2014

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Citation Details

Gordon, S.N.; Reynolds, K.M. 2014. The design and use of forest decision support systems in the USA. In: Borges, J.; Trasobares, A.; Garcia-Gonzalo, J.; Hujala, T.; Nordström, E.-M., eds. Computer-based tools for supporting forest management. The experience and the expertise world-wide. Luxembourg: Publications Office of the European Union https://pub.epsilon.slu.se/11417/

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27 The design and use of forest decision support systems in the USA

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27.1 Introduction

27.1.1 Forest types

About 33% of the 930,000 km^2 of land area in the US. is considered forested by the latest national assessment (Smith et al. 2009). This figure is determined by land-use category as well as forest cover, and so does not include another estimated 80-120,000 km^2 of land with forest cover but another primary land use (mostly in and around urban areas).

The USA contains nine major ecoclimatic zones (Figure 1). In the northeastern and north-central US (predominantly temperate humid zone) there are eight major forest types of at least 4,000 km^2, with Maple-beech-birch (32%) and Oak-hickory (31%) being the most plentiful. Spruce-fir (9%) and White-red-jack-pine (6%) are the most common evergreen forest types. In the southeastern and south-central US, Oak-hickory occupies the largest area, but it is followed by the Loblolly-shortleaf pine (32%). The southeast still has significant area in the Longleaf-slash pine forest type (11%), although this has declined significantly since the 1950s due to conversion to loblolly plantations and exclusion of fire. Oak-pine and Oak-gum-cypress are the next most extensive types in the south-central zone.

The central and central western portion of the country is called the Great Plains and contains relatively little forest cover. A mix of hardwoods is the most common forest type (61%), followed by ponderosa pine (25%). Forest diversity and cover increases around the Rocky Mountains; here pinyon-juniper (33%) is most common, followed by fir-spruce (15%), and mixed hardwoods and Douglas-fir (13% each). Douglas-fir dominates the Pacific Northwest coastal region (37%); ponderosa pine is the second most common (14%), occurring in the eastern portion of the zone. The Pacific Southwest becomes more arid and is occupied mostly by mixed hardwoods (40%) and mixed softwoods (26%). The one state of Alaska comprises the second largest region in the west, and it contains mainly mixed softwoods (46%) and fir-spruce forests (36%) (Smith et al. 2009).

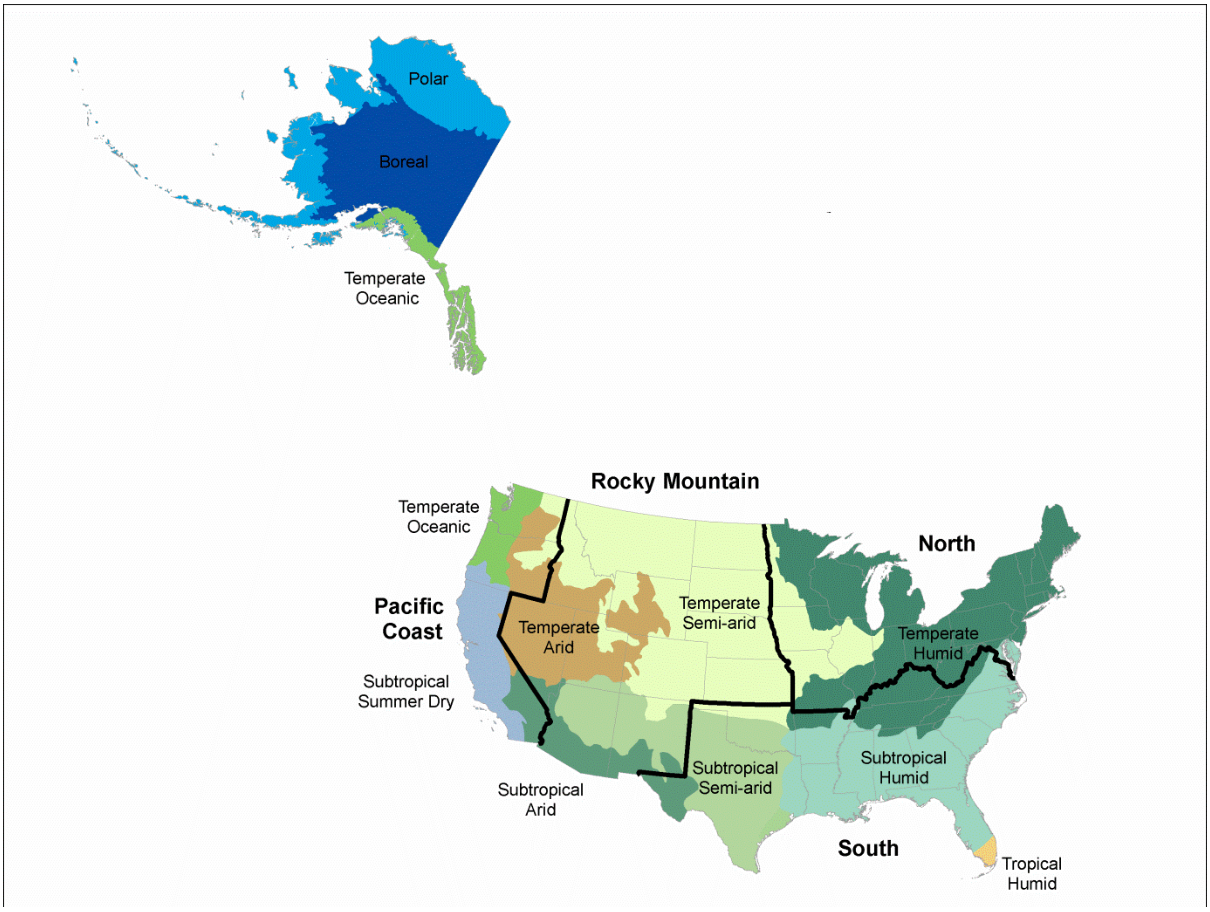


Figure 1. Ecoclimatic zones of the United States (Smith et al. 2009)

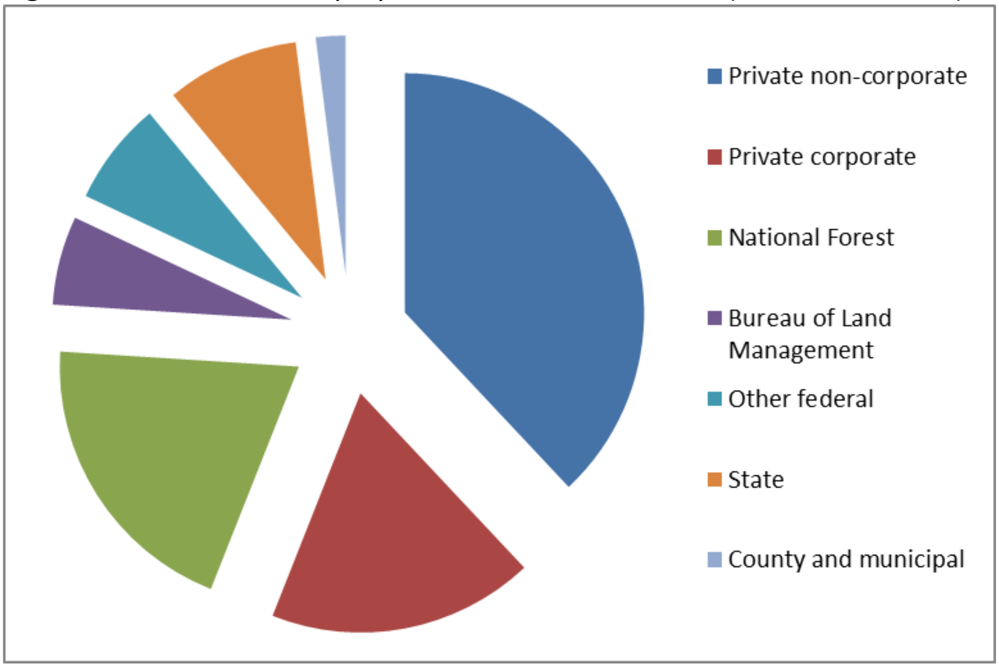
27.1.2 Forest ownership

Forest ownership in the US is diverse. 56% (1.7 million km^2) is owned by private individuals, corporations, and other private groups and 44 % (1.3 million km^2) is controlled by public agencies (Figure 2). Historical development patterns led to more private ownership in the North and South regions, while public ownership dominates in the Rocky Mountain and Pacific Coast regions (Smith et al. 2009).

Private non-corporate owners possess the largest share of forest land (38%, see Figure 2). This class includes families, trusts, non-governmental organizations, clubs, associations, and other unincorporated groups. The majority of lands (62%) within this class belong to individual families. Small private owners (0.4 – 3.6 ha) are the most numerous (61% or approximately 1.1 million owners). 18% of US forest land is owned by private corporations. These owners include forest industry and forest management companies, timber investment management organizations, and other companies that may or may not have forest management as a primary ownership objective (Smith et al. 2009).

There are 155 national forests managed by the US federal Forest Service (USFS), which comprise the largest share of public forest land (20%, 595,000 km^2). The Bureau of Land Management and other federal agencies also control significant acreages. Overall, states own 9% of forest lands in the USA. The amount owned by each of the 50 state governments varies widely, from over 20% (Alaska, Hawaii, Michigan, Minnesota, New Jersey, and Pennsylvania) to less than 1% in some states. The amount of forest land in county/municipal ownership is generally 5% or less by state, with the exceptions of Wisconsin (15%), Minnesota (12%), and a few other eastern states (Smith et al. 2009).

Figure 2. Forest ownership by area in the United States (Smith et al. 2009)



27.1.3 Forest uses and stakeholders

Forest uses are determined primarily by ownership, but they are also subject to the influence of other stakeholders. Major changes in uses, stakeholders, and their methods of influence have occurred in just the last decade (Cubbage and Newman 2006).

Private corporate owners' uses are the most homogeneous, with most focused on commercial timber production. However, a recent decoupling of land ownership from forest products manufacturing may lead to more land sales for housing development. At the same time, corporate forest managers have faced increasing pressure to improve environmental practices (social uses) through forest certification programmes emerging from environmental groups, consumers more generally, and from within their own industry (Cubbage and Newman 2006).

Family forest owners, the largest segment of the private non-corporate owner category, use their forests in diverse ways. The most popular identified uses are for aesthetic purposes (beauty/scenery, privacy, part of home); nature protection and recreation also rank high (Butler 2008). Timber production is important to only about 10% of owners, but it is a significant use for 30% of family-owned areas because it is more important for larger owners. Other non-corporate owners include clubs and associations, which are typically formed around particular recreational activities (e.g. hunting). Many non-profit land-trust organizations exist, from local to national in scope, which own land to preserve open space and provide recreation opportunities. Biodiversity conservation is the dominant purpose for which nature conservation non-profits purchase land. Other stakeholders have influence over these private lands through the promulgation of state regulations, especially related to land conversion, forest practices, water quality, and endangered species.

Public lands are the most subject to the influence of diverse stakeholders and therefore are generally managed for multiple uses, a precept which has been recognized since the establishment of the first public forest reserves by the Organic Act of 1897. Timber production on national forests became a dominant use on national forests post-WWII but has declined since the 1980s due to changes in societal preferences, environmental laws, and increasing pressure from environmental groups. Management for ecosystem health, water quality, and recreation are now all higher public priorities (Shields et al. 2002). To our knowledge, no synthesis of the uses of state and county/municipal forests exists. From our personal knowledge of a few states, we know they have multiple-use mandates similar to federal forests; however, timber harvesting rates may be higher because of their lower public profile and the more direct financing harvesting provides to state institutions (e.g. schools).

27.1.4 Forest management planning

Forest planning in the USA is organized and executed on an ownership basis. Ownership, to a large extent, determines both the objectives of forest management and the planning processes used. Federally-owned forests must comply with a distinct set of federal laws and regulations, which are different than those of state forests and private forests as well. In order to identify comparable types of planning problems across countries, the FORSYS project chose a number of criteria, including objectives, goods and services considered, decision processes, participation, and temporal and spatial scales. Based on these criteria, we have identified five generic planning problem types to describe the USA (Table 1). We have further broken down the broad problem classes into different ownerships within a class, as appropriate.

Table 1. Major US planning problem types and their characteristics

Problem type	Temporal scale	Spatial context	Spatial scale	Decision-making structure	Participation process	Objectives
Private timber-oriented	Tactical (medium-term)	Spatial	Forest	Unilateral	None	Market wood products
Private multiple use	Strategic (long-term)	Spatial	Forest	Unilateral	None	Market non-wood products Market wood products Market services Non-market services

Problem type	Temporal scale	Spatial context	Spatial scale	Decision-making structure	Participation process	Objectives
Public forests	Strategic (long-term)	Spatial	Forest	Collegial	Public	Market non-wood products Market wood products Market services Non-market services
Policy and administrative	Tactical (medium-term)	Aspatial	Regional/ national	Collegial	Stakeholder	Market non-wood products Market wood products Market services Non-market services
Broad scale cross-ownership	Strategic (long-term)	Spatial	Regional	Bargaining/ participative	Stakeholder	Market non-wood products Market wood products Market services Non-market services

The private profit-oriented forest planning type comprises most private, corporately-owned forests and some family forest owners (usually larger properties) that are oriented towards timber production. Decisions for these ownerships are made by a unilateral decision-maker (individual or company) at the scale of forest properties comprising multiple stands and generally with no public participation. Two major trends are influencing the planning in this sector. The first is forest certification. Certification standards generally require planning for longer time frames and broader scope of resources. The second trend is that there has been a recent and pervasive shift from vertically-integrated forest companies to real estate investment trusts (REITs) and timber investment management organizations (TIMOs). This shift can be inferred to change the type of planning done in a two ways. First, although strategic planning in the 50-100 year range continues to be the norm, these corporate structures must give more emphasis to shorter-term financial returns, thus placing more emphasis on medium-term planning (2-10 years). Second, there is a shift from a more exclusive focus on an even flow of timber production to a more opportunistic and broader consideration of land values (e.g. real estate development).

Private non-profit-oriented forest planning includes non-governmental organizations, such as land trusts and the Nature Conservancy, clubs and associations, and family forest owners. The diversity of these owners creates a diversity of planning problems, but in general the approach could be characterized as long-term, spatial (different areas within an ownership), small scale, with a unilateral decision-maker looking at multiple resources, considering both market and non-market goods and services. Larger non-profit organizations, such as the Nature Conservancy and Trust for Public Land have sophisticated planning processes for their own lands and have pioneered techniques in the areas of market and non-market ecosystem services. We are also including non-timber-oriented family forest lands in this category because they appear to share the same characteristics according to the FORSYS criteria. However, the level planning is quite different, with only 4% of family forest owners having a written plan, although this rises to 18% for owners of 40+ hectares (100+ acres) (Butler 2008).

As described above, 44% of US forest land is owned and managed by government organizations at three principle levels: federal, state, and local. Each level, and in fact each state and locality, operate under somewhat different laws and planning rules; however, they are similar enough in broad terms that they can be considered as belonging to one general planning problem type. These plans are generally strategic (long-term), spatial (zones within a larger ownership), and cover market and non-market wood products and ecosystem services. Formal public participation is almost always required and the decision-making approach used is collegial, in the sense that multiple participants express their preferences but a single decision-maker (agency representative, governing commission, etc.) bears the ultimate decision-making authority.

Governments also do forest planning that is not related to specific lands but rather is oriented towards broader forest policy and administration. Examples we include in this category are planning related to state forest regulations and some recent federal level efforts to consistently evaluate and prioritize lands in terms of fire, watersheds, and terrestrial ecosystems. This type of planning is more abstract than the other place-based types, but these plans do have management objectives and they frame decisions in terms of resources considered and when and where management activities can take place. These planning processes focus on the short to medium-term, are non-spatial (or very generally spatial, such as by regions), and cover market and non-market wood products and ecosystem services. Decision-making is collegial (national programme managers, state forestry boards) and includes stakeholder participation.

The fifth and final planning type we have identified is planning across multiple ownerships. In the late 1980s and early 1990s, scientists increased emphasis on the fact that natural patterns and processes do not conform to administrative boundaries. The adoption of this idea by managers became known as ecosystem management, and it spawned a number of broad-scale assessments of forest resources and more focused cross-ownership planning for certain processes (e.g. fire) and landscapes. Both government agencies and larger non-profit organizations have led these efforts. These plans are strategic (long-term), spatial (zones within a larger landscape), and cover market and non-market wood products and ecosystem services. Technically, the decision-making structure for some of these plans has been collegial, where decision authority rests with single agency decision-makers. However, in practice, since cross-ownership assessment is involved, these decisions have been much more political, resulting in more of bargaining/participative decision-making structure.

27.1.5 Objectives of the country report

The objective of this report is to synthesize trends in the diverse requirements of forest planners, in order to identify priorities for the development of DSS to meet future needs.

27.2 Materials and methods

Information about forest DSS used in the USA was developed from the published and grey literature, the internet, and in particular past surveys of forest decision support systems. In one of the latest reviews, Gordon (2006) built on previous surveys to compile a list of over 100 DSS potentially used for forest and biodiversity management, which has been integrated into an online database (University of Redlands and SDS Consortium 2011). As a follow-up to the survey, a series of case studies was compiled, which documented planning problems and DSS uses for a sample of organizations spanning the spectrum from federal to small landowners (Johnson et al. 2007). We also attempt to build on other synthetic reviews of forest DSS (Gustafson et al. 2002; IGDSNRE 1998; Mendoza and Vanclay 2008; Oliver and Twery 2000; Rauscher 1999; Rauscher 2005; Rauscher and Potter 2001; Rauscher et al. 2006; Reynolds et al. 2000; Reynolds 2005; Shao and Reynolds 2006). The following paragraphs describe resources more specific to particular owners.

27.2.1 Private timber-oriented planning

Little literature exists on planning with respect to the types of DSS used by corporate owners, probably because this information is generally regarded as strategic (trade secret) and DSS specialists in this sector are not encouraged to publish. One exception is a trip report prepared by an Australian forest planner (McLarin 2006). We also used case study information from two of the largest forest products firms (Weyerhaueser and International Paper) developed as part of Johnson et al. (2007), and we also consulted with a few colleagues with private sector experience to develop the problem type and DSS applications.

27.2.2 Private multiple-use planning

The US Forest Service conducts an annual survey of family forest owners called the National Woodland Owner Survey (NWOS). The NWOS mails surveys to approximately 6,000 randomly selected forest owners across the nation annually (www.fia.fs.fed.us/nwos/), and Butler (2008) has provided the latest summary. The NWOS asks a number of questions related to planning, including reasons for woodland ownership, management concerns, written plans, and sources of information. Not much published information is available on the use of DSS by family forest owners; however, Kirilenko et al. (2007) cite a few different efforts. Planning processes used by some of the major non-profit landowners are well documented on their websites (TNC 2011; TPL 2011).

27.2.3 Public forest planning

The most extensively studied forest planning problems in the US relate to the national forest system. The Forest Service maintains a website which describes the planning objectives (USDA FS 2010). Although no recent extensive survey of DSS use on national forests exists, two older surveys exist (Mowrer 1997; Schuster et al. 1993). Many more recent applications have reached the published literature because the research community is often involved in their implementation (Gustafson et al. 2006; Shifley et al. 2008).

Forest planning at the state level has been the subject of extensive surveys by the University of Minnesota Center for Environment & Natural Resource Policy (UMCENRP 2011). In particular, Kilgore et al. (2005; 2006) describe the practice and objectives of comprehensive forest planning at the state level, and a wider variety of planning types for the northeastern states. The National Association of State Foresters provides some information on planning (NASF 2011b). No surveys on the use of DSS tools for state or county/municipal forest planning exist, however, Johnson et al. (2007) include a few case studies at these levels, and Barker and Crist (2002) did a survey of local government tool and information use in the related field of biodiversity planning.

27.2.4 Public policy and administrative planning

Few publications on DSS use in public policy and administrative planning have appeared in the peer-reviewed literature; however, a considerable amount of information is available in government documents. State regulations are also covered in the surveys from the University of Minnesota mentioned previously (UMCENRP 2011).

27.2.5 Broad-scale cross-ownership planning

Larger, cross-ownership forest planning efforts are typically well-documented and often result in publications in the peer-reviewed literature. Johnson et al. (1999) broadly describe seven bioregional planning efforts, and Johnson et al. (2007) more specifically review DSS used in five additional cross-ownership planning efforts. Kilgore, Hibbard and Ellefson (2006) synthesized information on comprehensive state forest assessments from a 2003 survey. No synthesis has yet been performed on the results of the recent 2010 mandate for all states to produce such assessments, but individual reports are available through the National Association of State Foresters website (NASF 2011b).

27.3 Results

Table 2 summarizes the major DSS used in the USA by problem type, and Table 3 provides a reference for their abbreviations and websites. A few other related DSS are referenced in the text but not included in these tables because they fell outside the FORSYS core focus of assisting with the timing and location of forest management options.

Table 2. Planning problem types and DSS used

Problem type	Computerized tool/DSS	Models and methods	KM techniques (if applicable)	Methods for participatory planning
Private timber-oriented	Remsoft Spatial Planning System	- Linear programming - Optimization heuristics - Simulation	Process structuring	Certification
	Habplan	- Linear programming - Optimization heuristics	Process structuring	
Private multiple use	NED	- Simulation - Goal assessment	Written plans	Family conversations
	LMS	- Simulation	Assessment model library	

Problem type	Computerized tool/DSS	Models and methods	KM techniques (if applicable)	Methods for participatory planning
Public forest	FVS	- Simulation	Model library	NEPA/EIS Interdisciplinary teams Internet mapping
	VDDT	- Simulation	Process structuring	
	SPECTRUM	- Linear programming - state, flow, and accessory variables	Process structuring	
	INFORMS ArcFuels Starfire	- simulation	Process structuring	
	Remsoft Spatial Planning System	- Linear programming - Optimization heuristics - Simulation	Process structuring	
	Habplan	- Linear programming - Optimization heuristics	Process structuring	
	NED	- Simulation - Goal assessment		
Policy & administrative	EMDS	- Fuzzy logic - MCDA	Knowledge model structuring	Expert workshops
	LMS	- Simulation	Assessment model library	Public rulemaking processes
Broad-scale cross-ownership	LANDIS	- Simulation	Process structuring	
	VDDT	- Simulation	Process structuring	
	HARVEST	- Simulation	Process structuring	

Table 3. DSS abbreviations and websites

Abbreviation	Full Name	Website or Reference
ArcFuels	ArcFuels	www.fs.fed.us/wwetac/arcfuels/
EMDS	Ecosystem Management Decision Support	www.fsl.orst.edu/emds/
FVS	Forest Vegetation	www.fs.fed.us/fmsc/fvs/

Abbreviation	Full Name	Website or Reference
	Simulator	
Habplan	Habplan	http://ncasi.uml.edu/projects/habplan/
Harvest	Harvest	www.ncrs.fs.fed.us/4153/harvest/harvhome.asp
INFORMS	Integrated Forest Resource Management System	www.fs.fed.us/informs/
LANDIS	LANDIS	http://landscape.forest.wisc.edu/projects/landis.htm
LMS	Landscape Management System	http://lms.cfr.washington.edu/
NED	NED	www.fs.fed.us/ne/burlington/ned
OptFuels	Fuel Treatment Optimization	www.fs.fed.us/rm/human-dimensions/optfuels/main.php
RSPS	Remsoft Spatial Planning System (Woodstock, Spatial Woodstock & Stanley)	www.remsoft.com
Starfire	Starfire	http://warnercnr.colostate.edu/starfire-home/
Spectrum	Spectrum	www.fs.fed.us/institute/planning_center/plan_spectrum.html
VDDT / TELSA	Vegetation Dynamic Development Tool / Tool for Exploratory Landscape Scenario Analyses	www.essa.com/downloads/vddt/ www.essa.com/downloads/telsa/

27.3.1 Private timber-oriented planning

This problem category captures traditional planning for the production of forest products by forest companies and larger, timber-focused individual landowners. McLarin (2006) found the Remsoft Spatial Planning System to be the most widely used, often with a linear programming approach at the strategic level and to reveal tactical scale optima, followed by heuristic or simulation runs at the tactical level to better represent spatial and other constraints. A few firms had used Habplan, a DSS developed by the National Council for Air and Stream Improvement, which is an independent, non-profit research institute that focuses on environmental topics of interest to the forest products industry. Habplan incorporates a spatial optimization heuristic and also a non-spatial linear programming module. Little mention was made of growth and yield modelling, except that one company used FVS. Other significant growth and yield simulators in the western US include Organon and FPS. Interviews with two large forest companies (Weyerhauser, International Paper) indicated that they also developed their own growth and scheduling systems to fit their individual business needs.

27.3.2 Private multiple-use planning

The use of forest planning in this sector is low. Small landowners appear to lack the time, expertise or incentive (relatively simple needs) to use DSS directly. Planning support is generally provided by state and university extension agents, and private consultants (Butler 2008), and there are some documented cases where these professionals have used DSS to help prepare landowner plans.

Johnson et al. (2007) documented the use of NED by a number of consultants in the northeastern US. NED links inventory data and external growth models to provide users with a number of alternative algorithms for translating these data into attainment measures for broad resource goals (visual quality, wildlife, water, wood production, and general ecological objectives) using a rule-based MCDA approach.

Extension agents from Washington State University have used the Landscape Management System (LMS) in forest stewardship planning short-courses to help small, private owners collect inventory data for their tree farm and simulate future economic, ecological, and aesthetic conditions. LMS integrates a number of existing tools into a common software framework, including growth and yield simulators (FVS and Organon) and visualization packages (SVS and Envision). It also links these tools to a geographic information system (ArcGIS) and provides a library of assessment routines (wildlife, carbon, etc.).

A few spreadsheet growth models also have been developed, primarily aimed at smaller landowners: WestPro for simulating uneven-aged Douglas-fir stand growth and yield in the Pacific Northwest (Ralston et al. 2003) and CalPro for California mixed-conifer stands (Liang et al. 2004). Users can choose cutting regimes by specifying the interval between harvests (cutting cycle) and a target distribution of trees remaining after harvest. The state of Texas has developed an online "Timberland Decision Support System," which provides a growth and yield simulator for loblolly pine and a timberland investment calculator (http://tfsfrd.tamu.edu/tdss/default.htm).

Because of the low level of planning by non-industrial owners, Kirilenko et al. (2007) developed an internet-based DSS called 4S (Forest Stand Software Support System, https://www.purdue.edu/apps/forestry) that is designed to be more of an educational tool than a management planning tool. It uses a picture-enhanced interface to allow the user to describe their forest (as a single stand) and then run one of three management approaches (no management, thin from below, commercial harvest). The program stores a matrix of pre-computed yields from FVS, as well as species diversity indices for wildlife and plant groups. The output report consists of these timber yields and diversity indices, but also includes links to further information and extension specialists, thus serving as a "bridge" between forest owners and forestry experts.

27.3.3 Public forest planning

27.3.4 National forest planning

Each of the 155 national forests is required to have a forest-wide plan and to update it every

15 years. Planning for these lands is unique in that it is governed by the National Forest Management Act, a federal law passed by Congress, and a "planning rule," a federal regulation derived from the Act by the USDA Forest Service (USFS) as the responsible agency. These plans are intended to provide strategic guidance (management standards, zoning). Before actions on the ground in a national forest are carried out, project-level planning is done. The basic problem structure and requirements are quite similar to forest-wide planning, except for narrower temporal and spatial scales (tactical, stand-level). In recent years, framing of the planning problem has changed from timber supply to "restoration treatments," which in turn requires more assessment tools for diverse resources and disturbances.

From 1979 to 1996, the USFS required the use of the FORPLAN DSS (and its successor, SPECTRUM), a matrix generator for input to linear programming solvers. Various growth and yield models were used to project management options. Since 1996, there has been a diversification of DSS used. One of SPECTRUM's enhancements is the ability to define and use state, flow, and accessory variables. These variables enable the simulation of ecological processes and can be used as dynamic constraints in the optimization model. Some forests are still using SPECTRUM, but as part of more ecologically-oriented vegetation analyses (see the Boise-Payette-Sawtooth National Forest Plan case study in Johnson et al. (2007)). In general, however, there has been a trend away from optimization approaches, due to difficulties in representing the complexities of the forest system, and towards more use of simulation tools such as FVS and the VDDT state-transition modelling framework. FVS has a variety of extensions, such as for fire and fuels, insects and disease, and wildlife. Other published DSS applications for national forest planning include HARVEST (Gustafson et al. 2006), LANDIS (Shifley et al. 2008), and SIMPPLLE (USDA FS 2008; USDOI BLM 2005).

Since the adoption of a national fire plan (USDA and USDI 2003) fire and fuels management has become a major planning emphasis. There has been considerable DSS development in this area; Peterson et al. (2007) document over 40 tools relevant to fire planning. Tactical planning for fire and fuels at the local level is still diverse. A national effort to improve and harmonize DSS support identified four existing comprehensive fuels treatment planning systems and diagrammed their workflows: INFORMS, ArcFuels, IFP-LANDFIRE, and Starfire (Funk et al. 2009). INFORMS, ArcFuels and Starfire all link various data sources, fire simulation models, and the ArcGIS platform. IFP-LANDFIRE is more of a procedural guidance library that helps planners integrate appropriate tools. An additional system was later identified - OptFuels is a system which integrates existing fire behaviour (FlamMap) and vegetation simulation (FVS-FFE) tools with a simulated annealing optimization system (MAGIS) for land management planning (USDA FS 2011b).

Different types of knowledge management (KM) are embedded in these DSS. FVS encapsulates knowledge of tree species growth and is essentially a model library. SPECTRUM and VDDT do not include any factual knowledge but do incorporate procedural knowledge – they provide methods for problem structuring and ways to store the generated knowledge. The fire and fuels DSS generally include both factual knowledge (in the fire and effects simulation) as well as procedural knowledge in the form of an analysis methodology.

Planning on all federal lands is subject to the National Environmental Policy Act, which requires certain procedures intended to increase public transparency and involvement in the planning process. Although the national forest planning problem requires considerable public participation, the DSS most used do not have any specific capabilities to facilitate it. The public may influence the scenarios projected, but this interaction occurs indirectly through USFS analysts. DSS, beginning with FORPLAN, have broadened participation of disciplinary experts by bringing non-timber concerns explicitly into decision options (Johnson 1987; Gordon 2006). A number of forests are now using internet-based interactive maps to share plan options and solicit input (Brown and Reed 2009). While not a DSS in sense of this project, this approach provides a promising avenue for development of more participatory DSS.

27.3.5 State-owned lands

Most state governments own and manage forest land for the benefit of their citizens. Planning for state lands varies with the amount of state ownership, types of forest owned, and the desired uses and cultural norms of the state. Little synthesis of the use of decision support technologies for state forest planning exists. However, Kilgore et al. (2005) surveyed forestry agencies in 18 northeastern states about their planning efforts and included a section on planning technologies used. They found that geographic information systems were regarded as the most important technology (mean of 3.3 on a scale of 1 to 4), followed by remote sensing (2.6), ecological, economic and resource simulation models (1.9), and decision support models (1.7). Although DSS received the lowest score, the authors added that several planners expressed the need for forest growth, harvest scheduling, and spatial models that could help them assess alternative long-term strategies.

Since no synthesis of specific DSS use by the 50 states exists (and it was beyond the capacity of our effort), we are limited to a few examples: two short case studies on Maryland and Oregon (Johnson et al. 2007) and our personal knowledge of Washington state (WADNR 2010). All three used the common strategy of using growth and yield software to model alternative pathways, which then fed into a harvest scheduling heuristic to help identify efficient strategies. Obtaining accurate growth and yield models over a range of conditions was a major challenge for both Oregon and Washington; both used FVS but had to invest considerable resources in updating inventories and calibrating the model for different areas. The Maryland case focused on a single forest property, and relied on a simpler growth projection using the single-species Tauyield loblolly pine growth model (FMRC 2011).

For harvest scheduling projections, Maryland used the Habplan DSS, and Washington used the Remsoft Spatial Planning System; both are tools used by private industry and are discussed above under private timber-oriented planning (section 3.1). Oregon contracted with a local university professor and DSS specialist to build a customized scheduling system, based on a simulated annealing optimization heuristic. The three states handled goal-setting and environmental effects differently. Maryland included a simple habitat model for the endangered Delmarva fox squirrel in their optimization goals to generate a possibility curve of harvest volume versus habitat. Oregon integrated a coarse-filter measure of old forest with complex structure into the goal statements of four of their five alternatives.

Considerable knowledge management was obviously involved in constructing the DSS in all three states. The Oregon model development process is well described in two publications (Sessions et al. 2006; Overhulser et al. 2006), however, specific knowledge management techniques are not documented.

In regard to participation, the Oregon case mentions that a major shortcoming in the first iteration was that there was little time to involve the various district and field foresters in refining the results. In the second iteration, district foresters were involved at every stage in the development of model inputs and in a feedback loop with the modellers to help check and refine the feasibility of model operations. This on-the-ground feedback was also solicited in the Washington case. All three efforts had to pass through public reviews, but the DSS were not described as playing a role in this process (although their results were certainly scrutinized).

27.3.6 Local governments

Two particular issues related to forests at the local level are protection of water supplies and the control of land use development patterns to preserve natural amenities. Planning related to these issues can be either long-, medium-, or short-term, but is generally spatial (zones within a larger forested area), and covers market and non-market wood products and ecosystem services. Public participation is generally required since the ultimate decision authority is usually a local government council.

Johnson et al. (2007) included two brief case studies on local government DSS-use related to the issues mentioned. The city of Baltimore, Maryland, used a combination of computer-based tools, primarily the ArcView geographic information system (GIS) and the NED forest DSS, to analyze risks to the long-term sustainability of their reservoir lands and to develop and evaluate alternative scenarios for management of the lands. While maintaining water quality was the primary goal, the second and third goals were maintaining and enhancing the forest habitat as a contribution towards regional biodiversity. NED inventories incorporated data needed to evaluate wildlife habitat composition and structure and the quality of habitat along first- and second-order streams. While providing a platform for the management and analysis of data on numerous key abiotic and biotic forest characteristics, the NED decision support software did not provide a mechanism for evaluating the relationships of these landscape elements. The need to understand how landscape context and current ecological processes were shaping the forest required a synthesis of tools and often required stepping outside the decision support mechanism for critical answers to conservation problems.

The second case focused on Summit County, Colorado, which has been one of the fastest growing counties in the nation, while at the same time having over 80% of its land area in a national forest (White River National Forest). Theobald and Hobbs (2002) developed a tool for evaluating the biodiversity impacts of land-use planning alternatives; it does not schedule harvests, as a traditional forest DSS, but rather projects development and associated forest and biodiversity impacts based on alternative zoning options. While tool development ceased with the project, ideas from it were incorporated into a statewide online Natural Diversity Information Source (NDIS). NDIS provides basic county-level statistics, species status lists, and internet maps of historical land-use development trends. Similar in theme, Barker and Crist (2002) did a survey of local government tool and information use related to biodiversity, which identified a need and led to the development of the Vista DSS (www.natureserve.org/prodServices/vista/overview.jsp). Vista is a MCDA tool, which evaluates the interaction between conservation elements and land-use or management policies through user-input decision rules about compatibility between uses/management and the conservation elements.

Another DSS designed for municipalities is the iTree software (www.itreetools.org), which provides urban tree managers with tools for quantifying the structure of their trees and the environmental services that trees provide. Local government interest in forest-related decision support appears more related to ecosystem services than tree growth and harvest scheduling related to traditional wood products.

27.3.7 Policy and administrative planning

27.3.8 Federal interagency planning and national assessments

Federal land management agencies developed with a culture of considerable local autonomy (MacCleery 2008). However, in the last 10 years these agencies have come under increasing pressure from federal oversight agencies to provide nationally-consistent, rational, transparent, and repeatable processes for planning and tracking agency performance on core business activities (GAO 2002; GAO 2003; GAO 2004; GAO 2007). Fire and fuel treatment have been a major focus of these national planning efforts, especially in the western US, where decades of fire suppression have led to fuel buildups. Suppression costs have escalated and yet losses from fire continue to mount.

In 2002, a federal interagency effort to standardize and support fire planning and budgeting was begun and is referred to as the Fire Program Analysis system (FPA, www.fpa.nifc.gov/index.html). The goal is to help prioritize fire management investments, including fire prevention, initial response, and fuel treatment options. One of the first pieces of this system developed was a nationally-consistent vegetation database, called LANDFIRE (Rollins and Frame 2006). The first DSS developed focused on the geographic and administrative allocation of fire-fighting resources (people, planes, etc.). An initial optimization approach was abandoned after it was judged as not sensitive to operational constraints and too vulnerable to inconsistent inputs across planning units; it has been replaced by an approach that simulates and evaluates scenarios designed by local managers (GAO 2009).

At the national level, the EMDS system has been used since 2006 to provide knowledge-based decision support for budget allocation to regions for forest-fuels treatment for the US Forest Service and bureaus of the Department of Interior (Reynolds et al. 2009). EMDS is a system for integrated environmental analysis and planning that provides decision support for landscape-level analyses through logic and decision engines integrated with a GIS system. The logic engine evaluates landscape data against a logic model to derive logic-based interpretations of complex ecosystem conditions such as wildfire potential. A decision engine evaluates outcomes from the logic model, and other feasibility and efficacy data related to fuel-treatment actions, against a decision model for prioritizing landscape treatments, based on the analytic hierarchy process and a simple multi-attribute rating technique.

Two other national-scale assessments of federal lands have more recently been initiated. In 2010, the US Forest Service completed a national assessment of watershed conditions called the Watershed Condition Framework (WCF). The WCF establishes a nationally consistent reconnaissance-level approach for classifying watershed condition, using a set of 12 indicators in a multi-criteria decision analysis approach, modelled after the EMDS methodology (USDA FS 2011c). A similar assessment for terrestrial resources is now being planned.

27.3.9 State forest regulations

In the USA, there is no federal forest practices law that applies to non-federal lands, although landowners must comply with a variety of related federal laws, such as the Clean Water and Endangered Species Acts. State governments often take primary responsibility for regulating and enforcing forest practices on private lands in their jurisdictions. While this is more of a policy-setting than planning activity, states where forest products are an important part of the economy will want to know how different levels of regulation might affect harvesting activity. We would assume that DSS have been used for these analyses in a number of states, but this type of assessment rarely makes it into the published literature. One exception is the documented use of the Landscape Management System (LMS, see private multiple use, section 3.2) by the state of Washington. LMS was used to simulate the possible impacts of new forest practice regulations over 19 scenarios representative of small private landowners. LMS was also used to create templates for alternative management plans that improved forest health while providing sustainable cash flows and that could be easily implemented by landowners regardless of computer skills (RTI 2003; RTI 2005).

27.3.10 Broad-scale cross-ownership planning

There have been intermittent attempts to conduct cross-ownership planning based more on ecological than administrative boundaries. These efforts have been variously referred to as bioregional assessments (Johnson et al. 1999) and landscape planning, with the former generally encompassing larger areas. This planning problem type is similar to policy and administrative planning in the sense that it is strategic rather than tactical. Assessments often do not define the timing and location of forest management options, but they do establish an important context in which such plans are elaborated.

27.3.11 Bioregional assessments and landscape plans

Assessment and planning at this level have used a number of DSS because of their extensive analytical demands and some have had the financial and human resources to create new DSS. The bioregional assessments described by Johnson et al. (1999) were unique efforts. The Nature Conservancy's ecoregional assessment program was one of the first to institutionalize a repeatable process over a variety of landscapes, although its process is focused on biodiversity conservation and not forest management (TNC 2006). Just in the past year, a number of new landscape management initiatives have been started by the primary federal forest management agencies: Collaborative Forest Landscape Restoration Program (USDA FS 2011a), Rapid Ecoregional Assessments (USDOI BLM 2011), and Landscape Conservation Cooperatives (USDOI FWS 2011).

The Vegetation Dynamic Development Tool (VDDT) was developed as part of the Interior Columbia River Basin Ecosystem Management Project (Hemstrom et al. 2001). It has become one of the most popular DSS for broad-scale vegetation simulation modelling because of its relatively simple and flexible state-transition modelling approach. While the basic tool is aspatial, the extension TELSA allows setting up rules for the spatial distribution of results. The VDDT approach enables structuring knowledge (statistical or expert) in models for specific vegetation types and management regimes.

HARVEST is a raster, stand-based simulation model which has been used to project the consequences of alternative harvesting patterns across ownerships (Gustafson et al. 2007). HARVEST simulates harvest practices that reset the age of forested sites to a specific age. This includes even-aged timber harvest techniques (e.g., clearcutting, shelterwood, seed tree techniques) and uneven-aged group selection, and some capability to simulate other uneven-aged techniques where such treatments predictably change stand structure, by using stand age as a surrogate for stand structure. The user specifies harvest parameters (such as harvest size, rotation age, green-up interval) by forest types and management areas over multiple time periods. Management areas are relatively large, multi-stand areas that are to be managed by specific objectives.

LANDIS is another vegetation simulation system which has been used for a number of landscape assessments (Scheller et al. 2007; Scheller et al. 2011; Scheller et al. 2005). It is a more complex tool designed to simulate vegetation over large landscapes (10,000 to 1 million ha) using an interaction of spatially explicit disturbance (wind, fire, insect, and harvesting) and succession regimes.

Knowledge management and participatory techniques are particularly important aspects for planning involving diverse stakeholders, but none of the forest DSS mentioned above include features for these needs beyond their forest modelling focus.

27.3.12 State forest resource assessments and strategies

The federal government supplies a significant amount of assistance funding to state forestry programmes. The most recent reauthorization of these funds included a new requirement for states to prepare state-wide forest assessments and strategies every five years, and the first assessments were due in June 2010 (Food, Conservation, and Energy Act). The plans are intended to address the following objectives (NASF 2011a):

- Identify and provide an analysis of present and future forest conditions, trends, and threats on all ownerships;
- Identify any areas or regions of that state that are a priority;
- Identify any multi-state areas that are a regional priority;
- Incorporate existing forest management plans including state wildlife action plans and community wildfire protection plans.

There has been no survey of the decision support technologies used in these efforts, but review of a few plans and conference presentations suggests that the principal technology application is GIS overlays of various resource layers, often using a scoring system (essentially a multi-criteria decision support approach). This overlay approach could be considered a type of knowledge management aimed at problem structuring and problem solving (identifying priority action areas).

27.4 Discussion and conclusions

The wide diversity of forest owners in the USA leads to a range of planning processes and needs in terms of decision support. Although a few textbooks (Bettinger 2009; Davis et al. 2001) and many journal articles on forest planning have been published in the past decade, there is a scarcity of published surveys regarding forest planning techniques and needs across the sectors. In fact, more synthetic information appears to exist on DSS available than the planning problems in need of support.

27.4.1 Private timber-oriented planning

From the case studies and other literature, we can see that long-time challenges to traditional harvest scheduling problems still exist. Maintaining inventory data of sufficient quality can be a challenge, especially in times of declining budgets. Accuracy related to moving from tactical to operational scales also continues to be an issue. It is becoming possible to integrate more operational feasibility factors (e.g. road access) into DSS models; however, interviews indicate that it is still a difficult process, even in advanced, commercial systems such as Remsoft's (RSPS). Involving field personnel in iterative planning seems to be a key process, but is challenging to do. Further work on knowledge elicitation and management techniques and systems could be helpful here.

27.4.2 Private multiple-use planning

Few DSS options are available for the largest land owner group, small individual and family owners. This sector is a challenge to reach, given how few engage in formal planning. However, as access to and the capabilities of home computers and internet increase, along with the familiarity of these tools to younger generations, there should be more opportunities for DSS to serve this ownership. Basic spreadsheet tools have already been developed related to growth and yield and financial planning. Moving these tools to simple web applications, linking with new visualization techniques and methods for valuing various forest goods, and possibly even structuring them in a gaming format could increase decision support use in this sector.

27.4.3 Public forest planning

The focus of forest plans, especially in the public sector, continues to broaden from trees and timber to a wide variety of ecosystem services. Federal forest planning has moved away from focus on old metrics, such as the "allowable sale quantity" to plans centered on forest restoration. States are preparing comprehensive forest resource plans, and local governments and NGOs are even more focused on non-market services. A trend toward forest management certification and emerging markets for ecosystem services are even driving private, timber-focused owners in this direction. This trend has long been recognized by the DSS community, as evidenced by numerous reviews related to ecosystem management (Mowrer 1997; Oliver and Twery 2000; Rauscher 1999; Reynolds et al. 2000; Reynolds 2005). The principle need appears to be linking the growth and scheduling capabilities of existing forest DSS to methods for valuing the broader set of ecosystem services they provide.

Links to a variety of ecosystem services have been made in many individual modelling efforts, but methods are lacking for systematically managing and sharing this knowledge. For example, innumerable forest-wildlife habitat models have been developed, but these models have not been systematized into libraries similar to those employed by growth and yield models. FVS has some of this ability in terms of adding extensions, but relatively little design and exchange of these occurs between users. The modular approach of LMS is more promising, as it appears to be providing an ever increasing number of “filters” to evaluate forest conditions for wildlife, carbon, and other resources.

Another major challenge to broadening the scope of forest DSS is how to integrate across these various resources. To a large extent analysis and reporting for different resources remain separate: wildlife is modelled and impacts calculated separately from hydrologic concerns, carbon, and so forth. It is then up to the decision-maker to try to synthesize overall impacts, often from resources reported in very different metrics. On the other hand, one of the objections to the FORPLAN model was that it forced the expression of all resources into net present value terms. Obviously there is a balancing act needed here, and DSS should provide methods for the aggregation of different resources, as well as flexibility in the level of aggregation. MCDA tools are already available to accomplish this (EMDS, Vista); NED’s multi-objective focused design has also been pioneering in this regard. However, what is still needed are easier links to forest management models and better ways to model the interactions between resources.

27.4.4 Policy and administrative planning

Policy and administrative planning can exert a strong influence over the timing and location of forest management options, and there appears to be increasing demands for rationalization and transparency that analytical tools can support. At these levels the difficulties of implementing optimization approaches appears even greater than at the individual forest level; there tend to be too many factors which are too poorly understood to accurately quantify and relate. Simulation tools, which allow policy-makers to test scenarios, have had more success. There is a dearth of information on the use of analytical tools related to state forest regulations, a very important arena for forest policy in the US that deserves further study.

27.4.5 Broad-scale cross-ownership assessments

The broadening the scope of public concerns also leads to forests not being considered on their own, but rather as pieces of larger landscapes. In this case, it is forest DSS that must be modified to fit into other modelling frameworks. Non-governmental conservation organizations have pioneered much of the work in this direction in the US because of their focus on the needs of diverse species. One of the top forest concerns for local governments is the impact of development patterns, where the focus of modelling is development and not forest management per se.

Finally, forest (or natural resource) planners in all sectors have come under increasing pressure to broaden the participation in planning. This need is especially acute when considering multi-ownership landscapes. Many national and state forests have been using the internet to share planning documents and solicit public comments, and national forests are developing the capacity to share online interactive maps. The integrative and participatory nature of the new state forest assessments and strategies should position them to serve as web portals for forest issues. The next logical step (and challenge) appears to be linking these capabilities with dynamic DSS, which allow users to test assumptions and learn about ecosystems (and perhaps human systems) instead of being limited to analyses of only a few predetermined options, as is currently the case. Simpler, faster and more visual tools have shown promise in this area (MarineMap 2010). For larger, more complex landscape problems, tiered public involvement strategies have been effective at bridging the science-policy divide (Hulse et al. 2004).

References

Barker, K. and Crist, P. 2002. Market research for the development of a DSS to support local-level land use planning. NatureServe, Washington DC.

Bettinger, P. 2009. Forest management and planning. Academic, Amsterdam ; London. 331 p.

Brown, G.G. and Reed, P. 2009. Public participation GIS: a new method for use in national forest planning. Forest Science 55:166-182.

Butler, B.J. 2008. Family Forest Owners of the United States, 2006. Gen. Tech. Rep. NRS-27. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA. 72 p. http://treesearch.fs.fed.us/pubs/15758

Cubbage, F.W. and Newman, D.H. 2006. Forest policy reformed: A United States perspective. Forest Policy and Economics 9:261-273.

Davis, L.S., Johnson, K.N., Bettinger, P.S. and Howard, T.E. 2001. Forest management: to sustain economic, ecological, and social values. McGraw-Hill, New York. 804 p.

FMRC. 2011. TAUYIELD 1.1 for Windows. Virginia Tech University, Forest Modelling Research Cooperative, http://frec.vt.edu/ForestModellingResearchCooperative/tauyield.htm (April 30)

Food, Conservation, and Energy Act of 2008. United States Federal Law 110-234, 122 Stat. 923.

Funk, T., Rauscher, M., Raffuse, S. and Chinkin, L. 2009. Findings of the current practices and needs assessment for the Interagency Fuels Treatment Decision Support System (IFT-DSS) project. Sonoma Technology Inc. http://frames.nbii.gov/documents/ift-dss/task1_system_eval_memo_20090121.pdf

GAO. 2002. Severe wildland fires: leadership and accountability needed to reduce risks to communities and resources. United States General Accounting Office, Washington, DC.

GAO. 2003. Forest Service: Little Progress on Performance Accountability Likely Unless Management Addresses Key Challenges. United States General Accounting Office, Washington, DC. http://www.gao.gov/products/GAO-03-503

GAO. 2004. Wildland Fires: Forest Service and BLM Need Better Information and a Systematic Approach for Assessing the Risks of Environmental Effects. United States General Accounting Office, Washington, DC. http://www.gao.gov/products/GAO-04-705

GAO. 2007. Wildland Fire Management: Better Information and a Systematic Process Could Improve Agencies' Approach to Allocating Fuel Reduction Funds and Selecting Projects. United States General Accounting Office, Washington, DC. http://www.gao.gov/products/GAO-07-1168

GAO. 2009. Wildland Fire Management: Federal Agencies Have Taken Important Steps Forward, but Additional, Strategic Action is Needed to Capitalize on Those Steps. United States General Accounting Office, Washington, DC. http://www.gao.gov/products/GAO-09-877

Gordon, S.N. 2006. Decision support systems for forest biodiversity management: A review of tools and an analytical-deliberative framework for understanding their successful application. Oregon State University, Corvallis, OR.

Gustafson, E., Nestler, J., Gross, L., Reynolds, K., Yaussy, D., Maxwell, T. and Dale, V. 2002. Evolving approaches and technologies to enhance the role of ecological modelling in decision-making. In: Dale, V. (ed.). Ecological modelling for resource management. Springer-Verlag, New York. Pp. 135-164.

Gustafson, E.J., Roberts, L.J. and Leefers, L.A. 2006. Linking linear programming and spatial simulation models to predict landscape effects of forest management alternatives. Journal of Environmental Management 81:339-350.

Gustafson, E.J., Lytle, D.E., Swaty, R. and Loehle, C. 2007. Simulating the cumulative effects of multiple forest management strategies on landscape measures of forest sustainability. Landscape Ecology 22:141-156.

Hemstrom, M.A., Korol, J.J. and Hann, W.J. 2001. Trends in terrestrial plant communities and landscape health indicate the effects of alternative management strategies in the interior Columbia River basin. Forest Ecology and Management 153:105-125.

Hulse, D.W., Branscomb, A. and Payne, S.G. 2004. Envisioning alternatives: using citizen guidance to map spatially explicit assumptions about future land and water use. Ecological Applications 14:325-341.

IGDSNRE. 1998. A strategy for the development and application of decision support systems for natural resources and the environment. Interagency Group on Decision Support for Natural Resources and the Environment, http://www.i4sd.org/article-11.html

Johnson, K.N. 1987. Reflections on the development of FORPLAN. In: Hoekstra, T.W., Dyer, A.A. and LeMaster, D.C. (eds.). FORPLAN: An evaluation of a forest planning tool. USDA Forest Service Rocky Mountain Research Station, Denver, CO. Pp. 45-51.

Johnson, K.N., Swanson, F., Herring, M. and Greene, S. (eds.). 1999. Bioregional assessments: science at the crossroads of management and policy. Island Press, Washington, D.C.

Johnson, K.N., Gordon, S.N., Duncan, S., Lach, D., McComb, B. and Reynolds, K. 2007. Conserving creatures of the forest: A guide to decision-making and decision models for forest biodiversity. College of Forestry, Oregon State University, Corvallis, OR. 88 p.
http://ncseonline.org/sites/default/files/A10%20%28II%29%20Final%20Report%20ConservingCreatures%208.21.07.pdf

Kilgore, M., Salk, R., Carpenter, C. and Prichard, T. 2005. State forest resource planning programs in the northeast United States. Northern Journal of Applied Forestry 22:221-228.

Kilgore, M.A., Hibbard, C.M. and Ellefson, P.V. 2006. Comprehensive strategic planning for the use and management of forest resources: The experiences of state governments in the United States. Forest Policy and Economics 9:42-49.

Kirilenko, A., Chivoiu, B., Crick, J., Ross-Davis, A., Schaaf, K., Shao, G., Singhania, V. and Swihart, R. 2007. An Internet-based decision support tool for non-industrial private forest landowners. Environmental Modelling & Software 22:1498-1508.

Liang, J., Buongiorno, J. and Monserud, R.A. 2004. CalPro: a spreadsheet program for the management of California mixed-conifer stands. Gen. Tech. Rep. PNW-GTR-619. 32 p.
http://www.treesearch.fs.fed.us/pubs/viewpub.jsp?index=7506

MacCleery, D. 2008. Re-inventing the United States Forest Service. In: Durst, P., Brown, C., Broadhead, J. [and others]. (eds.). Re-inventing forestry agencies: experiences of institutional restructuring in Asia and the Pacific. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. Pp. 45-78.

MarineMap. 2010. MarineMap consortium wins award for innovation in technology from the U.S. Institute for Environmental Conflict Resolution. MarineMap Consortium, http://marinemap.org/news/marinemap-wins-innovation-in-technology-award (April 30)

McLarin, M. 2006. Forest estate modelling of multiple-use forest management. http://www.gottsteintrust.org/media/mmclarin.pdf

Mendoza, G.A. and Vanclay, J. 2008. Trends in forestry modelling. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 3:1-9.

Mowrer, H.T. 1997. Decision support systems for ecosystem management: an evaluation of existing systems. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

NASF. 2011a. Forest action plans. National Association of State Foresters, http://www.forestactionplans.org (June 11)

NASF. 2011b. National Association of State Foresters. National Association of State Foresters, St. Paul, MN. http://www.stateforesters.org (Feb 29)

Oliver, C.D. and Twery, M.J. 2000. Decision support systems: models and analyses. In: Johnson, N.C., Malk, A.J., Sexton, W.T. [and others]. (eds.). Ecological Stewardship: A Common Reference for Ecosystem Management. Elsevier Science Ltd. Pp. 661-685.

Overhulser, P., Sessions, J., Holloway, R., Rasmussen, M. and Johnson, D.L. 2006. Oregon state forests - an approach to policy analysis under complex demands. In: (ed.)^(eds.) CAES--FLP --CATPRN Joint Workshop: Crisis in Agriculture and Resource Sectors: Analysis of Policy Responses. Calgary, Alberta. October 17. http://www.farmlevel.re.ualberta.ca/Meetings/Overhulser.pdf

Peterson, D.L., Evers, L., Gravenmier, R.A. and Eberhardt, E. 2007. A consumer guide: tools to manage vegetation and fuels. GTR-PNW-690. USDA Forest Service, Pacific Northwest Research Station, Portland, OR. http://www.treesearch.fs.fed.us/pubs/25953

Ralston, R., Buongiorno, J., Schulte, B. and Fried, J. 2003. WestPro: a computer program for simulating uneven-aged Douglas-fir stand growth and yield in the Pacific Northwest. Gen. Tech. Rep. PNW-GTR-574. USDA Forest Service, Pacific Northwest Research Station, Portland OR. http://www.treesearch.fs.fed.us/pubs/viewpub.jsp?index=5344

Rauscher, H.M. 1999. Ecosystem management decision support for federal forests in the United States: a review. Forest Ecology and Management 114:173-197.

Rauscher, H.M. 2005. Decision-support systems for forest management. Computers and Electronics in Agriculture 49:1-5.

Rauscher, H.M. and Potter, W.D. 2001. Decision support for ecosystem management and ecological assessments. In: Jensen, M.E. and Bourgeron, P.S. (eds.). A Guidebook for Integrated Ecological Assessments. Pp. 162-183.

Rauscher, H.M., Schmoldt, D.L. and Vacik, H. 2006. Information and knowledge management in support of sustainable forestry: a review. In: Shao, G. and Reynolds, K.M. (eds.). Computer Applications in Sustainable Forest Management Including Perspectives on Collaboration and Integration. Springer-Verlag, New York.

Reynolds, K., Bjork, J., Hershey, R.R., Schmoldt, D., Payne, J., King, S., DeCola, L., Twery, M. and Cunningham, P. 2000. Decision Support for Ecosystem Management. In: Johnson, N.C., Malk, A.J., Sexton, W.T. [and others].

(eds.). Ecological Stewardship: A Common Reference for Ecosystem Management. Elsevier Science Ltd. Pp. 687-721.

Reynolds, K.M. 2005. Integrated decision support for sustainable forest management in the US: fact or fiction? Computers and Electronics in Agriculture 49:6-23.

Reynolds, K.M., Hessburg, P.F., Keane, R.E. and Menakis, J.P. 2009. National fuel-treatment budgeting in US federal agencies: capturing opportunities for transparent decision-making. Forest Ecology and Management 258:2373-2381.

Rollins, M.G.; Frame, C.K., tech. eds., 2006. The LANDFIRE Prototype Project: nationally consistent and locally relevant geospatial data for wildland fire management. Gen. Tech. Rep. RMRS-GTR-175. Fort Collins: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 416 p.

RTI. 2003. Fact Sheet #20: Impacts of the Forest and Fish Rules on non-industrial private forest landowners in north eastern Washington: some key consequences from riparian zone case study evaluation. University of Washington, Rural Technology Initiative, Seattle, WA.
http://www.ruraltech.org/pubs/fact_sheets/fs020/index.asp

RTI. 2005. Fact Sheet #36: Technology transfer from research to forestry applications: using the Landscape Management System (LMS). University of Washington, Rural Technology Initiative, Seattle, WA.
http://www.ruraltech.org/pubs/fact_sheets/fs036/index.asp

Scheller, R.M., Mladenoff, D.J., Crow, T.R. and Sickley, T.A. 2005. Simulating the effects of fire reintroduction versus continued fire absence on forest composition and landscape structure in the Boundary Waters Canoe Area, northern Minnesota, USA. Ecosystems 8:396.

Scheller, R.M., Domingo, J.B., Sturtevant, B.R., Williams, J.S., Rudy, A., Gustafson, E.J. and Mladenoff, D.J. 2007. Design, development, and application of LANDIS-II, a spatial landscape simulation model with flexible temporal and spatial resolution. Ecological Modelling 201:409-419.

Scheller, R.M., Hua, D., Bolstad, P.V., Birdsey, R.A. and Mladenoff, D.J. 2011. The effects of forest harvest intensity in combination with wind disturbance on carbon dynamics in lake states mesic forests. Ecological Modelling 222:144-153.

Schuster, E.G., Leefers, L.A. and Thompson, J.E. 1993. A guide to computer-based analytical tools for implementing national forest plans. USDA Forest Service, Intermountain Research Station,

Sessions, J., Overhulser, P., Bettinger, P. and Johnson, D. 2006. Linking multiple tools: an American case. In: Shao, G. and Reynolds, K.M. (eds.). Computer Applications in Sustainable Forest Management Including Perspectives on Collaboration and Integration. Springer-Verlag, New York. Pp. 223-238.

Shao, G. and Reynolds, K.M. (eds.). 2006. Computer Applications in Sustainable Forest Management Including Perspectives on Collaboration and Integration. Springer-Verlag, New York.

Shields, D.J., Martin, I.M., Martin, W.E. and Haefele, M.A. 2002. Survey results of the American public's values, objectives, beliefs, and attitudes regarding forests and grasslands: A technical document supporting the 2000 USDA Forest Service RPA Assessment. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 111 p. http://www.treesearch.fs.fed.us/pubs/4817

Shifley, S.R., Thompson, F.R., III, Dijak, W.D. and Fan, Z. 2008. Forecasting landscape-scale, cumulative effects of forest management on vegetation and wildlife habitat: A case study of issues, limitations, and opportunities. Forest Ecology and Management 254:474-483.

Smith, W.B., Miles, P.D., Perry, C.H. and Pugh, S.A. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO-78. U.S. Department of Agriculture, Forest Service, Washington Office, St. Paul, Minn.

Theobald, D.M. and Hobbs, N.T. 2002. A framework for evaluating land use planning alternatives: protecting biodiversity on private land. Conservation Ecology 6:5.

TNC. 2006. Conservation by Design: A framework for mission success. The Nature Conservancy, Washington DC. http://www.conservationgateway.org/file/conservation-design-framework-mission-success

TNC. 2011. Planning at The Nature Conservancy. The Nature Conservancy, http://www.conservationgateway.org/content/planning-nature-conservancy (March 27)

TPL. 2011. Conservation Vision & GIS. The Trust for Public Land, http://www.tpl.org/what-we-do/services/conservation-vision/ (March 27)

UMCENRP. 2011. University of Minnesota Center for Environment & Natural Resource Policy. University of Minnesota Center for Environment & Natural Resource Policy St. Paul, MN. http://www.forestry.umn.edu/ENRPolicyCenter/Research/natResGovernance.html (Feb 29)

University of Redlands and SDS Consortium. 2011. Resources: tools and models. http://www.institute.redlands.edu/sds/ontology/tools/ (January 10)

USDA and USDI. 2003. National Fire Plan. US Department of Agriculture Forest Service and US Department of Interior Bureau of Land Management, Washington, DC. http://www.fireplan.gov

USDA FS. 2008. Beaverhead-Deerlodge National Forest, Revised Forest Plan, Final Environmental Impact Statement. U.S. Department of Agriculture, Forest Service, Region 1, http://www.fs.fed.us/r1/b-d/forest-plan/index-plan-document-maps.shtml

USDA FS. 2010. The forest planning rule. U.S. Department of Agriculture, Forest Service, http://fs.usda.gov/planningrule (December 20)

USDA FS. 2011a. Collaborative Forest Landscape Restoration Program. USDA Forest Service, http://www.fs.fed.us/restoration/CFLR/ (April 22)

USDA FS. 2011b. OptFuels: Optimizing Spatial and Temporal Treatments to Maintain Effective Fire and Non-Fire Fuels Treatments at Landscape Scales. USDA Forest Service, Rocky Mountain Research Station, http://www.fs.fed.us/rm/human-dimensions/optfuels/main.php (April 30)

USDA FS. 2011c. Watershed Condition Framework: a framework for assessing and tracking changes to watershed condition. FS-977. U.S. Department of Agriculture, Forest Service, Washington, DC. 24 p. http://www.fs.fed.us/publications/watershed/Watershed_Condition_Framework.pdf

USDOI BLM. 2005. Proposed Dillon resource management plan and final environmental impact statement. United States Department of Interior, Bureau of Land Management, http://www.blm.gov/mt/st/en/fo/dillon_field_office/rmp/Final.html

USDOI BLM. 2011. Rapid ecoregional assessments. US Department of Interior, Bureau of Land Management, http://www.blm.gov/wo/st/en/prog/more/climatechange/reas.html

USDOI FWS. 2011. Landscape conservation cooperatives. US Fish and Wildlife Service, http://www.fws.gov/science/shc/lcc.html (April 22)

WADNR. 2010. Forest land plan for the South Puget Habitat Conservation Plan planning unit: final environmental impact statement. Washington Department of Natural Resources, Olympia, WA. http://www.dnr.wa.gov/ResearchScience/Topics/SEPANonProject/Pages/amp_sepa_nonpro_flp_southpuget.aspx