives are used to delineate land management zones, namely, protection, resource management, and development. Protected zones include national parks, wilderness areas, and wildlife refuges. Resource management zones include special-use, general recreation, and multiple-use areas. National forests are an example of a multiple-use area. Development zones are devoted to residential, commercial, and industrial uses.

In the third step, landscape change patterns over time are quantified based on landscape structure attributes, such as fragmentation, aerial extent, patchiness, patch density, interspersion, juxtaposition, and others for each land management zone using FRAGSTATS software (McGarigal and Marks 1995). Finally, landscape changes between years are used to estimate transition probabilities for conversion of land from one land-use/cover class to another in each land management zone (Baker 1989; Hall et al. 1988; Luque et al. 2000).

## Functional landscape model

The functional landscape model explains how economic development affects land use and economic activity and how land-use changes affect landscape structure and ecological integrity. The functional landscape model consists of an economic projection sub-model and a landscape change prediction sub-model.

***Economic projection sub-model.*** The economic projection sub-model determines how changes in final demand alter gross output, income, employment, and population. Final demand is the sum of personal consumption expenditure, investment expenditure, government expenditure, and net exports (exports minus imports). Increases in final demands are serviced in two ways. First, goods and services flow into the local economy from other regions. The flow of money generated in this manner constitutes the export sector. Second, increases in final demands are serviced by production of goods and services within the geographic boundaries of the local economy for local consumers, such as individuals, households, businesses, and government. The flow of money generated by local economic activities denotes the secondary sector (Summers and Field 2000). Growth in export and secondary sectors increases residential and commercial development, production of food and fiber, government facilities and services, transportation networks, and community infrastructure, which in turn increases the demand for land. Growth in final demand causes changes in land-use/cover and conversions of land from one use or cover type to another. Gross economic output, personal income, and total employment for each county in a greater ecosystem are determined using the Impact Modeling for Planning (IMPLAN) models for the counties that constitute the ecosystem (Lindall and Olson 1993).

Total land required to support projected or scenario-based increases in final demand are determined for the years 2010, 2020, and 2030 in each of the counties that constitute the greater ecosystem. Specifically, estimated final demand is multiplied by the amount of land required per $1,000 of final demand to obtain projected land-use requirements for each sector in a county. Land-use requirements per $1,000 of final demand for a sector are estimated by dividing the amount of land used by that sector determined from the 2001 TM image and 2000 census data by the gross economic output of that sector estimated from the IMPLAN model. Land-use requirements by sector and county are used in the landscape change prediction sub-model.

***Landscape change prediction sub-model.*** The landscape change prediction sub-model involves two processes. In the first, the following spatially dependent transition probabilities are used to determine the most likely land-use changes within each land management zone in the ecosystem:

$$f_{xyt+1} = P_{xyt} f_{xyt}$$

where $f_{xyt+1}$ and $f_{xyt}$ are vectors of fractions of location x,y in particular land-use/cover classes at time t+1 and t, respectively, and $P_{xyt}$ is a local transition probability matrix for conversion between land-use/cover classes in location x,y at time t. The most likely land-use changes within land management zones in a county are determined by combining the average transition probabilities for a land management zone with the county land-use requirements determined using the economic projection sub-model.

In the second process, converted lands are spatially allocated within each land management zone using a best-process technique or prescriptive technique. The best-process technique uses the local transition probabilities to identify areas with the highest probability of conversion. For example, if 20 acres of a zone are converted to a particular land use, then cells with the highest local transition probabilities for conversion to that use are selected until the 20-acre requirement is achieved. The prescriptive technique determines the spatial pattern of land changes in a land management zone using a multiple-criteria utility function (Prato 1999). The spatial allocation giving the highest utility score is selected.

### Ecological impacts of predicted landscape changes

Regional ecological impacts of predicted changes in land-use/cover are evaluated using two types of landscape structure metrics: a) the frequency of object (patch) characteristics, such as the number of patches in a specific size class and diversity of patch types, and b) the spatial relationship between different objects, such as inter-patch distance (Griffiths et al. 1993). These metrics influence species diversity and abundance and other measures of ecological integrity and biological diversity. Landscape structure metrics include: patch number size, shape, and perimeter, patch size coefficient of variation, isolation, connectivity, relative richness, relative evenness, relative patchiness, matrix porosity, diversity, dominance, fractal dimension, nearest neighbor probability, contagion, edges, and vegetative cover (Forman and Godron 1986; Turner 1989).

### Economic impact assessment

County-level economic impacts are determined by substituting the projected or scenario-based increases in final demands for 2010, 2020, and 2030 into the IMPLAN models for the counties that constitute the ecosystem. Economic impacts are measured in terms of county-level gross output, personal income, and employment. Regional-scale economic impacts are determined by summing county-level impacts.

### Integration with SDSS

An SDSS offers new insights into the structure of spatial decision problems by helping users generate new alternatives and strategies in a problem-solving process (Wherrett 1996). The TM images, historical changes in land-use/cover based on those images, the landscape change prediction sub-model, the economic projection sub-model, landscape structure metrics, and supporting databases are integrated into an Internet-based SDSS. Design and development of the SDSS utilizes client server transactions wherein the client (user) makes a request to the server and the server gives the results back to the client (Harder 1998). This task is accomplished using various software, including ArcView GIS and Internet Map Server (ArcView IMS or ArcIMS), the ArcView Image Analysis (AIA) extension, Java, JavaScript, HTML, and Avenue programming.

The SDSS allows protected area managers, land-use planners/managers, stakeholders, and policy-makers to: a) evaluate the ecological and economic impacts of predicted landscape changes, b) determine tradeoffs between economic and environmental impacts, and c) evaluate the effectiveness of alternative land-use policies and conservation strategies in alleviating undesirable ecological impacts of predicted landscape changes. In particular, the SDSS allows users to evaluate policies and strategies such as land donations, land exchanges, conservation easements, land-use restrictions, and others (Brown 1999). The SDSS can be used to compare the ecological and economic impacts of alternative policies and strategies.

## Conclusions

Human-induced changes in land use and land cover often have significant ecological and economic impacts that are especially acute in ecologically sensitive greater ecosystems experiencing rapid economic development. Rapid advancements in geospatial analytical techniques (remote sensing, GIS, and GPS) make it possible to develop SDSSs that allow protected area managers, resource management agencies, regional planners, and stakeholders to predict regional changes in land-use/cover and landscape structure, and their impacts on ecological integrity and economic activity. An SDSS is proposed that integrates an ecosystem-wide assessment of land-use/cover changes, a functional model that predicts landscape changes in response to biophysical and economic drivers, and an assessment of predicted landscape changes on ecological integrity and economic activity. The SDSS incorporates TM images, historical changes in land-use/cover based on those images, a landscape change prediction sub-model, an economic projection sub-model, landscape structure metrics, and supporting databases. The SDSS allows protected area managers and others to evaluate the ecological and economic impacts of predicted landscape changes, determine tradeoffs between economic and environmental impacts, and evaluate the extent to which alternative land-use policies and conservation strategies alleviate undesirable impacts of future landscape changes in greater ecosystems.

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