Using Basic Geographic Information Systems Functionality to Support Sustainable Forest Management Decision Making and Post-Decision Assessments

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ABSTRACT. Sustainable management of natural resources requires informed decision making and post-decision assessments of the results of those decisions. Increasingly, both activities rely on analyses of spatial data in the forms of maps and digital data layers. Fortunately, a variety of supporting maps and data layers rapidly are becoming available. Unfortunately, however, user-friendly tools to assist decision makers and analysts in the use and interpretation of these data generally are not available. Such tools would properly be in the form of decision support systems that incorporate basic geographic information system (GIS) functionality. A spatial decision support system featuring basic GIS functionality was designed to illustrate how such systems may be used to support decision making and post-decision assessments. This utility is illustrated with four sustainable forest management examples. Decision making is the focus of three of the examples: (1) allocating funding for forest wildfire mitigation purposes, (2) identifying forested watersheds at risk of conversion to non-forest land uses, and (3) identifying lands in the Rocky Mountains with potential for management for water yield. An assessment of the results of previous decisions is the focus of the example: (4) evaluating the socio-economic effects of the allocation of wildfire mitigation funds. doi:10.1300/J091v23n04_02

KEYWORDS. Decision support system, Montréal Process, digital data layers

INTRODUCTION

McRoberts et al. (2004) provide a historical review of issues that have led to the current interest in sustainable forest management. Borrowing from that review, the concept of forest sustainability is surrounded by a complex web of environmental, social, and economic interactions. Definitions of forest sustainability generally incorporate three components: (1) a process based on the integration of environmental, economic, and social principles; (2) satisfaction of present environmental, economic, and social needs; and (3) maintenance of forest resources to assure that the needs of future generations are not compromised. Of all the forest sustainability initiatives, the Montréal Process (1998) is geographically the largest, involving 12 countries on five continents and accounting for 90 percent of the world's temperate and boreal forests (Forests of the Future, 1999). The Montréal Process prescribes a scientifically rigorous set of criteria and indicators that have been accepted for evaluating the sustainability of forest management practices. A criterion is a category of conditions or processes by which sustainable forest management may be evaluated and is further characterized by a set of indicators that are monitored periodically to assess change. An indicator is a measurable quantitative or qualitative variable which, when observed over time, demonstrates trends. The specific Montréal Process Criteria and indicators are provided online (*http://www.mpci.org/home_e.html*).

Assessments of Montréal Process Criteria, which often are the means for evaluating the sustainability of forest management, increasingly require the analysis of spatial data in the forms of maps and digital data. In the USA, maps and data layers to accommodate these requirements rapidly are becoming available as a result of the mapping priorities and capabilities of programs such as the Multi-Resource Land Characterization consortium of the U.S. Geological Survey (Vogelmann et al., 1998), the Forest Inventory and Analysis (FIA) program (McRoberts et al., 2004) of the USDA Forest Service, the LandFire project (Landfire, 2003) of the USDA Forest Service, and the U.S. Census Bureau (USCB, 2003). However, the first priorities of these organizations are to compile and distribute spatial data, not to create tools to facilitate the analysis and interpretation of the data. Unfortunately, natural resources decision makers and analysts need such tools, and they need them now.

Relevant tools are currently available in two forms, geographic information systems (GIS) and spatial decision support systems (DSS). GIS, while providing broad arrays of functionality, require a relatively high level of expertise which decision makers and analysts usually do not have. Spatial DSS, while not requiring exceptional GIS skills, usually are limited in geographic scope and/or are targeted to specific themes. A user-friendly software system that provides basic GIS functionality without requiring extensive GIS expertise would be particularly useful at this time. Such a system would provide spatial analysis tools to support both decision making and assessments of the effects of decisions that have already been made.

SPATIAL DECISION SUPPORT SYSTEMS

Spatial DSS are computer programs that typically consist of four components: (1) a database of spatial information relevant to the decision;

(2) an analytical engine to process the data; (3) output capabilities in the forms of tables, graphs, and maps that depict results in ways useful to decision makers; and (4) a graphical user interface. Spatial DSS have considerable overlap with GIS; in fact, one application of a GIS may be considered to be a spatial DSS. Functionally, however, the roles of spatial DSS are as information systems that provide selected GIS functions to decision makers and analysts who generally do not have the expertise to use a GIS, nor the time and resources to assemble and manage the requisite spatial data. Thus, many of the distinctions between GIS and spatial DSS are derived from differences in their intended users rather than their functions. Finally, spatial DSS create efficiencies by assembling data only once and then providing the database and selected system functionality to a decision maker or analyst.

The geographic context of many natural resource management decisions includes regions with diverse climates, topographies, land uses and covers, resource conditions, human population densities, and economic conditions. Spatial DSS accommodate this multi-faceted decision context, provide the capability to evaluate scenarios derived from multiple and competing objectives, reveal the consequences of decision alternatives under consideration, and provide a means of assessing the effect of decisions following their implementation.

Spatial DSS have been developed for a variety of environmental and natural resources applications. Mowrer (1992) and Power et al. (1995) provide excellent overviews and discussions of DSS for a variety of applications including, but not limited to, forest management planning, scheduling management treatments, scheduling and transportation planning for forest harvest, landscape disturbance, wildfire, watershed analyses, and forest insect and disease risks.

Forestry-related DSS tend to be defined by a small number of application themes of which forest protection and forest treatment are most common. In the former category, the New Brunswick Department of Natural Resources and Energy has developed the Spruce Budworm Decision Support System to help forest managers make protection-related decisions during outbreaks as well as to assist them in minimizing future damage when scheduling harvests and silvicultural prescriptions (MacLean and Porter, 1994). The Pacific Forestry Centre of the Canadian Forest Service has constructed decision support tools to address questions related to the spread and control of the mountain pine beetle (Shore and Riel, 2002). The system uses susceptibility, risk rating, spread, and impact models to address questions of where and when the beetles will attack and how much damage they will cause and to assist in developing mitigation strategies. The Southern Research Station, USDA Forest Service, has constructed a DSS that addresses prevention and mitigation of losses due to the southern pine beetle (Holmes, 1993). Decision making under conditions of risk and uncertainty is assisted using outputs from models of beetle growth in a spatially explicit manner. Reynolds and Holsten (1997) developed SBexpert, a knowledge-based DSS that provides recommendations for reducing spruce beetle hazard and risk to spruce stands. The common features of these forest protection systems are that the applications are regional in scope, the system themes focus on a single pest, and the analyses rely heavily on predictive models or local data analyses for their spatial outputs.

In the category of forest treatment, the Rocky Mountain Research Station, USDA Forest Service, has developed two complementary systems, Multi-resource Analysis and Geographic Information system (MAGIS) and Simulating Vegetative Patterns and Processes at Landscape Scales (SIMPPLE; Jones, 1999). MAGIS spatially schedules treatments that satisfy resource and management objectives and compares schedules with respect to tradeoffs, while SIMPPLE simulates disturbance processes with and without management treatments. The Canadian Forest Service and the Ontario Ministry of Natural Resources collaborated to construct a DSS to assist in identifying stands to be thinned and selecting the timing, type, and intensity of thinning (Newton, 2002). The Landscape Management System (LMS; McCarter et al., 1998) is a joint effort among the University of Washington, Yale University, and the USDA Forest Service. LMS assists in the development of forest management concepts and tools to accommodate social values including commodities, wildlife habitat, fire safety, employment, and carbon sequestration. The system integrates forest inventory data and growth models with visualization and analysis tools for evaluating stand- and landscape-level forest management alternatives. The common features of these forest treatment systems are similar to the common features of the forest protection systems: they are regional in scope; they focus on specific applications; and they rely heavily on models, simulations, or analyses tailored to the applications.

In the more general environmental arena, the U.S. Geological Survey constructed a DSS to help decision makers manage development in the northern Colorado Front Range urban corridor (USGS, 1998). The system allows planning agencies to integrate natural resources data with socio-economic information to create different scenarios with respect to jobs, transportation networks, energy, schools, species habitats, water resources, and other factors. TAMARIN (Toolbox of Applied Metrics and Analysis of Regional Incentives; Stoms et al., 2004), developed at the University of California, Santa Barbara, under a grant form the World Bank, supports the design and evaluation of conservation strategies intended to satisfy biodiversity objectives. The evaluation focuses on the economic and ecological consequences of particular designs. The system has been applied in the construction of a forest biodiversity corridor in south Bahia, Brazil. The U.S. Bureau of Reclamation collaborated in construction of a DSS to help land use planners make decisions in the multiple-use/multiple stakeholder environment of Snake River, Idaho (Lute, 2002). The system presents diverse data sources as an interactive map tool that allows users to select a category of interest and then select map options to portray relevant information. Corbett et al. (2001) describe an African spatial DSS that emphasizes the assembly of current, reliable, environmental baseline data characterizing agroecosystems. The intent is to create efficiencies in decision making by paying the one-time cost of assembling generally accepted environmental databases and then providing them to decision makers in remote locations. The Landscape Ecological Analysis Package (LEAP II; Perera et al., 1997) was developed in Ontario. LEAP II permits users to explore landscapes with respect to fragmentation, edges, connectivity; to monitor temporal changes following implementation of management decisions; and to assess the results of spatial simulations of management decisions when used with landscape simulators. These environmental DSS have common features also: they tend to be regional in scope; they focus on assembly of a large suite of relevant data from multiple sources; they permit integrations and portrayals of the data; and they do not rely heavily on application specific prediction systems.

THE SPATIAL RESOURCE SUPPORT SYSTEM

The integration and analysis of data layers portraying spatial information is becoming crucial to decision making and post-decision assessments in the natural resources field. Inevitably, these analyses require selections of data layers and parameters for integrating the layers, and each selection may lead to a different implementation which, in turn, may lead to different outcomes. Thus, a DSS that emphasizes spatial analyses and permits multiple approaches to integrating data layers and comparisons of the effects of the different approaches would contribute objectively to decision making and be of substantial benefit to decision makers and analysts who are not GIS experts. The Spatial

Resource Support System (SpaRSS) has been designed to demonstrate how basic GIS functionality can be used to inform decision making and post-decision assessments.

Objective and Specifications

SpaRSS is a GIS-based system that incorporates a suite of digital data layers; provides intuitive, accessible, user-friendly tools for analyzing spatial data; but does not require high-level spatial or GIS skills. SpaRSS permits decision makers to design alternatives using real data and then display the results in tabular and graphical formats. The system displays nuances of decision alternatives, permits refinements prior to implementation of a decision, and accommodates post-decision assessments. SpaRSS provides decision making and analytical support in three areas: (1) assembly of relevant, digital data layers obtained from external sources or created internally; (2) analyses based on the integration of spatial data; and (3) comparison of results of different methods for integrating spatial data and different decision alternatives. To achieve these objectives, SpaRSS has been designed with specific features:

1. A user-friendly, graphical user interface;
2. Database with a core set of useful layers;
3. Options for approaches for integrating data layers;
4. Options for selection of parameters for a given integration approach;
5. Options for summarizing and portraying results;
6. User help documentation.

Many of SpaRSS's features are more similar to those of environmental DSS than to those of forestry-related systems. In particular, SpaRSS relies more heavily on created or acquired data layers than on internal models or prediction systems, although prediction systems may easily be incorporated. However, SpaRSS has two features not known to be represented in existing spatial DSS. First, nearly all the existing systems are limited in scope; either they are limited geographically to localized areas of pest risk, corridors of burgeoning urban development, or single-river basins, or they are limited thematically to specific pests, species, or environmental issues. SpaRSS has been designed to be national in scope and appropriate for data of any theme, although the accompanying database focuses on forestry-related problems. Second, the range of scenarios featured by existing systems derives nearly exclusively from using the same integration methods or the same models. SpaRSS permits scenarios derived in these same ways but also permits scenarios to be derived from different approaches to integrating the data. SpaRSS should be viewed as national in scope, generic with respect to thematic data, and flexible with respect to approaches for analyzing data.

Database

The SpaRSS database includes digital data layers including, but not limited to, the following:

1. *Census*: For example, population centers, distance to population centers, census block data, housing densities, and projected housing densities;
2. *Socio-economic*: For example, measures of persistent poverty, mill locations, and wild land-urban interfaces, land ownership, and land use;
3. *Abiotic*: For example, drought and fire risk indices, locations of historic forest wildfires, and digital elevation models;
4. *Biotic*: For example, land cover, natural fire history regime, fire condition class, fuel loadings, and treatment opportunities.

Before incorporation into the system, all data layers were converted to a common grid system with common and fixed projection and spatial resolution of 1 km^2. This spatial resolution is appropriate for large area analyses but would not be appropriate for analyses at the scale of forest stands, for example. Data layers with finer spatial resolution could be used, but the tradeoff for large area analyses would be increased processing time, a potentially limiting factor for Web-based systems.

Functionality

SpaRSS provides tools for accomplishing three categories of GIS tasks: portraying data layers, integrating data layers, and providing estimates in tabular form. Portrayals may be for categories or aggregations of categories of data layer variables, or they may be for only those grid cells for which the values of data layers satisfy selected threshold criteria. Portrayals of continuous variables are also by categories, although a large number of small width categories provides the sense of a continuous mapping.

Integrating data layers may be accomplished either by a portrayal of one data layer overlaid on another data layer or by combining the values of two or more data layers on a grid cell by grid cell basis. Combining values is accomplished using one of three approaches. The first approach, designated INTERSECTION, selects grid points for which values of all layers to be integrated simultaneously satisfy threshold criteria. The INTERSECTION approach is extremely restrictive. Although values for all except one layer may satisfy their threshold criteria by large margins, if the value for a single layer fails to satisfy its threshold criterion, even by an infinitesimal amount, the grid point is not selected. The second approach, designated ADDITION, selects grid points on the basis of whether the sum of values for all layers to be integrated satisfies a threshold criterion. Whereas the INTERSECTION approach is very restrictive, the ADDITION approach is very permissive, because for any grid point the value for one layer may dominate the sum and satisfy the threshold criterion, regardless of the values for the other layers. The third approach, designated MULTIPLICATION, selects grid points on the basis of whether the product of values for all layers to be integrated satisfies a threshold criterion. The MULTIPLICATION approach tends to produce results midway between the INTERSECTION and ADDITION approaches, although in the absence of large numbers of values at the extremes of the distributions of values for the layers, the differences between the ADDITION and MULTIPLICATION approaches may be slight.

With all three approaches, individual data layers may be weighted to reflect the importance the decisionmaker wishes to attach to layers to be integrated. Weighting data layers is particularly useful when objective standards for thresholds do not exist or when decisionmakers wish to incorporate explicit indications of relative importance. Finally, debates about whether the perceived importance of data layers matches outcomes may be informed through the use of thresholds and weights.

Once layers, weights, and threshold values have been selected and the data layers have been integrated, decision makers usually desire a meaningful summarization of the results. In some instances, a map depicting the geographic areas satisfying a threshold criterion may be the only summarization necessary. Frequently, however, a quantification of the results is desired. For example, the number of acres represented by the grid points of a data layer with values satisfying a threshold criterion may be desired. Also, suppose that several layers are to be integrated as a means of determining areas at risk of forest wildfire. The proportions of observed wildfires located inside and outside the area resulting from a particular selection of data layers, threshold values, and weights may be used to guide the selection process, thus providing a means of ground-truthing decisions. SpaRSS provides the capability of quantifying and tabulating results for selected areas such as National Forest Regions, congressional districts, and states.

ILLUSTRATIONS

Four examples illustrate how basic GIS functionality, implemented via a system such as SpaRSS, may be used to support forest management decision making and post-decision assessments in the context of the Montréal Process Criteria. Three examples focus on decision making, while the fourth focuses on post-decision assessment. The first, the Community Action Prioritization System, develops a method for objectively allocating wildfire mitigation funds in the USA; the second example, Forests on the Edge, identifies forested watersheds in the USA that are threatened by conversion to exurban and urban land uses; the third example, Rocky Mountain Water Yield, identifies forested lands in the Rocky Mountains region of the USA that could be managed to increase snowpack and subsequent water availability; and the fourth example, Wildfire and Poverty, illustrates relationships among indicators of wildfire and poverty, in particular the degree to which economically deprived areas in the Pacific Northwest region of the USA receive federal and state wildfire mitigation funds. All four examples address either forest management decision making or post-decision assessments, evaluate forest management practices relative to the Montréal Process Criteria, and rely on the analysis of spatial data.

The Community Action Prioritization System

Among forestry issues for which spatial analyses are appropriate, none has been more crucial in the USA in recent years than the mitigation of wildfire risk, prioritization of associated activities, and allocation of funding. Cooperative Forestry (CF) of State and Private Forestry, USDA Forest Service, and three USDA Forest Service Research Stations collaborated in the development of the Community Action Prioritization System (CAPS), a set of procedures designed to support informed allocation of the Economic Action Programs (EAP) component of National Fire Plan (NFP) funding.

CAPS' technical objective was to identify forested areas in the United States that satisfied three criteria: (1) high wildfire risk, (2) close to populated areas, and (3) simultaneously suitable for treatment to mitigate wildfire risk and to contribute to alleviating rural poverty. The overall objective of mitigating wildfire risk places CAPS squarely in the context of Montréal Process Criterion 3, *Maintenance of forest ecosystem health and vitality*. In addition, the allied objective of contributing to the alleviation of rural poverty incorporates aspects of Criterion 6, *Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of society*. To accomplish the objective: CAPS researchers found or created consistent, national digital data layers for factors in two categories: Communities and Ecosystem. For the Communities category, U.S. Census populated places data were used to create a national layer depicting the spatial proximity of all areas of the United States to population centers of between 100 and 50,000 persons, an operational CAPS definition of rural. The Ecosystem category consisted of two factors, abiotic and biotic. The abiotic factor was assessed using Palmer Drought Index (PDI; Heim, 2000).

The biotic factor in the Ecosystem category was assessed using three data layers, historic natural fire regime (HNFR; Schmidt et al., 2002), current fire condition class (CFCC; Schmidt et al., 2002), and FIA yield. The HNFR layer describes the frequency and severity of fires represented by pre-settlement, historical fire processes; the CFCC layer describes the relative risk of losing one or more key components that define an ecosystem and is based, at least partly, on historic natural fire regimes; and the FIA yield layer provides spatial estimates, in units of biomass per unit area, of the amount of biomass that may be removed from overstocked forest stands to promote more optimal forest conditions. The measure of overstocking is based on the concept of maximum empirical stand density index (Vissage et al., 2003), which, in turn, is based on the self-thinning rule (Yoda et al., 1963, Reineke, 1933). The FIA yield layer is based on and estimated from forest inventory plot data that was collected by the Forest Inventory and Analysis (FIA) program of the USDA Forest Service. For CAPS, the implicit assumption is that greater overstocking contributes to greater fire risk and that a treatment to reduce overstocking also mitigates fire risk. In addition, funds allocated to communities experiencing persistent poverty for the removal of this biomass promote the development of economic capacity.

The selected data layers were integrated using the INTERSECTION approach to produce a map that represented forested areas in the conterminous USA satisfying the CAPS criteria. The proportion of all acres selected nationally that were located in a particular National Forest Region provided an objective estimate of the proportion of CF's NFP-EAP funds that should be allocated to that Region. The areas selected by National Forest Region (Figure 1 and Table 1) resulted from use of the INTERSECTION approach with the following data layers and threshold values: (1) areas of the country within 30 miles of population centers with 100 to 50,000 residents; (2) the 50 percent of the nation with the most severe drought conditions as indicated by PDI; (3) areas in the HNFR class with return interval 0-35 years; (4) CFCC classes 2 and 3, the two categories with greatest risk; and (5) the 50 percent of the

FIGURE 1. Areas selected by National Forest Region for the CAPS example.

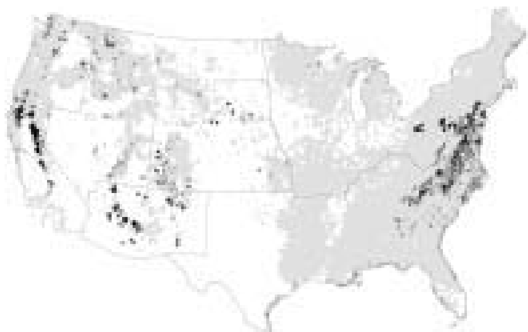


TABLE 1. Areas selected by National Forest Region for the CAPS example.

National Forest Region		Acres Selected (Millions)	Proportion of Total Area Selected
1	NO	11.3	0.155
2	RM	8.0	0.109
3	SW	6.9	0.094
4	IM	2.6	0.036
5	PNW	13.5	0.185
6	PSW	9.3	0.127
8	SO	13.1	0.179
9	E	8.4	0.115
Total		73.1	1.000

forested portion of the nation with the greatest FIA yield values. Other selections of layers and/or thresholds would produce different maps and tables.

Forests on the Edge

The Forests on the Edge project (Stein et al., 2005) is sponsored by the CF staff, State and Private Forestry, USDA Forest Service. The project objective is to identify watersheds simultaneously satisfying three criteria: (1) high proportion of forest land, (2) high proportion of forest land in private ownership, and (3) high proportion of forest land that is projected to shift from rural to exurban or urban land use or from exurban to urban land use. These criteria place the project in the context of Montréal Process Criterion 2, *Maintenance of the productive capacity of forest ecosystems*. Rural forest lands have 6.2 or fewer housing units per km^2 (≤ 16 units/mi^2) and support a diversity of economic and ecological functions such as management for timber, most wildlife species, and water quality. Exurban forest lands have 6.2-24.7 housing units per km^2 (16-64 units/mi^2) and support wildlife species and other ecological functions at a reduced level but little management for commercial timber. Urban forest lands have 24.7 or more housing units per km^2 (≥ 64 units/mi^2), are unlikely to contribute to timber production, are far less able to provide for water quality and wildlife habitat, and often do not qualify for favorable property tax assessments or technical or financial assistance through State or Federal forest management programs.

Watersheds were selected as the spatial unit of analysis to emphasize the contributions of privately owned forest land to water and watershed quality and condition. Three categories of spatial layers were used: watershed, forest land ownership, and projected housing density. Watersheds were delineated using the HUC250 database (USGS, 2005) which is based on maps of fourth order (8-digit) hydrologic unit codes (HUCs) published by the U.S. Geological Survey. A forest land ownership layer was constructed from the 1992 National Land Cover Dataset (NLCD; Vogelmann et al., 2001) and the Protected Areas Database (PAD; DellaSala et al., 2001). NLCD is a 30 m × 30 m resolution, land cover classification derived from nominal 1991 Landsat Thematic Mapper imagery and ancillary data by the U.S. Geological Survey. The 21 NLCD classes were collapsed into forest and non-forest classes. PAD is an ArcInfo polygon coverage compiled by the Conservation Biology Institute. PAD contains boundaries of most federal and state owned/

managed protected areas in the conterminous USA and Alaska, and includes county, city, and private reserves where data were available. Derivations from the NLCD and PAD were combined to form a single dataset with six categories: public non-forest, public forest, protected private non-forest, protected private forest, unprotected private non-forest, and unprotected private forest.

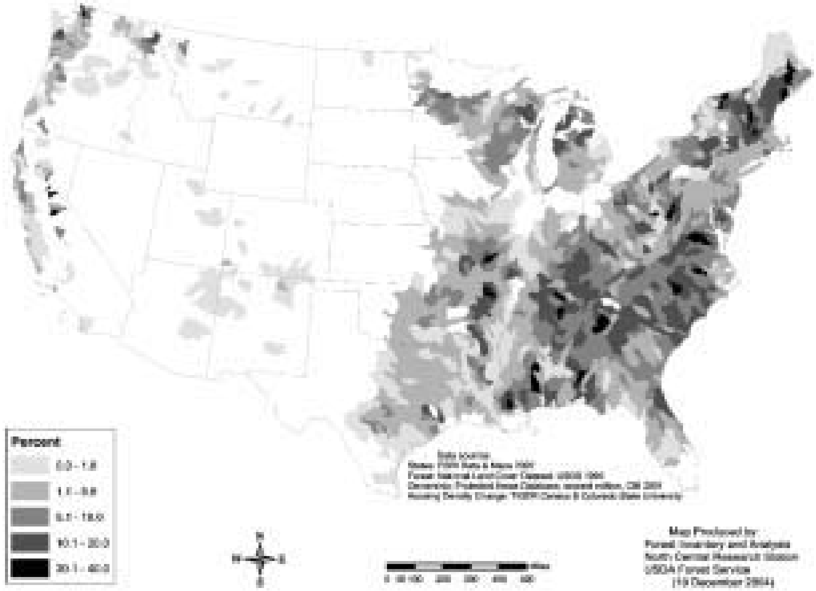
Projected housing densities were estimated using historical and current housing and population densities and a forecast simulation model of future housing density patterns. Estimates of population and housing densities were computed from the US Census Bureau data (USCB, 2001) and refined using the forest land ownership layer to adjust for water and public land where no private housing development occurs. The Spatially Explicit Regional Growth Model (SERGoM v1; Theobald, 2001a,b) was used to forecast future housing patterns on a decadal basis in four steps:

1. The number of new housing units in the next decade was forced to meet the demands of the projected county-level populations;
2. Location-specific average growth rates were computed for four density classes: urban, suburban, exurban, and rural;
3. Distributions of new housing units were adjusted to conform to the typical historical patterns of conversion to urban and exurban land use; and
4. New housing density projections were added to the current housing densities.

The INTERSECTION method was used to combine the watershed, forest land ownership, and housing density layers to identify watersheds satisfying three criteria: (1) a 10 percent or greater forest cover, (2) 50 percent or more of the forest land in private ownership, and (2) projected housing density increases between 2000 and 2030.

Most watersheds satisfying the 10 percent forest cover and 50 percent private ownership criteria were in the eastern USA where forest cover is more extensive and most forest land is in private ownership (Figure 2). By 2030, housing density is projected to increase on nearly 18 million ha of these watersheds. Of this 18 million ha, slightly more than 9 million ha is in rural private forest land projected to shift into the ex-urban category, and slightly less than 9 million ha is in rural or ex-urban private forest land projected to shift into the urban category.

FIGURE 2. Private, forested watersheds projected to experience shifts of lands from rural to exurban or urban land uses or exurban to urban land use.



Rocky Mountain Water Yield

In the Western USA, 70-90% of the water supply is generated from 15-20% of the land base (Troendle and Olsen, 1993), most of which is in publicly owned mountainous regions administered by the National Forest System, USDA Forest Service. In the Rocky Mountains, melting snow directly accounts for 90 percent of the stream flow coming from these mountainous regions (Troendle, 1987), indicating that winter precipitation contributing to the snowpack is the key factor that affects water yields in this region. Because winter snow increases with elevation in the Rocky Mountains, high-elevation National Forest lands provide most of the water that is stored and later distributed for agricultural and municipal purposes in the western USA.

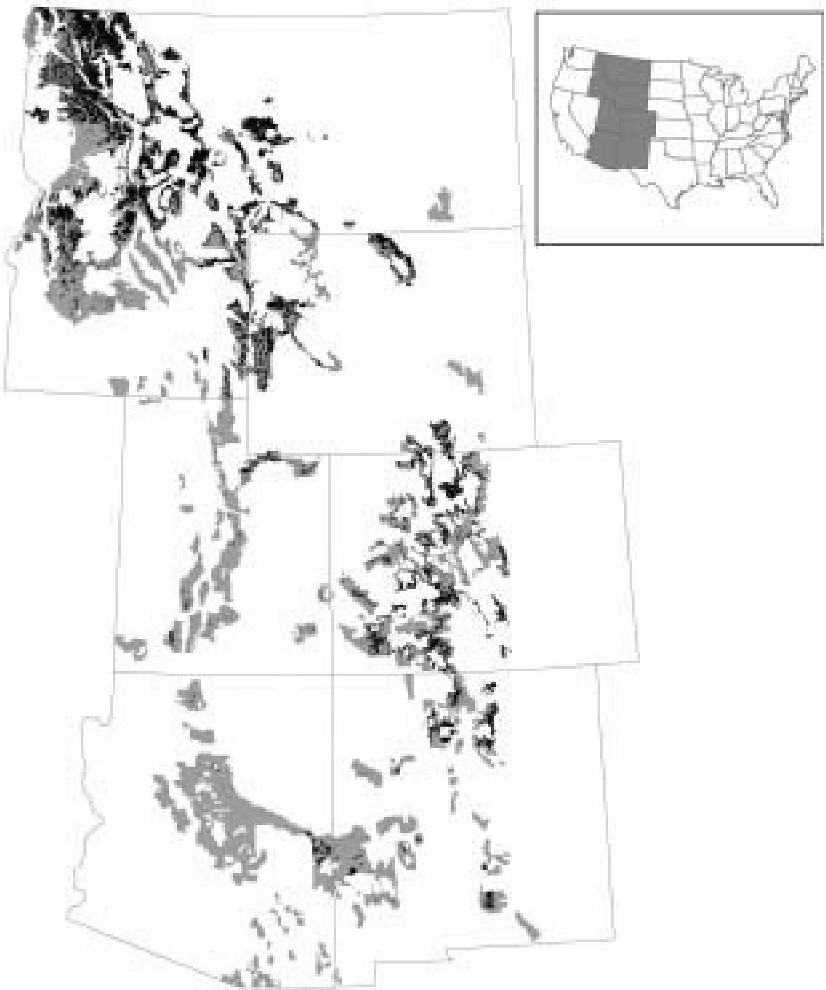
Consequences of prolonged drought in the western USA are substantial and include the potential for decreases in water yield from forest snowpack and increases in wildfire danger. In response to the second consequence, western forest management practices have focused on strategic thinning as a means of mitigating wildfire risk. This response, in combination with the knowledge that thinning to reduce Rocky Mountain forest canopies can also increase water yield by increasing snowpack and decreasing evapotranspiration, has led forest land management decision makers to ask if the two objectives, increasing water yield and mitigating wildfire risk, may be achieved simultaneously with the same thinning treatments.

To address this question, decision makers must first identify forest lands that could, potentially, contribute to increasing water yields in the western USA. Because the snowpack in lower-elevation forest stands is relatively thin, patchy, and sometimes transient, water yield in dry years is generally minimal to non-existent. Thus, thinning to reduce forest canopy in these regions has little, if any, potential for increasing water yield. In higher elevation, subalpine, conifer-dominated watersheds, however, water yield can be measurably augmented by removing 20% or more of the canopy (Stednick, 1996) from mature, closed canopy, forest stands. However, because fire-return intervals in these areas have not been affected substantially by fire suppression in the past century, and because the conditions under which fires burn in these upper elevation areas is historically so extreme, there is doubt that the public would accept the level of thinning necessary to alter substantially fire behavior in these regions. Nevertheless, based on preliminary analyses, the forest lands for consideration by decision makers must satisfy five criteria: (1) administered and managed by the National Forest System of the USDA Forest Service and available for treatment, (2) elevations above prescribed thresholds, (3) conifer forest cover, (4) short fire return interval, and (5) high degree of forest stocking. The elevation thresholds varied with higher thresholds in the southern regions and lower thresholds in the northern regions (Mowrer et al., 2003). To identify lands that satisfy these criteria, four digital layers were used, a public lands boundary map (McGhie, 1996); a 30-arcsecond (approximately 1 km), regular interval, digital elevation map (USGS, 1996); a 1-km resolution land cover map based on AVHRR satellite imagery (Hansen et al., 2000), and the upper quartile of FIA yield on lands in the 0-35 year historic natural fire regime. Using the INTERSECTION approach, the lands in the Rocky Mountain region of the western USA satisfying these criteria were identified for further consideration by decisionmakers (Figure 3).

Wildfire and Poverty

The primary goal of the Wildfire and Poverty project (Lynn et al., 2005) is to illustrate relationships between indicators of community

FIGURE 3. National Forest System lands (gray) in the Rocky Mountains and lands (black) satisfying the water-yield selection criteria: (i) owned and administered by the National Forest System, (ii) above-prescribed elevation thresholds, (iii) and conifer forest cover.



poverty, wildland urban interface/intermix and wildland intermix areas, wildfire protection capability, and the allocation of federal wildfire-related resources (*http://cwch.uoregon.edu*). The wildfire component of the project makes it relevant to Montréal Process Criterion 3, *Maintenance of* *forest ecosystem health and vitality*, and the poverty focus makes it relevant to Criterion 6, *Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of society*. Although the same Criteria are relevant as for the CAPS project, the latter project focuses on decision making, while the Wildfire and Poverty project focuses on post-decision assessment. The overall objective of the project is to construct maps to portray relationships among the indicators as a means of increasing understanding in three areas: (1) Relationships between wildfire and poverty; (2) the degree to which economically disadvantaged regions have received wildfire mitigation resources; and (3) the sufficiency of currently available data for assessing progress on community and wildfire issues. Although the focus is on post-decision assessment, the maps are also intended to inform decision making regarding the future allocation of federal wildfire mitigation resources.

The technical objective is to identify geographic areas that simultaneously satisfy four criteria: (1) high wildfire risk, (2) lack of wildfire protection capabilities, (3) high levels of poverty, and (4) lack of receipt of wildfire protection resources. For a preliminary analysis for the State of Washington, USA, spatial data layers were obtained or created in three categories: wildfire risk, economic status, and geographic allocation of wildfire mitigation and protection resources. The Wildland Intermix class of the Wildland Urban Interface dataset (Stewart et al., 2003) was used as a surrogate for wildfire risk; U.S. Department of Housing and Urban Development (HUD) data for census blocks with median household income below the state median were used to portray economic status; and locations of 2002, 2003, and 2004 National Fire Plan grants and Economic Action Plan grants were used to identify areas that had been allocated wildfire mitigation and protection resources. The INTERSECTION method was used to combine data for the three layers. Preliminary results indicate that fewer resources may be going to the most remote and low-income areas. However, data limitations on grants and wildfire risk make it difficult to interpret the extent to which resource allocation has occurred in areas of high wildfire risk and poverty (Figure 4).

SUMMARY

Spatial information in the forms of maps and digital data layers and GIS tools for analyzing them are of substantial value for decision making and post-decision assessments in the natural resources. As the four

FIGURE 4. Locations of wildfire mitigation grants in the state of Washington, USA, relative to areas characterized simultaneously as at high risk of wildfire and below median household incomes.

examples illustrate, using basic GIS techniques to integrate maps and data layers assists both decision making and post-decision assessments by facilitating comparisons of alternatives, by leading to more objective and defensible decisions, and by portraying the effects and results of decisions. Unfortunately, decision makers and analysts frequently do not possess or do not have access to the GIS expertise necessary to integrate, analyze, and interpret relevant data layers. Spatial DSS, of which SpaRSS is only one example, may be designed to provide accessible, user-friendly, functional GIS tools to assist decision making post-decision assessments in the natural resources. The greatest utility for spatial DSS will be if they are made accessible via online applications. Such development is underway for SpaRSS.

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