METHODS FOR PROJECTING LARGE-SCALE AREA CHANGES FOR U.S. LAND USES AND LAND COVERS: THE PAST AND THE FUTURE

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ABSTRACT

Over the past 25 years, renewable resource assessments have addressed demand, supply, and inventory of various renewable resources in increasingly sophisticated fashion, including simulation and optimization analyses of area changes in land uses (e.g., urbanization) and land covers (e.g., plantations vs. naturally regenerated forests). This synthesis reviews related research over the more than two decades since area projection modeling systems replaced expert opinion approaches in the national Resources Planning Act (RPA) assessments, as part of state of the art approaches for regional and national resources assessments. Such models reflect that key land base changes such as afforestation and deforestation are driven by quite different socio-economic factors. Projections of area changes are important for a wide range of natural resource analyses, including those for wildlife habitat, timber supply, global climate change, water, recreation, and others. The demand for applications in global change analyses has increased recently, and the synthesis addresses information needs in such macro assessments. Significant challenges in the research area in general include systematic integration of approaches and therefore findings across resource areas to support sustainability analyses. Another challenge is a unified view of future forest conditions constructed at a scale that serves all of these uses adequately.

INTRODUCTION

Over the past 25 years, renewable resource assessments have addressed demand, supply, and inventory of various resources at large spatial and over long temporal scales in increasingly sophisticated fashion, including simulation and optimization analyses of area changes in land uses (e.g., conversion of forests to agriculture or developed uses) and land covers (e.g., plantations vs. naturally regenerated forests). This synthesis reviews related research over the last quarter century since area projection modeling systems replaced expert opinion approaches in the national Resources Planning Act (RPA) assessments (e.g., Alig and Butler 2004, Alig and others 2003a).

It is important upfront to define what policy-relevant questions that land use and land cover research have been designed to answer, given the many demands for information about the current and future land base. The core research described here was designed to support periodic U.S. natural resource assessments mandated by the national Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974, to support USDA Forest Service strategic planning and policy analyses. The RPA act requires that decadal national assessments, with mid-decade updates, include an analysis of present and anticipated uses; demand for and supply of the renewable resources of forest, range, and other associated lands; and an emphasis on pertinent supply, demand, and price relationship trends. Land use and land cover changes have important consequences for the future availability of timber, wildlife habitat, and other renewable resources and, therefore, are a critical component of this analysis.

The RPA act clearly defines the national assessment as a forward-looking exercise in examining resource conditions and services. The first RPA Assessment was carried out quickly around 1975 in response to the 1974 RPA

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legislation. Over the past 25 years, assessment efforts have addressed demand, supply, and inventory of various renewable resources in increasingly sophisticated fashion. Methods developed through the RPA in many areas define the state of the art approaches for regional and national resources assessments. One area that remains a significant challenge in the field in general is the systematic integration of approaches and therefore findings across RPA resource areas.

The 2000 RPA assessment is the most recent one and the context has broadened over time (USDA Forest Service 2001). Interest in sustainable management of the world's forest resources was heightened by the United Nations Conference on Environment and Development in 1992. Since that time, various countries have joined together to discuss and attempt to reach consensus on ways to evaluate progress toward the management of their forest resources. The United States participates in the Montreal Process, designed to use a set of criteria and indicators for the conservation and sustainable management of temperate and boreal forests. The criteria provide a common framework for describing, assessing, and evaluating a country's progress toward forest sustainability at the national level. The 2000 RPA assessment provides a broad array of information about the Nation's forests and rangelands, including the current situation and prospective area changes over the next 50 years. Such information can help shape perceptions about whether we can sustain both increasing consumption of forest products and forest resource conditions (Alig and Haynes 2002). Related data illustrate the dynamics of our Nation's land base, and how adjustments are likely to continue in the future. The projections of land use and forest cover changes also provide inputs into a larger system of models that project timber resource conditions and harvests, wildlife habitat, and other natural resource conditions (USDA Forest Service 2001). Current debates about sustainability involve both physical notions of sustainability and competing socioeconomic goals for public and private land management. The land-base changes also indicate the importance of viewing "sustainability" across the entire land base and across sectors, in contrast to the current typical sector approach, as in examining "sustainable forest management" (Alig and Haynes 2002).

This paper focuses on land use changes that involve forestry. Land use is the purpose to which land is put by humans, e.g., protected areas, forestry for timber products, plantations, row-crop agriculture, pastures, or human settlements. Land cover is the observed (bio)physical cover on the Earth's surface, e.g., oak-hickory forest.

REVIEW OF MODELS

Over the last 25 years, land use projections at large scales for RPA assessments have moved from an expert opinion basis (e.g., Wall 1981) to systematic models. Substantial population growth in the United States has been associated with an increase in the rate of conversion of forest and agricultural lands to residential, commercial, and industrial uses (Alig and others 1983, USDA SCS 1989, USDA NRCS 2001), increasing the importance of models that can aid in assessing future land use scenarios. An example of an improvement introduced by systematic approaches was the elimination of possible double accounting of land use changes when projections were done by sector (e.g., agriculture). With a total land base perspective and zero-sum constraints built in, systematic approaches ensured that land base totals would sum appropriately across sectors.

Availability of additional quantities and types of data was a major contributor to the expanded number of models developed over the last 25 years. A major boost was broad coverage in data collection by the Natural Resources Inventory (NRI) (e.g., USDA NRCS 2001) that provided a national snapshot of land use for a particular year. This was in contrast to the periodic forest inventories by state staggered across time in Forest Inventory and Analysis forest inventories (e.g., Rosson 2001). The NRI covers the entire nonfederal land base, with major land uses classified as cropland, pastureland, forest land, and urban and developed.

I next look at three classes of land use models that utilized NRI and other types of land use data. This review supplements and updates earlier ones by Alig and others (1984) and Parks and Alig (1988).

Classes of Land Use Models

Land use models characterize human and natural influences on landscapes. Theoretical land use models are derived from rules that are assumed to govern human and natural processes. Typically profit-maximization is assumed as the goal of forest and agricultural commodity production. Theoretical models explore the types of land-use patterns that emerge from given sets of behavioral assumptions. Empirical land-use models can provide a test of theoretical models, using real world data to quantify model parameters and see how consistent they are with underlying hypothesized behavioral relationships. Empirical models can be used to predict how land use will change in response to changes in economic conditions and policies. Three basic types of empirical land-use models are econometric, mathematical programming, and simulation, each varying in their relative strengths and spatial and temporal scales.

Econometric Models—Econometric land use models are based on statistical methods that are used to quantify relationships between land uses and hypothesized determinants. Landowners' profit maximization typically is the theoretical basis for these models--landowners are assumed to allocate land parcels to that use generating the highest land rent or present value of future profits. Models are estimated with data describing land use decisions and profits derived from alternative land uses. Additional variables may be included to control for land-use regulations and other factors that influence land use decisions. For example, land-use policies often are used to mitigate potential negative impacts of urbanization. Econometric land use models typically are estimated with sample plot data comprised of a random sample of parcels or aggregate data such as county-level observations of land use (e.g., Alig 1986, Plantinga 1996, Wear and others 1996, Hardie and Parks 1997, Kline and Alig 1999, Ahn and others 2000, Kline and Alig 2001). With the advent of satellite imagery and geographical information systems (GIS), econometric land-use models have been estimated using spatially-referenced plot or parcel-level data (e.g., Bockstael 1996, Wear and Bolstad 1998, Irwin and Geoghegan 2001, Kline and others 2001). Examples of explanatory variables in such models are rents (or proxies) for forestry, agriculture, and urban/developed uses.

The principal advantage of econometric land use models over other approaches is that they are based on the observed or revealed landowner behavior (e.g., Stavins 1999). In particular, they measure how landowners actually respond to observed changes in economic and other decision variables. Econometric models may capture the combined influence of several factors motivating land use decisions that may otherwise be difficult to describe in an explicit way. Because econometric models can be estimated with highly disaggregated data, such as plot or county data, they can generate land use projections at correspondingly fine spatial scales. Although estimation based on historical data is the strength of econometric models, it is also a weakness. Econometric models may not always yield accurate predictions outside observed historical ranges. For example, it may be difficult to use econometric models to predict consequences of a major land use policy change not within the bounds of historical data. In addition, factors influencing land use decisions that cannot be explicitly controlled for in the model estimation will be carried along in predictions of future land use changes.

Findings from econometric studies indicate that drivers for deforestation differ notably for those of afforestation and reforestation activities. Major determinants for deforestation associated with conversion to urban and developed uses in the United States are population and personal income levels. The rate and extent of urbanization are typically governed by such determinants that shift demand for urban and developed uses. Revealed behavior by landowners indicates that values for developed uses (e.g., deforestation for residential purposes) generally dominate those for rural uses such as forestry and agriculture (Alig and others 2004). Within the rural land base, relative land rents between forestry and agriculture affect deforestation (i.e., forest converted to agriculture), afforestation, and reforestation decisions. The significance of these findings for RPA Assessment and global climate change analyses is that policy deliberations recognize that the growth in developed area is not likely to be arrested, but rather may be diverted or relocated by policies offering preferential tax assessment or other traditional programs.

Implications regarding future policy deliberations about afforestation programs include focusing on incomes for rural land enterprises. A series of econometric studies offer insights about determinants of afforestation (e.g., Plantinga and others 1999) and reforestation activities (e.g., Alig and others 1990, Kline and others 2002).

Most econometric models of land use developed to date have been regional in nature, although Lubowski (2002) recently developed a national land use model. His work takes advantage of transition rates among major land uses, as identified by the NRI survey (USDA NRCS 2001). Modeling transitions among land uses, in contrast to net area changes, enhances analysis of land-based policies that can cause ripple effects across major uses. For example, Lubowski (2002) finds that rising government subsidies for agricultural crops restrained an increase in forest area in the Mississippi Delta area by 10% from 1982 to 1997. This approach is being tested in the 2005 RPA Assessment Update.

Mathematical Programming Models—Mathematical programming models of land-based economic sectors are a second land-use modeling approach. Mathematical programming describes land use allocations using numerical optimizing techniques to find the multi-market price and quantity vectors that either maximize or minimize the value of an objective function, resulting in an optimal land use allocation (e.g., USDA SCS 1989, Adams and others 1996, Alig and others 1998). Maximization or minimization of the objective function can be subject to sets of constraints that characterize the resource commodity production over time, initial land and resource conditions, availability of fixed resources, such as land, and policy constraints. Land is modeled as an input resource that moves among different sectors depending on relative land rents, in an optimization, as contrasted to a positivistic approach (Alig and others 1984). This allows "what if" questions with respect to optimal land allocation to be investigated, based on selected or prescribed objective functions such as economic efficiency. Dynamic economic behavior pertaining to land use is investigated using intertemporal optimization by mathematical programming models (e.g., Alig and others 1998).

Advantages of the mathematical programming approach include its theoretical basis of market equilibrium, whereas econometric models can sometimes suffer from incorrect specifications of economic variables or omitted variables where data are not available to fully represent theoretical constructs. Mathematical programming models are better able to handle economic conditions outside of historical ranges, which facilitate evaluating new policies. However, such models may also be limited by data unavailability that affects representation of responses to policies. Programming models can incorporate a wealth of physical structural detail, which is important when physical structure strongly influences the behavioral response, such as existing forest age class structure and timber harvest behavior. Disadvantages of mathematical programming land use models are their high level of spatial aggregation, behavioral relationships are determined to a greater extent by the researcher, either based on assumed or revealed behavior, and greater difficulty in calibrating to recent historical trends where appropriate. Programming models based on intertemporal optimization also are less able to incorporate feedback effects due to biophysical processes and explicitly account for the spatial distribution of decision variables. However, the latter limitation can also apply to econometric models in some broad-scale applications.

Other Simulation Models—Another spatially explicit land use modeling approach is to simulate land use change using spatial land use data and sets of decision rules. For example, several studies have combined cellular automata models and spatial land-use data (e.g., Clarke and Gaydos 1998, Wu 1998, Webster and Wu 1999a,b). Cellular automata models generally consist of an action space, a set of initial conditions, and a set of behavioral rules. In land use modeling, the action space is a grid of cells where the state of each cell is one of a finite number of land uses, initial conditions are land uses described by a GIS base land-use layer, to which are applied decision rules that specify how land uses change over time. Decision rules typically are conditional on the initial land use as well as the land uses of surrounding cells.

Wu (1998) develops a cellular automata model of the transition from undeveloped to developed land in a province in China. At each time step in the simulation, a development suitability index is computed for each undeveloped cell. The index is a weighted average of distances to urban features such as transportation hubs and the degree of development in the neighborhood of the cell. Based on their suitability for development, cells are converted until an aggregate (and exogenous) "demand" is satisfied. Using a related approach, Landis (1995) simulated land development in the San Francisco Bay Area. The spatial unit of analysis is a Developable Land Unit—a polygon construct with similar environmental (e.g., slope) and policy (e.g., zoning) attributes. Developable land units are identified through the overlay of the corresponding GIS layers. Each undeveloped unit is scored according to its profitability for development, taking into account location-specific home sales prices and construction costs. As in Wu (1998), developable land units are "converted" according to profitability given exogenous demands for developed land.

The advantage of simulation methods is that they can provide very detailed information about spatial patterns of land use change and are very flexible with regard to the types of rules that govern change. Although decision rules adopted in some studies seem somewhat arbitrary, it is possible to specify rules consistent with empirical evidence. For example, an updated version of the Landis (1995) model incorporates a statistical model of urban land use change (Landis and Zhang 1998). Another example is the transition-based model by Theobald and Hobbs (1998), employing a single-step Markov transition function. This is in contrast to regression-based approaches that are used to understand underlying historical relationships. The principal drawbacks of simulation models relate to their data and computational requirements. These models have mostly been developed for individual urbanized areas. Such an approach is needed for modeling land use change in urban areas due to the importance of location and existing land use zoning in determining land development. When considering changes in the rural landscape, it may make sense to sacrifice spatial detail for broader regional coverage. This is particularly the case with econometric modeling since many important economic factors, such as prices, often exhibit little spatial variation.

Increasing Use of Spatial Analyses

With the increased interest in land use modeling, the geographic scales at which investigators have been working have expanded in both directions. More ecological assessments at finer scales have increased demand for land use and land cover projections that are spatially explicit, including investigations of forest fragmentation (e.g., Butler and others 2004) and ownership parcelization, i.e., an ownership is subdivided into one or more ownerships. Spatial modeling is growing in its use and application in the natural resources because natural resource processes are spatially linked. Economists increasingly face opportunities to collaborate with ecologists and other scientists in multi-disciplinary research involving landscape-level analyses of socio-economic and ecological processes.

Spatial statistics investigates the relationship between a subject of interest and the subjects around it to determine if they are more related to each other than to other subjects that are farther removed. Using remotely sensed data can involve some degree of dependency between pixels, most likely in the form of positive spatial autocorrelation. Such dependence has potentially a dual impact on the analysis of image data. It can be a source of nuisance and error, when traditional statistical techniques involving assumption of independence of sampling units are applied. On the other hand, it can represent valuable information, which may be exploited as an image characteristic. Diffusion of recent advances in GIS technology and modeling/simulation tools has increased the application of quantitative techniques in investigating land use and land cover changes. Changes in land use and land cover can result from the interplay of complex factors; some causative factors (e.g., land owner characteristics) cannot be measured cost-effectively over large areas; and sophisticated techniques of data manipulation do not offset the adverse effects of unreliable input data. Quality of basic data remains an issue, possibly affecting reliability of modeled predictions.

Spatial land use models based on econometric estimation can be viewed as extensions of area-base models first developed by economists about two decades ago (e.g., Alig 1986, Hardie and Parks 1997, Kline 2003). Area-base models describe proportions or shares of land in forest agriculture, urban, or other discrete use categories, within well defined geographic areas (e.g., counties).

The need to consider spatial relationships has grown with increased populations across regional and national landscapes. An example is the hypothesis that increasing population density in forested areas will cause changes in timber management, including likelihood of timber harvest. More people in the woods will also affect fire suppression efforts and costs. Private forestlands in the United States face increasing pressures from growing populations, resulting in greater numbers of people living in closer proximity to forests. What often is called the forest/urban interface is characterized by expansion of residential and other developed land uses onto forested landscapes in a manner that threatens forestlands as productive socioeconomic and ecological resources. Prevailing hypotheses suggest that such forestlands can become less productive, because forest owners reduce investments in forest management. Kline and others (2003) developed empirical models describing harvest, thinning, tree planting, and forest stocking in western Oregon, as functions of stand and site characteristics, ownership, and building densities. They use the models to examine the potential impacts of population growth and urban expansion, as described by increasing building densities, on the likelihood that forest owners harvest, pre-commercial thin, plant trees following harvest, and maintain forest stocking. Empirical results support the general conclusion that population growth and urban expansion are correlated with reduced forest management and investment on private forestlands in western Oregon. Results have potential implications for both economic outputs and ecological conditions, as well as for wildfire risks at the forest/urban interface.

LINKAGES TO OTHER MODELS IN RESOURCE ASSESSMENTS

Land use models have increasingly been linked to other models in order to extend the power of both types of models. In the RPA context, the shift to land use models from expert opinion approaches started around the time that timber supply and demand "gap" models were being replaced in the early 1980s by equilibrium models. Feedbacks among assessment models are important in that changes in land uses and land covers affect the condition and characterizations of future forests, which in turn influence timber market conditions. Projections of market conditions from supply and demand models feed back into the area change models, as timber prices from equilibrium models from the timber assessment are one input into the RPA land use models (Alig and Butler 2004, Haynes 2003). In general, RPA specialists have a long history of exploring linkages among models for different resource areas (Joyce and others 1986).

In the timber supply case, Alig and others (1984) described potential linkages among models used to represent the following activities: land allocation, timber growth and yield, timber harvest, and timber investment. In recent years, additional modeling components have been added to model forest carbon, biodiversity, wildlife habitat, and other forest-based goods and services. Linkages reflect both spatial (e.g., interregional shifts in timber production) as well as temporal changes. Examples of other linkages to address in future work include land allocation decisions in a particular region that leads to impacts in other regions or nations, affecting timber harvest decisions in other countries. In view of timber imports into the United States, this requires a broad view of sustainability in a multi-national context.

In addressing problems with complex biophysical, ecological, and economic aspects, testing linkages among modeling components is critical. Sensitivity analyses can reveal critical linkages and information gaps and need for feedback loops. The holistic approach, with land use and land cover changes as components, will vary depending on the composition of the portfolio of policy-relevant questions to be addressed. Data availability and accuracy are prime concerns in such complex modeling, and monitoring of land use and land cover at relatively frequent intervals is warranted. An example is monitoring any migration of tree species over space and time due to global climate change, for use in land cover modeling.

PROPOSED NEXT-GENERATION MODELS

To help improve analyses in future RPA Assessments and global change assessments, I propose assessment modules to explicitly project the condition of land in the United States (Alig and Wear 2003) (figure 1). This is at the core of what the national RPA Assessment seeks to accomplish. Characterizations of the future land base, including forest and aquatic ecosystems, are required to conduct all supply and demand analysis. For example, the timber assessment projects changes in timberland area and forest cover types, along with age class distributions and other vegetation information, in order to project growth and yield and the market-clearing outputs and prices for timber products. Examples of specific land condition attributes are plantations versus naturally regenerated forests, old versus young forests, and interior versus fragmented forests. The public has a direct interest in how forest conditions in their respective regions might change in the future. For example, public concerns in response to the Southern Forest Resource Assessment (Wear and Greis 2002) were largely focused on the anticipated future condition of forests—e.g., plantations vs. naturally regenerated forests.

In addition to information needs in the timber assessment, the wildlife assessment relies on projections of forest area, configuration, and condition. Salmon restoration analyses require information on what is happening on the entire land base, including urban areas where human activities may impact aquatic systems (e.g., fertilizer leakage into streams). Similar data needs characterize assessment activities in the areas of global climate change, water, and

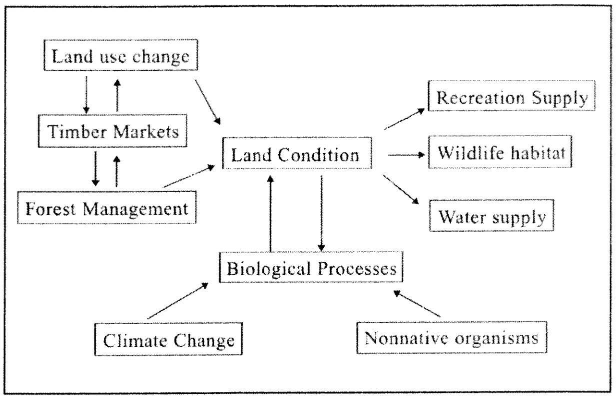

Figure 1—Schematic depicting conceptual framework for land condition projection system.

recreation. Characterization of land condition will depend on a comprehensive information needs assessment for applications such as in the national RPA Assessments, related global climate change assessments, and the U.S. Climate Change Science Program's plan (in process) for land use and land cover research. Figure 1 largely represents current RPA linkages involving land use and land cover modeling and opportunities exist to build in other two-way flows of information between resource areas, such as wildlife management that could influence vegetation management.

A primary need in global change assessments is to test models of drivers in land use and use them for projections of land condition. Analysts working on global change have a large body of land use theory, models, and empirical results to draw upon from applications in other areas of inquiry (e.g., RPA Assessment land use and land cover analyses). They can also draw upon both econometric models of revealed behavior, as well as optimization models (e.g., Adams and others 1996). Use of both modeling types can be designed to be complementary, and can address questions regarding land resource allocation and potential for reallocation. In the global climate change context, modelers are closer to dealing with a closed system, but face significant data gaps, such as consistent and comprehensive time series of consistent land use and land cover data.

One complication in past RPA assessments and global climate change assessments has been the lack of a unified view of future land conditions constructed at a scale that serves all of these assessment areas adequately. Attaining the ideal unification is a substantial undertaking, and this could be aided upfront by an assessment of common information needs. An example of a possible case study in the land condition context would focus on methodologies that model the evolution of land base conditions at the FIA plot level, and then scale to aggregate levels using plot expansion factors (Prestemon and Wear 2000). Such analyses could be updated on an annual basis as the continuous FIA inventory is implemented. Access to plot locations would be a critical element for the work to proceed along this track. Modeling at more aggregate levels will also be considered, as land markets are effectively analyzed at large enough scales where prices are formed. Sufficiently large scales are also necessary for addressing certain policy-relevant questions, such as whether land allocation in one region or country leads to increased timber imports from other regions or countries, e.g., land set asides for spotted owl and increased timber imports from Canada (Wear and Murray 2003). Micro- and macro-scale analyses can be linked, such as having city-scale or subregional analyses tied to larger scale regional or national studies.

A modeling system that can generate land base condition projections could provide for forest ecosystems a thorough and unified description of anticipated change in the extent, structure, and condition of the nation's forests at useful regional and subregional scales. At the same time, such a system could augment economic measures, useful when investigating changes in land markets and analyzing trends in land values. Land prices embody information on relative valuations by different sectors of the economy. For example, valuation of land currently in forest and agricultural uses in some areas is strongly influenced by trends in developed areas (e.g., Shi and others 1997).

Global Change Assessments

Improvements for global climate change analyses will require enhancements in climate change projections, production function information and ecological translations of climate-change effects, land owner behavior modeling, and socio-economic effect determination (e.g., equity). Key feedbacks also warrant more attention, such as between land use changes and climate change impacts. Uncertainty in projecting climate change impacts on land use and land cover include any carbon dioxide fertilization impact, interactions with air pollution on productivity under climate change, and impacts of climate change on abiotic and biotic disturbances (e.g., extreme events, insects, disease, fire regimes). Several studies have employed linkage of different modeling systems to investigate how changes in forest productivity may translate into impacts in the forest sector under climate change (e.g., Joyce and others 1995, Alig and others 2002). A key information gap appears to be empirical estimates of production function changes, including any migration of tree species. Sensitivity analyses in a systems analysis approach can aid in determining critical components, and linkages among those components (Sohngen and Alig 2000).

In reality, land use choices often involve a complex interaction of factors, including the initial land endowment of the owner, landowner characteristics, institutional influences (e.g., local zoning), and the economic and policy context in which the land use choices are made. Changes in the area of any of the major land use classes relate to demographic, economic, biophysical, and policy factors (Alig 1986), so that the suite of factors need to be considered in global climate change assessments. Projections of forest-land and timberland areas are based on projections of relevant demographic and economic factors, which are more likely to change in the future than biophysical factors. Current policies can be frozen in place in an initial conditions run or baseline, so that we can examine where the current policy trajectory (e.g., no U.S. action or implementation of policy for mitigating climate change) would lead, and then examine sensitivity of projections to certain policy-related assumptions.

Risk and uncertainty considerations include changes in technology. Impacts from global warming in some cases may be partially offset by technological changes, such as genetic stock improvements to boost forest carbon sequestration efforts. Other technological changes may also allow more output from input of land, especially in regional climates favorably affected regarding crop or forest production. The net outcome can not be easily forecast. Some scenarios may arise where forest use might be better able to compete with other major rural land uses, such as agriculture (e.g., Alig and others 2002).

Land use models based on historical data will not be as well suited to simulate global climate change as mathematical programming models if future events are outside the range of historical data. Changes in productivity for crops and forests may change slowly, although some hypothesize certain thresholds beyond which actions may accelerate. Global climate change will also affect the relative risk of land-based enterprises, given uncertainty of the magnitude, duration, and deleterious nature of such events.

Multidisciplinary research increasingly has striven to examine the impacts of land use and land cover changes on ecological conditions and processes brought about by timber harvesting, land use change, or other human-caused disturbances. However, these efforts can be costly and time-consuming. Planning upfront is critical for effectively augmenting land use and land cover analyses in both the general RPA and specific global climate change applications. A streamlined and relatively inexpensive approach enabling managers and policymakers to anticipate, describe, and plan for potential land use impacts on habitat and other goods and services is desirable.

Land Cover Monitoring and Projections

Another key part of land base changes is changes in major forest cover types. Although detailed discussion of them is outside the scope of this paper, I will describe some examples of modeling issues for land cover monitoring and modeling. Analogous to the snapshot of land-use information by USDA's NRI, land cover modeling would benefit from periodic nationwide estimates of changes in forest cover. A start down that path is the National Land Cover Data mapping project (an output of the Multi-Resolution Land Characteristics Consortium). This project will produce an updated version of the National Land Cover map for the year 2002, providing the means to conduct multi-temporal analysis.

A key goal of any forest cover monitoring program is to understand the processes affecting changes in forest cover. This would enable projections about future trends in forest cover and tie them to the local demands, forest investment (e.g., Alig and others 2003b), timber trade, and global issues of concern such as global change and biodiversity. The availability of modern technology of remote sensing and GIS makes this task feasible. The models should include the spatial component of the landscape and human activities. These new GIS data layers could be combined in models to obtain various indices that most likely influence or are influenced by human use of the land such as: (1) bio-physical and climatic factors, (2) fragmentation indices (e.g., perimeter/area ratios of forest area), (3) transportation networks (e.g., roads, rivers, railways), (4) population density and its rate of growth, and (5) socio-economic and political factors (e.g., land tenure, market availability, GNP/capita).

Sustainability Assessments

Many users and interests rely on the common land base, and myriad questions are asked about land conditions and sustainability prospects. Numerous approaches have been developed to address such questions, and land use planners, geographers, natural resource managers, and others have other information needs at spatial and temporal scales other than the primary ones for RPA and global climate change assessments. However, large-scale assessments provide a context for smaller scale inquiries, and aid in addressing policy-relevant questions. Other papers at this symposium pertain to smaller scale inquiries on the common land base. Regardless of scale, studies need to work toward common assumptions (e.g., population growth), consistent definitions, and sufficient use of statistical guides. Studies at different scales can inform each other, and this prospect can be enhanced if standard protocols are in place.

The common land base is competed for by different sectors of the economy, thereby complicating efforts to view sustainability from a single sector, such as "forest sustainability." A broad view could foster resolution of important forest and rangeland health issues through design of integrated decision systems that involve ecological, political, economic, and institutional factors. Focal areas include ecological risk assessment, socio-economic modeling, and policy/decision analysis–particularly as they relate to forest and rangeland productivity, fish and wildlife habitat, and human communities. Crucial to this endeavor is the ability to bridge multiple disciplines, recognize multiple values, and analytically evaluate risks and tradeoffs associated with various scenarios for improving the health of forests, rangelands, and related natural resources. The ability to articulate prospective outcomes for both short- and long-term time frames to policy makers and resource managers is also pivotal.

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