23 Computer-based tools for supporting forest management in Spain

Trasobares A.[1], Palahí M.[2], Marey M.[3],Diaz-BalteiroL.[4]

[1]Forest Ecology, Institute of Terrestrial Ecosystems. Department of Environmental Sciences.ETH Zurich.CH-8092 Zurich
[2]Mediterranean Regional Office, European Forest Institute, St. Antoni M. Claret, 167, 08025 Barcelona, Spain
[3]Research Group 1716-Projects and Rural Planning, Department of Agriculture and Forest Engineering, University of Santiago de Compostela Campus Universitario, s/n. 27002, Lugo, Spain
[4]Technical University of Madrid, Research Group "Economics for a Sustainable Environment", E.T.S, Ingenieros de Montes, Avenida Complutense s/n 28040 Madrid, Spain

23.1 Introduction

In Spain the forest surface occupies 27.5 million ha (54% of the total surface of the country; SECF 2010). However, only 36% of the total surface of the country is forested (i.e. with a percentage of canopy cover >= 20%); the remaining 18% is treeless or just covered by few trees. Forest ecosystems in the country can be classified according to the Atlantic and Mediterranean climatic zones (see Fig.1). Forests in the Atlantic region are characterized by its high wood productivity, which often relates to the practice of short rotation forestry (e.g. *Eucaliptus sp*, *P. radiata*, *P. pinaster*, *Populus sp*). Forests in the Mediterranean region are characterized by its complexity and average low productivity (long drought periods in summer). These conditions, combined with other factors such as topographic contrasts, often lead to no management (management is not profitable).

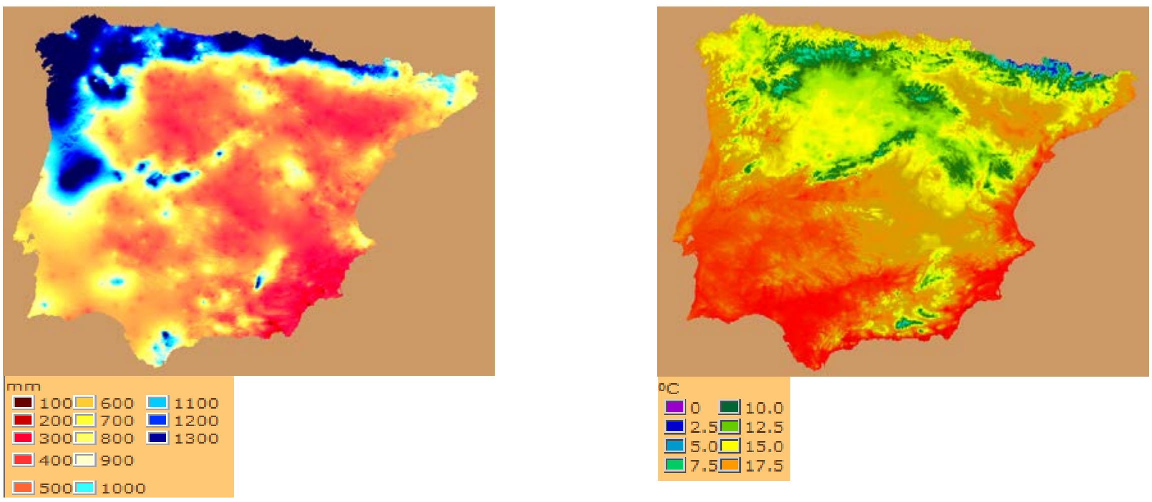

Figure 1. The Atlantic and Mediterranean climatic zones of the Iberian peninsula approximately shown by annual precipitation (left) and mean annual temperature (right) maps (Ninyerola et al. 2007a; Ninyerola et al. 2007b). The highly productive Atlantic zones relate to N-NW regions close to the Atlantic coast where annual precipitation and annual mean temperature range above 1000 mm and 5 °C, respectively.

Due to its location and climatic conditions, Spain presents large diversity in forest ecosystems. Around 20 dominant tree species can be identified, for example: *Q. ilex* (dominates in 14% of the forested area), *P. pinaster* (12%), *P. halepensis* (11%), *P. sylvestris* (9%), *P. nigra* (6%), *F. sylvatica* (4%), *Q. suber* , *P. pinea*, *Q. faginea*, *Q. pyrenaica*, *Castanea sativa*, *Juniperus thurifera*, *Q. robur*/*Q. petraea*, *P. uncinata*, *Pinus canariensis*, etc. Much of the forested area is also occupied by mixed forests. The growing stock (m^3/ha) increased 19.7% during the period 1996-2009 (SECF 2010) due to the lack of management. In Spain 41.3% of the annual growth/cutting budget is harvested (the average in the EU27 is 59%; SECF 2010). The majority of timber production is harvested in the Atlantic region (around 70% of the total production in the country).

Spanish forests (especially those in the Mediterranean region) are characterized by the existence of multiple goods and services. A representative list may be: timber, grazing, fire-wood and biomass, carbon sequestration, cork, resins, aspart, berries, mushrooms, aromatic and medicinal plants, hunting, fishing, biodiversity and protected areas (27.6% of the country's surface is protected by the National Network of Protected Natural Areas and the Natura2000 Network; SECF 2010), protection-regulation (erosion), recreation and amenity. The multiplicity of goods and services is also one of the main drivers in forest management planning (Table 1).

Abiotic (forest fires, erosion, drought, storms, etc.) and biotic (insects, diseases) natural hazards are also important drivers in forest management planning. Out of these, *forest fires* have usually the strongest impact on the ecosystems and therefore require special attention. Regarding this, it is remarkable that around half of the total investment in the forest sector (at the country level) during the period 2002-2008 was allocated on forest fires prevention and extinction (Foresdat, 2009). Forest fires are characteristic of Mediterranean forest ecosystems (long summer drought periods, high temperatures, strong winds) and have had significant negative impact in recent years, especially large fires (> 500 ha). In this context, sustainable forest management is not feasible if forest fires are not kept within a normal range. Extreme climatic conditions present a big challenge, but appropriate management measures regulating the abundance and continuity of fuels (silviculture, establishment of firebreaks) are crucial for prevention. Erosion is another relevant risk. Most forests in the steepest alpine and subalpine slopes are public protection forests.

Another challenge for sustainable forest management and planning in Spain is coping with *climate change*, especially in a Mediterranean context, where climatic conditions are already harsh. For instance, improving the water balance or creating appropriate forest stand structures that reduce vulnerability to increasing climate-driven risks (i.e. forest fires and droughts, etc.) may appear to be the most relevant management objectives in certain Mediterranean areas.

Forest ownership in Spain is characterized by a high degree of fragmentation (many properties smaller than 5 ha). This is often a challenge for regional planning and needs to be addressed by the establishment of forest associations. Approximately one-third of the Spanish forest surface is public (mostly forests from the municipalities, only a small proportion belongs to the state). In principle the legal framework allows free access to properties, and urban communities often search for recreation in nature (in private properties, permission from the owner is required in some case). Some activities are regulated (i.e. mushroom picking in some forests or provinces) or prohibited (e.g. camping, off-road motor biking, etc.), but many other activities are not regulated. These activities may cause damages, and forest owners often claim for the establishment of new forest policies that regulate some activities and evaluate possible compensations (i.e. the evaluation of forest externalities).

Similar to forest systems in the country, considerable variation in management planning problems can be found (see classification of forest management planning problems in Spain according to FORSYS dimensions, Table 1). Due to the common fragmentation of forest ownership ***stand level planning*** is very common and mainly relates to small private properties (<5ha, 1 or few stands). Typically the forest owner acts as a single decision-maker and one or two objectives are considered. Concerning goods and services, timber or/and biomass apply to problem *S_2* in Table 1, timber and mushroom production can be an example of problem type *S_3*, and the combination of timber with biodiversity or fire risk are common cases of problem *S_4*. At this spatial level the temporal dimension of planning may vary considerably. In small properties of the northern Atlantic regions (where short rotation forestry takes place) less than 10-year planning periods (problem *S_1*) may occur, while in many other cases strategic planning (10-20 years or longer) is usually considered.

Table 1. Classification of forest management planning problems in Spain according to the FORSYS dimensions

	Problem types [a]													
Dimensions	**S_1**	**S_2**	**S_3**	**S_4**	**L_1**	**L_2**	**L_3**	**L_4**	**L_5**	**L_6**	**L_7**	**L_8**	**L_9**	**R_1**
Temporal scale														
Long-term (strategic, more than 10y)		x	x	x	x	x	x	x						x
Medium-term (tactical, 2-10 years)	x								x	x	x	x		
Short-term (operational, 1y)													x	
Spatial context														
Non-spatial	x	x	x	x										x
Spatial with no neighbourhood interrelations							x	x			x	x		
Spatial with neighbourhood interrelations					x	x			x	x			x	
Spatial Scale														
Stand level	x	x	x	x										
Forest/landscape level					x	x	x	x	x	x	x	x	x	
Regional/national level														x
Parties involved														
Single decision-maker	x	x	x	x		x	x			x		x	x	
More than one decision-maker / stakeholders					x			x	x		x			x
Objectives														
Single	x													

Multiple		x	x	x	x	x	x	x	x	x	x	x	x	x
Goods and services														
Market non-wood products			x		x	x	x	x	x	x	x	x	x	x
Market wood products	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Market services					x	x	x	x	x	x	x	x	x	x
Non market services				x	x	x	x	x	x	x	x		x	x

[a] Problem types are named according to its spatial scale (*S*tand, *L*andscape, *R*egional). For a given spatial scale different problems are numbered consecutively.

Landscape level planning is conducted on public and private forests (>5ha):

- In the case of *private forests* it is important to distinguish between forests that belong to the pulp and paper industry (the national company ENCE manages around 70,000 ha in Spain, which implies a much smaller proportion of the total forest surface than in other countries such as Portugal) and forests belonging to non-industrial private owners. Private forests may relate to a single decision-maker (particular forest owner or industry, problem *L_2*) or to multiple decision-makers (*L_1*, *L_4*), for example in the case of private communal forests in Galicia where participatory planning between the owners takes place. Communal forests, or Montes Veciñais en Man Común (MVMC) are a specific form of communal land tenure and a singular legal category in Galicia (Northwest Spain). MVMC extend over one third of the area of the region (Gómez-Vázques et al. 2009). In other cases the administration is in charge of managing communal private forests (*L_2*, *L_3*).

  In properties where short rotation is used, the planning period may be less than 10 years (tactical planning, problems*L_5*, *L_6*, *L_7*, *L_8*) or one year (operational planning, type *L_9*). Relevant examples of forest systems that require intensive yearly planning are the forests of the pulp and paper industry, forests near a bioenergy plant, or the agrosylvopastoral systems "Dehesas". Dehesas occupy 2 million ha, mostly in the south of the country (generally in plateaus and valleys) and originate from thinnings in *Q. ilex*, *Q. suber* and *Q. coccifera* forests. Typically in arid summer conditions, the presence of trees prevents excessive soil temperatures and reduces the transpiration of the vegetation. Rainfed agriculture is usually practised in the uncovered surface, extensive cattle are fed with grasses, and trees provide fruits, fire-wood, timber, and cork.

- In landscape-level planning of *public forests* it is important to differentiate between forests with a single decision-maker (e.g. municipality, problems *L_2*, *L_3*) and forests with multiple decision-makers (*L_1*, *L_4*). Forests with multiple decision-makers are represented by communal forests (e.g. belonging to several municipalities in the Pyrenees) or by forests where some protected (nature conservation) area is included (then multiple stakeholders are involved in decision-making). Planning periods longer than 10 years are the most common in public forests.

Because forest systems in Spain are strongly characterized by its multi-functionality, landscape level planning (also regional planning) in most cases addresses all types of goods and services. Non-wood services/risks such as forest fires and biodiversity/habitat protection are almost always relevant objectives and therefore neighbourhood interrelations between stands (problem types *L_3*, *L_4*, *L_7*, *L_8*) need to be considered. However, there are cases in which neighbourhood interrelations are not crucial (e.g. if fire risk in the area is low etc.). In those cases spatial criteria with no neighbourhood interrelations (i.e. location) are implemented (problem types *L_1*, *L_2*, *L_5*, *L_6*).

The role of ***strategic regional planning*** was emphasized in the latest National Forest Plan (DGCN 2002). In recent years the development of strategic forest plans at the county level has been promoted by the autonomic governments, and it is expected to continue gaining importance. Some of the main objectives of these plans are: ensuring the achievement of pan-European sustainability criteria at different space-time levels, integrating forest management with the management of protected areas and with land-use in general, and addressing the common fragmentation of forest ownership by promoting forest owners associations, communal forests and participatory planning. Planning periods for regional strategic plans may range between 10-30 years, and usually a revision of objectives takes places every 10 years (*R_1* in table 1).

In 2006 only 12.7% of the forest surface (18.9% in terms of forested surface; SECF 2010) was regulated by an updated forest management plan (68.5% of the planned/regulated surface was public and 31.5% private). The main reason for this is the lack of profitability during the last decades (since 80s, 90s), mainly in the Mediterranean regions. The current national forest plan (DGCN 2002) aims to promote forest management planning at the national, autonomic (main administrative regional entity; Spain is divided in 17 autonomies), county and local levels (forest, stand), according to the current pan-European objectives of multi-functionality.

The largest part of the produced management plans is still based on classical approaches, i.e. cutting budget regulation methods (sometimes with some variation, see e.g. Madrigal Collazo 1995) usually based on poor/limited growth and yield models (yield tables that only apply to fully-stocked even-aged forests that sometimes are too old and not representative; simple models only based on tree size, etc.) that cannot be used in simulations. In fact economic efficiency objectives (e.g. NPV) are often not considered for doing the plans. This leads to a deficiency in formulating and evaluating alternative management regimes. Timber is the main objective and other objectives are integrated qualitatively, but not explicitly in the calculation/planning procedure. These methods are not goal-based methods, i.e. management proposals are not derived from the management goals set for the particular forest (Trasobares and Pukkala 2007). Modern multi-objective planning based on (1) the identification of decision-makers and their management goals, (2) the simulation of alternative treatment alternatives for stands, (3) the solution of a planning model (using information from simulations and information on management goals) by using an optimization tool, and (4) the use of sensitivity analysis tools for testing the solution, is required for this.

Though still not established in forest planning practice, in the last 10-15 years numerous tools for supporting modern planning have been actively developed in Spain. For example, several stand-level dynamic simulation tools enable the simulation of alternative management schedules for a broad range of stand types (see e.g. Sánchez-González 2007; Río et al. 2005; Calama et al. 2007; González et al. 2009). Some stand simulation tools have also been used in stand-level planning/optimization (Palahí and Pukkala 2003; Trasobares and Pukkala 2004; González et al. 2008, Palahí et al. 2009). At the forest/landscape level, various research studies on multi-objective forest planning (mainly for even-aged management systems) have been developed using real forest data (see e.g. Diaz-Balteiro and Romero 1998; Diaz-Balteiro and Romero 2003; Diaz-Balteiro et al. 2006; Bertomeu et al. 2009; Diaz-Balteiro et al. 2009a). The resulting planning models used mathematical programming (e.g. dynamic programming, heuristics) and multi-criteria analysis (e.g. Goal programming; Analytical Hierarchy Process) for integrating the preferences of decision-makers in the planning model. Besides, a method for aggregating expressed individual preferences has been adapted and applied to elicit social weights in the context of a real forest management problem (Diaz-Balteiro et al. 2009b). Finally, fully developed multi-objective decision support systems (integrating simulation, decision-making and sensitivity analysis tools) have been developed and applied at different spatial scales focusing on key issues such as fire risk prevention and habitat conservation (Palahí et al. 2004a; González et al. 2005).

The main objectives of this report are:

- To produce an inventory of computerized tools to support the forest management problem types prevalent in Spain.

- To include a summary description of the key features of these tools such as architecture, use of models, methods, knowledge management, and participatory functionalities, with a focus on how the tools came about (development and institutional context) and their success in addressing the key planning problems in the country.

- To evaluate the lessons learned in the assessment of decision support systems (DSS) in the country and define a possible roadmap for a successful transfer of these tools to practitioners in the coming years.

23.2 Materials and methods

The existing data and information on forest management planning and DSS in Spain were classified (and afterwards evaluated and used) as follows:

- Technical and scientific publications.

- Text books and publications on traditional forest planning (e.g. Dubordieu et al. 1993; Madrigal-Collazo 1995; González Molina et al. 2006).

- National and autonomic forest plans (e.g. DGCN 2002; Gobierno de Cantabria 2006), General instructions for forest management planning (e.g. Junta de Castilla y León 1999; Junta de Andalucía 2004).

- Publications and forest management plans developed by the autonomic forest services or private forest owners associations. See for example the various publications and reports of the Forest Planning Centre for private properties in Catalonia, CPF (www.gencat.cat/dmah/cpf), or several forest management planning manuals published in some Autonomous Communities (e.g. Martinez Sánchez-Palencia et al. 2011).

- Web pages:
    - Ministry of Environment: www.marm.es/es/biodiversidad/servicios/banco-de-datos-biodiversidad/informacion-disponible/default.aspx
    - TRAGSA: www.tragsa.es/es/sus-empresas/Paginas/tragsatec.aspx
    - INIA (forest species maps): http://sites.google.com/site/sigforestspecies/home/mapas-de-especies
    - Foreco Technologies SL: www.forecotech.com/
    - Universidad Santiago de Compostela: http://solar.usc.es/saddriade
    - Spanish Global Biodiversity Information Facility (GBIF) Node: www.gbif.es/index_in.php
    - Digital climatic atlas of the Iberian Peninsula: www.opengis.uab.es/wms/iberia/espanol/es_presentacio.htm
    - The use of spatial web services based on ISO and OGC standards (based on the EU directive INSPIRE, http://inspire.jrc.ec.europa.eu/) deserves special attention here. The Ministry of Environment publishes broad cartography related to forest systems and management through Web Map services (see www.marm.es/es/cartografia-y-sig/servicios/servicios-wms/default.aspx#para2). In addition, the administrative organization of the country in 17 autonomies also led to the establishment of specific regional servers (see e.g. http://cma.gva.es/web/indice.aspx?nodo=69939&idioma=V for Valencia)

In addition, a ***questionnaire*** (via email) was sent to the main forest management planning experts and DSS developers in the country (universities, research and technology institutes, regional forest services, public and private companies). The main objectives of the questionnaire were: (1) to identify the main planning problems in the country (according to the FORSYS dimensions); (2) to identify the main decision support tools and systems and relate them to the planning problems; (3) to collect information about the involvement of potential users and stakeholders in the development of the systems; and (4) to collect information about the use of the systems in practical applications.

The obtained results are assumed to be a good representation of the current situation, prevalent forest management planning problems (already presented in the introduction), and the available tools for supporting management planning in Spain, because the main experts and representatives from most of the requested institutions replied to the questionnaire.

The objective (supported by all tool developers) is that all selected tools will be included in the FORSYS Wiki page for Decision Support Systems (DSS) (www.fp0804.emu.ee/wiki/index.php/Main_Page).

23.3 Results

In this report we distinguish between decision support systems (DSS) and computerized tools (CT). We consider decision support systems to be those tools that integrate the main processes of decision-making (i.e. enable: 1. Selection of management objectives and its relative importance; 2. Simulation of a decision space based on a set of management alternatives; 3. Planning problem definition and solving; and 4. Evaluation of the solution using a sensitivity analysis). For those tools that only support some of the processes (e.g. a stand-level simulator of management schedules) we will use the term computerized tool (CT).

Because stand-level planning (i.e. find an optimal management schedule for a given stand and planning period according to the objectives of the decision-maker/s) on small private properties (<5ha, 1 or few stands) is the most common planning case in many regions of the country (e.g. Galicia, Catalonia), it is not surprising that many of the existing CT and DSS address this spatial level (Table 2). Management problems (already described in section 1) S_1 and S_2 (one or two wood products objectives, strategic and tactical temporal scales) are addressed by various tools. Often they are stand-alone CTs for the simulation of alternative management schedules, based on growth and yield model (G&YM), volume/assortment functions, and biomass functions. Examples of this type of tools are GesMO© simulator (Castedo-Dorado 2004; Diéguez-Aranda 2004; González et al. 2009 available in Diéguez-Aranda et al. 2009 and www.usc.es/uxfs/), PINASTER (Rodríguez Soalleiro et al. 1994), SILVES (Río et al. 2005), and ALCORNOQUE 1.0 (for cork production; Sánchez-González et al. 2007). Web-based support tools such as SIMANFOR (Bravo et al. 2010; www.simanfor.org) and SAD_DRIADE (http://solar.usc.es/saddriade) may also be used for problems S_1 and S_2. SIMANFOR allows simulating management schedules from any forest inventory source. SAD_DRIADE is based on a set of pre-defined management models/schedules that the user may select and includes GIS/maps and visualization tools. A more detailed description of stand-level support tools in Spain is also available in Bravo et al. (2011).

Some stand-level simulation tools also integrate models for predicting non-wood forest values and therefore dealing with problem S_3. PINEA2 (Calama et al. 2007) includes the prediction of pine nuts yield, while RODAL-ARBOREX (Trasobares and Pukkala 2004; González et al. 2008; Palahí et al. 2009; and www.forecotech.com/), a full DSS at the stand level (selection of objectives, simulation, optimization, sensitivity analysis tools; Table 2) integrates the prediction of mushroom yield and fire risk. Problem S_4, focusing on wood and non-market forest values can be evaluated by RODAL-ARBOREX (fire risk) and GOTILWA+ (Growth of Trees Is Limited by Water; Gracia et al. 1999, www.creaf.uab.es/gotilwa+/). GOTILWA+ is a climate sensitive process-based model that enables simulating alternative management regimes. This tool permits selecting environmental objectives such as stand water use efficiency or fire risk, and nowadays is evolving to the DSS level (the simulation module has been linked to an optimization algorithm, Table 2).

Table 2. CT/DSS, KM techniques and participatory planning methods used/developed for each Forest planning problem types

Problem type	Computerized tool/DSS	Models and methods	KM techniques (if applicable)	Methods for participatory planning (if applicable)

Problem type	Computerized tool/DSS	Models and methods	KM techniques (if applicable)	Methods for participatory planning (if applicable)
S_1, S_2	RODAL-ARBOREX	Multi-objective (G&Y_M, biomass, CO2, mushrooms, fire risk) stand simulator Selection of objectives, Optimisation (non-linear programming) of stand management	Database, Visualization	-
	GesMO©	G&Y_M, simulation of stand management		-
	PINEA2	G&Y_M, simulation of stand management	-	-
	ALCORNOQUE 1.0	G&Y_M, simulation of stand management	-	-
	PINASTER	G&Y_M, simulation of stand management	-	-
	SILVES	G&Y_M, evaluation of thinnings	-	-
	SAD_DRIADE	Management models based on growth, management costs, economic models	GIS, Database, Visualization	-
	SIMANFOR	Web platform, G&Y_M, simulation of stand management	Database	-
S_3	RODAL-ARBOREX	Same as previous description of the tool	Same as previous	-
	PINEA2	Multi-objective (timber, biomass, CO2, cone production) stand simulator	-	-
S_4	GOTILWA+	Climate sensitive multi-objective (timber, biomass, CO2, water use efficiency, fire risk) simulation-optimisation (Particle Swarm alg.) of stand management	Database, data mining	-
	RODAL-ARBOREX	Same as previous	Same as previous	
L_1, L_2, L_2, L_5, L_6, L_7, L_8	MONTE	Multi-objective stand simulation models (wood products, mushrooms, fire risk, etc.); prescription writer; objectives/preferences selection module; planning module: model writer + optimization tool (including spatial objectives); sensitivity analysis tools	Database, data mining, Visualization tools, thematic maps, interactive dialogs	Multi-attribute utility function in objectives/preferences selection module enables group decision-making
L_4	SILVANET	Multi-objective and group decision-making model, G&Y_M	Visualization and interactive	Group decision-making techniques

Problem type	Computerized tool/DSS	Models and methods	KM techniques (if applicable)	Methods for participatory planning (if applicable)
			dialogs	
	MONTE	Same as previous	Same as previous	Same as previous
R_1	ESCEN	Reads regional forest inventory sample (e.g. NFI grid); Multi-objective stand simulation models of various goods and services (timber, biomass, CO2, fire risk, diversity, etc.)	Database, Visualization tools	-
	SIMANFOR	Allows simulation of management alternatives using a regional forest inventory sample	Database	-
	SAD_DRIADE	Management models can be applied at the regional level	GIS, Database	-
L_9	Not covered			

As described in section 1, the prevalent landscape level planning problems in Spain encompass variation in terms of temporal scale, spatial context, parties involved and objectives (Table 1). To date, MONTE (Palahí et al. 2004b; www.forecotech.com) is the main tool available for landscape/forest problems (i.e. determine a specific management schedule for each stand in the forest so that a global objective is maximized). MONTE is a forest/landscape-level DSS designed to optimise forest resources and maximise forest owner benefit. MONTE is organized into various subsystems: 1) database management system; 2) multi-objective simulation system (timber, biomass, carbon, fire risk, mushroom yield, fire risk; *All landscape planning problems*); 3) planning system that formulates and solves problems using an optimisation tool (mathematical programming or heuristics; Pukkala 2002); and 4) sensitivity analysis system (visualization of forested landscapes based on the DTM of the forest, tree symbols or Virtual reality modelling). MONTE permits considering spatial objectives (i.e. neighbourhood interrelations: *Problems L_1, L_2, L_5, L_6*), for example the impact of forest management on the habitat of indicator species (Palahí et al. 2004a) or forest fires (González et al. 2005).The system may be adjusted to interpret the spatial context of stands with no neighbourhood interrelations (*L_3, L_4, L_7, L_8*) and also to tactical (*L_5-L_8*) and strategic (*L_1-L_4*) temporal scales.

MONTE can be used for solving problems with one or multiple decision-makers (module with multi- attribute utility function for participatory planning; *L_1, L_4, L_5, L_7*). *Participatory planning* may also be conducted using SILVANET (Martinez Falero et al. 2010). This software can be used for *problem L_4* and provides a tool to aggregate different preferences in order to choose the best management planning. The application requires a LIDAR-based inventory of the stands studied and yield tables. No other CT or DSS allows the integration participatory processes in management planning (Table 2). It is important to remark that to date no *tools are available for addressing Problem L_9* (operational planning landscape-level problems).

Strategic Regional planning (*problem R_1*) can be supported using simulators that project regional forest inventory samples according to optional management alternatives (e.g. NFI). ESCEN (www.forecotech.com/), SIMANFOR, and to some extent SAD_DRIADE (not simulating but assuming a given set of management models) can be used for this purpose. For example ESCEN, that uses multi-objective stand simulation models of various goods and services (timber, biomass, CO_2, fire risk, diversity, etc.), has been used for simulating alternative regional management scenarios in Catalonia. This gives the planner the possibility to analyse the overall development of the forest resource (biomass, carbon sequestration, biodiversity, etc.) and the long-term consequences of policy alternatives.

Although it is not really a tool for forest management planning, but a support tool for soil evaluation and protection, we believe it is relevant to mention the MicroLEIS DSS (http://.evenor-tech.com) here. The system incorporates a set of information tools grouped into the following main modules: i) basic data warehousing, ii) land evaluation modelling, and iii) model application software. Custom applications can be carried out on a wide range of problems related to sustainable use, optimum biomass productivity, minimum environmental vulnerability and maximum CO_2 sequestration (Anaya-Romero et al. 2011). Additionally, climate change scenarios may be considered together with other important global change elements (e.g. land use change, Muñoz et al. 2011; desertification; and agriculture intensification, Shahbazi et al. 2008), in order to develop and implement territorial strategies. MicroLEIS has more than 5,000 users worldwide (although most belong to academia).

Databases, GIS, and in some cases visualization tools (e.g. MONTE DSS), are *Knowledge Management* techniques commonly used in the reviewed support tools. In general, knowledge management doesn't play a central role in the available tools. However, its role is significant in the above described MicroLEIS DSS, and to some extent in MONTE and SAD_DRIADE.

It is of relevance for the purpose of this review report to go through the type of users, development context, and use in practical management problems of the presented support tools. Table 3 shows some of the main results obtained from the questionnaires sent to the main forest management planning experts and DSS developers in the country. In most cases the education of the users is graduate or higher level, although some tools are also used/conceived for users that are not graduates but have a minimum IT knowledge. Many of the tools resulted from research projects during the last 10-15 years (e.g. PhD thesis). In some cases the projects were also related to the public administration, industries, or consulting companies. Consequently, the tools are often used in education and most of the users belong to universities and research centres (followed by the administration and some consulting company). In many cases a rather short training time is assumed (few hours or one day),but some tools may require one week or more. The number of forest management practical applications ranges from 0 to >100. Practical applications seem to be more common in stand-level tools. It seems that users participate often in the development of the tools (at least to a preliminary identification of needs). However, in most occasions the interaction is based on possible modifications of an existing tool rather than collecting guidelines for building a new tool from scratch.

Table 3. Description of the users, development context, and practical application of the presented support tools.

Computerized tool/DSS	Education of users	Organization of users (to date)	Required training time	Number of practical applications	Project origin	Use in education	Participation of users in development
RODAL-ARBOREX	Any, provided min. IT knowledge	Administration, Industry, Consulting company, University/ Res. Centre	1 hour	>50	Research/ Consultancy (2004)	Direct use by students	Tool already existing Needs identification, development, evaluation
GesMO©	Any, provided min. IT knowledge	Administration, Industry, Consulting company, University/ Res. Centre	1 hour	>100	PhD thesis (2003)	Direct use by students	Tool already existing Evaluation phase
PINEA2	Graduate/ Postgraduate	Administration, University/ Res. Centre	1 day	<=10	Administration/PhD thesis (2001)	Demo/direct use by students	Tool already existing Needs identification
GOTILWA+	Graduate/ Postgraduate	University/ Res. Centre	1 week	0	Research (1999)	Demo/direct use by students	Tool already existing
ALCORNOQUE 1.0	Graduate/ Postgraduate	University/ Res. Centre	<= 1 day	0	PhD thesis (2006)	Seminar	Tool already existing Needs identification
SILVES	Graduate/ Postgraduate	Administration University/ Res. Centre	-	<=3	PhD thesis (2001)	-	No
MONTE	Graduate/ Postgraduate	Administration, Consulting company,	1 day	<=10	Research/ Consultancy (2004)	Direct use by students	Tool already existing Needs identification, development,

Computerized tool/DSS	Education of users	Organization of users (to date)	Required training time	Number of practical applications	Project origin	Use in education	Participation of users in development
		University/ Res. Centre					evaluation
SILVANET	Graduate/ Postgraduate	University/ Res. Centre	-	1	Research (2010)	-	-
SAD_DRIADE	Graduate/ Postgraduate	Administration, Industry, Consulting company, University/ Res. Centre	1 day	<=10	Research/ Consultancy (2009)	Direct use by students	Needs identification, design, development, evaluation
SIMANFOR	Graduate/ Postgraduate	University/ Res. Centre	2-3 hours	0	Ministry of science and innovation (2006)	Direct use by students	Needs identification, design, development, evaluation
ESCEN	Graduate/ Postgraduate	Administration, University/ Res. Centre	2-3 hours	<=3	Research/ Consultancy (2004)	Seminar	Tool already existing Needs identification
MicroLEIS	Graduate/ Postgraduate	University/ Res. Centre Administration, Consulting company,	<= 1 week	>100	Research (2009)	Demo/direct use students	Yes, but most belong to academia

23.4 Discussion and conclusions

The regular use of CT and DSS in forest management planning is still limited to a small group of users, most of them working in universities and research institutions. However, some practical use is starting to arise in public administrations and consulting companies. In most cases this relates to stand-level simulation tools, because they are simple (a few hours of training required, Table 3) and close to the basic skills/knowledge from practitioners. However, the transfer of fully developed DSS systems (e.g. landscape-level systems or stand-level simulation-optimization tools) is more challenging. These tools are more complex and rely on modern information technologies which often are unknown by practitioners, especially by those that graduated some years ago.

The survey on computerized tools developed to support forest management planning in Spain revealed the existence of a wide range of tools to support *stand-level planning*. Examples of the increasing relevance of these tools in practice are the use of RODAL-ARBOREX by the Forest Planning Centre for private properties in Catalonia (CPF, Public institution in charge of promoting and regulating forest management planning in private properties of Catalonia), the use of GesMO© by the public administration and industries in Galicia, or the use of PINEA2 by the administration.

The interaction with practitioners in the development of the tools has been identified as a key aspect for promoting practical use. The example of RODAL-ARBOREX illustrates this. Initially a preliminary version of the tool was not very successful in meeting the daily requirements of the planners in CPF. For example, the calculated variables by the tool were not exactly the same as those considered in local management plans, and some dialogs and results tables were not meeting daily work requirements. Consequently, quite intensive interaction was needed to meet the needs of the users. Up to now only the simulation module of the tool has been transferred. Dealing with the solution of an optimization problem, even when proposing an easy-to-use interface, may require longer interaction and training.

If interaction with users is promoted (seems to start taking place in most cases, see Table 3) and training is sufficient we believe that many of the already existing tools for solving problems *S_1*, *S_2*, *S_3* could be successfully transferred to practice. In addition, in the case of recently developed tools, it may be more efficient to interact with the users/stakeholders since the initial design phase of the tool. This seems to be the path adopted by some recently developed tools such as SIMANFOR (Table 3). In the case of problem *S_4* and similarly to the use of optimization tools, the integration of risk (e.g. fire, drought) and climate scenarios in the predictions may require more specific consideration. Even though a process-based tool such as GOTILWA+ already provides good self-explanatory and intuitive interfaces, special emphasis should be placed on both the design of an effective/simple user interface and training. The success of stand-level support tools may also be improved by the integration of multiple objective techniques (i.e. integrating missing models for relevant non-wood and non-market values, adding an explicit dialog for objective selection and ranking) and expert knowledge (expert recommendations displayed as metadata, i.e. knowledge management).

Few tools are available for modern landscape-level strategic and tactical planning (Table 2). Basically only MONTE is a full DSS and has been used in various pilot projects, while SILVANET appears to be a more specific tool for group decision-making. In principle this may look surprising because large variation in forest/landscape management problems (L_1-L_9) has been identified. However there are several reasons for this. For instance, DSS for landscape-level planning are conceptually more complex than stand-level tools, and require more training and knowledge on modern information technologies. This is often hard to achieve with technicians who are used to applying traditional cutting budget methods. In addition, the common high fragmentation of the forest ownership often prevents the use/establishment of a more complex planning approach.

The example of the adaptation of MONTE to various practical problems (public and private forests representative of management *problems L1-L8*) is also illustrative (and also required significant interaction with practitioners). The baseline version of the system, originally developed in a research framework, was attractive (e.g. interactive dialogues, visualization) but difficult to understand/use by the average user. In general some user interfaces were not intuitive enough for beginners and the main steps to follow were not adequately presented. To solve this, several dialogues were simplified and the main steps in planning (i.e. calculation of current state, simulation of alternatives, selection of objectives, optimization, and sensitivity analyses) were clearly introduced along the planning process. The integration of non-wood (mushroom yield) and non-market objectives (fire risk, scenic beauty, biodiversity) as well as the use of thematic maps in problems considering neighbourhood interrelations was also important in the practical adaptation of the tool. Nowadays, the current version of the tool is more accessible and for most users. Nevertheless the required training effort is still a challenge. Until DSS are regularly used in all education centres it is more realistic to expect that in each institution or group one person could learn how to use the tool in detail rather than hoping that most members will reach that level.

The lack of tools for operational management planning (optimizing time/space relationships for harvesting and transportation of products; *problem L_9*) may be explained by the small relative presence of the industry compared to other countries such as Portugal. Still, the application of this type of system could also be useful for the emerging management problems focusing on potential biomass supply for bioenergy plants (perhaps also to the agrosylvopastoral systems "Dehesas"). Therefore the development or adaptation of such tools should be considered in the near future.

Simulating regional scenarios is probably simpler than landscape-level planning. However, very few applications in regional strategic planning have been reported so far. Some initial exercises, for example projecting the NFI grid for a given region, have been developed but the required structure of the tools for this type of management problem is still not clear. To develop the recently promoted strategic regional plans one may need to combine regional simulations (e.g. using ESCEN or SIMANFOR) with analyses at more detailed spatial resolution (landscape or even representative stands). For this purpose using a GIS module and/or a link with Google Earth may supply a good basis for analyses. SAD_DRIADE provides a good example of this approach.

The following points may be of relevance for improving the existing tools and achieving significant transfer to practical use in the coming years:

- Multi-objective (spatial considerations such as fires risk or biodiversity or the development of missing models for non-wood and non-market goods and services) and group decision-making approaches for landscape and regional planning should be developed and integrated in the tools.

- The integration of GIS and visualization technologies (Google Earth) combined with knowledge management (databases on previous periods, expert knowledge) approaches may ease the solution of regional and spatial landscape problems and improve usability and attractiveness of the tools (for the users).

- The use of the tools by and through the administration (i.e. the administration prescribes the use of a given tool/set of tools for developing, for example, regional and landscape-level management plans in a given region) should be strongly promoted.

- Modern planning and information technologies concepts as well as the use of representative CT and DSS tools should become an essential item in the study plans of all universities and education institutions related to forest and natural resources management planning in the country.

Finally, another challenge for forest management and planning in Spain is coping with climate change, especially in a Mediterranean context. In such a context, forest management objectives, decision-making tools and strategies will need to adapt to potential new conditions and new demands for goods and services. There are several ways to respond to this increased uncertainty. The first option is to convert current static periodical planning into a dynamic continuous process which allows updating or re-planning when something makes the plan obsolete (a fire, a change in the management objectives, etc) or no longer justified. Another way to address risk and uncertainty is to accommodate them explicitly in the forestry decision-making process (see González et al. 2005 and GOTILWA+). This can be done by analysing the outcome of different management plans under different scenarios with known or unknown probabilities. Such approach converts deterministic planning into stochastic analysis, providing information about the alternative plans through the probability distributions of the objective variables (Gonzílez et al. 2005). Stochastic planning allows for considering the attitude of decision-makers towards risk and uncertainty.

Adaptive planning is another approach to react to risk and uncertainty. In adaptive planning, decision-makers may adapt their plan according to the changing situations because adaptive planning produces instructions on how to react to different changes; in growth predictions, management objectives, sudden droughts or forest damages from fires, etc. Relevant examples of the development of methods and DSS for copying with climate uncertainty and adaptation are being developed within the framework of the MOTIVE project (Models for Adaptive Management; http://motive-project.net/).

References

Anaya-Romero, M., Muñoz-Rojas, M. and De la Rosa, D. 2011. MicroLEIS DSS, a sustainable land use and management decision support system for maximizing carbon sequestration. European Geosciences Union General Assembly 2011.Vienna (Austria). Geophysical Research Abstracts Vol. 13, EGU2011.

Bertomeu, M., Diaz-Balteiro, L., Gimenez, J.C. 2009. Forest management optimization in Eucalyptus plantations: a goal programming approach. Can. J. For. Res. 39: 356–366.

Bravo, F., Rodríguez, F. and Ordoñez A.C. 2010. SimanFor: sistema de apoyo para la simulación de alternativasde manejo forestal sostenible. Available in www.simanfor.es (last access 15th april 2010). [In Spanish].

Bravo, F.,Alvarez-Gonzalez, J. G., Del Rio, M., Barrio, M., Bonet, J. A., Bravo-Oviedo, A., Calama, R., Castedo-Dorado, F., Crecente-Campo, F., Condes, S., Dieguez-Aranda, U., Gonzalez-Martinez, S. C., Lizarralde, I., Nanos, N., Madrigal, A., Martinez-Millan, F. J., Montero, G., Ordoñez, C., Palahi, M., Pique, M., Rodriguez, F., Rodriguez-Soalleiro, R., Rojo, A., Ruiz-Peinado, R., Sanchez-Gonzalez, M., Trasobares, A., and Vazquez-Pique, J. 2011. Growth and yield models in Spain: historical overview, contemporary examples and perspectives. Forest Systems 20(2): 315-328.

Calama, R., Garriga, E., Bachiller, A., Gordo J., Finat, L. and Montero, G. 2007. PINEA2: un modelointegrado para la gestión de las masas regulares de Pinuspinea L. en la Meseta Norte. Cuadernos SECF 23, 147-152. [In Spanish].

Castedo-Dorado F., 2004. Modelo dinámico de crecimientopara las masas de Pinus radiata D. Don en Galicia.Simulación de alternativas selvícolas con inclusión delriesgo de incendio. Doctoral thesis. Universidad de Santiagode Compostela, Lugo. [In Spanish].

DGCN, Plan Forestal Español, Ministerio de medio Ambiente, Madrid, 2002.

Diaz-Balteiro, L. and Romero, C. 1998. Modelling Timber Harvest SchedulingProblems with Multiple Criteria: An Application in Spain.ForestSci. 44(1): 47-57.

Diaz-Balteiro, L., Romero, C, 2003. Forest management optimisation models when carbon captured is considered: a goal programming approach. For.Ecol.Man. 174, 447–457 pp.

Diaz-Balteiro, L., Rodriguez, L.C.E., 2006. Optimal rotations on Eucalyptus plantations including carbonsequestration - A comparison of results in Brazil and Spain.For.Ecol.Man. 229,247–258.

Diaz-Balteiro, L., Bertomeu, M., Bertomeu, M., 2009a. Optimal harvest scheduling in Eucalyptus plantationsA case study in Galicia (Spain).ForestPolicyEcon. 11, 548-554.

Diaz-Balteiro, L., González-Pachón, J.,Romero, C, 2009b. Forest management with multiple criteria and multiple stakeholders:An application to two public forests in Spain. Scand. J.ForestRes.24: 87-93.

Diéguez-Aranda U., 2004. Modelo dinámico decrecimiento para masas de Pinus sylvestris L. procedentesde plantación en Galicia. Doctoral thesis. Universidad deSantiago de Compostela. [In Spanish].

Diéguez-Aranda U., Diéguez-Aranda, U., Rojo Aboreca, A., Castedo Dorado, F., Álvarez González, J.G., Barrio Anta, M., Crecente-Campo, F., González González, J.M., Pérez-Cruzado, C., Rodríguez Soalleiro R., López-Sánchez, C.A., Balboa Murias, M.A., Gorgoso Varela, J.J., Sánchez Rodríguez F.. 2009. Herramientas selvícolas para la gestión forestal sostenible en Galicia. Consellería do MedioRural, Xunta de Galicia. 268 pp. + CD-Rom. [In Spanish].

Dubourdieu, J., Prieto, A., LópezQuero, M. 1993. Manual de ordenación de montes. Paraninfo. Madrid.

Foresdat, 2009. Asociación Nacional de Empresas Forestales. http://www.foresdat.es/

Gobierno de Cantabria, Consejería de Agricultura, Ganadería y Pesca, 2006. Plan Forestal de Cantabria.

Gómez-Vázquez, I., Álvarez-Álvarez, P., Marey-Pérez, M.Fco. 2009. Conflicts as enhancers or barriers to the management of privately owned common land: A method to analyze the role of conflicts on a regional basis. Forest Policy Econ. 11: 617-627.

González, JR., Palahí, M., Pukkala, T. and Trasobares, A. 2005. Integrating fire risk considerations in forest management planning – a landscape level perspective. Landscape Ecol. 20 (8), 957-970.

González, J.R., Palahí, M., Trasobares, A. and Pukkala, T. 2006. A fire probability model for forest stands in Catalonia (north-east Spain). Ann. For.Sci.63: 169-176

González, J.R., Trasobares, A., Palahí, M. and Pukkala, T, 2007. Predicting stand damage and tree survival in burned forests in Catalonia (North-East Spain).Ann.For. Sci.64: 733-742.

González González, J.M., Castedo-Dorado F.,Diéguez-Aranda U., Rojo Alboreca A., Álvarez González J.G., 2009. GesMO 2009. Simulador decrecimiento y producción de rodales forestales. Universidadde Santiago de Compostela (available at www.usc.es/uxfs).

González Molina, J.M., Piqué, M.,Vericat, P. 2006. Manual de ordenación por rodales. Gestión multifuncional de los espacios forestales. Centre Tecnològic Forestal de Catalunya.

González-Olabarria, J.R. Palahí, M. Pukkala, T. Trasobares, A. 2008 Optimising the management of PinusnigraArn.stands under endogenous risk of fire in Catalonia.InvestigacionAgraria: Sistemas y Recursosforestales.17 (1): 10-1

Gracia C.A., Tello E., Sabaté S. and Bellot J. 1999. GOTILWA: An Integrated Model of Water Dynamics andForest Growth. In Rodà F. et. al. (eds) Ecology of Mediterranean Evergreen Oak Forests. Ecological Studies,Vol. 137. Springer Verlag, Berlin Heidelberg. pp 163-179.

Junta de Andalucía, 2004. Instrucciones Generales para la Ordenación de Montes de la Comunidad Autónoma deAndalucía. ORDEN de 26 de enero de 2004.

Junta de Castilla y Léon, 1999. Instrucciones Generales para la Ordenación de los Montes Arboladosen Castilla y León, DECRETO 104/1999, de 12 de mayo de 1999.

Madrigal Collazo, A. 1995. Ordenación de montesarbolados, ICONA, Madrid, Spain.

Martínez Falero, J.E., Martín Fernández, S., García Abril, A. 2010. SILVANET. Participación pública para la gestión forestal sostenible. Fundación Conde del Valle Salazar, Madrid.

Martínez Sánchez-Palencia, S., Prieto, A., Díaz Balteiro, L., Saura Martínez de Toda, S. 2011. Manual para la redacción de instrumentos de gestión forestal sostenible en Castilla la Mancha. Junta de Comunidades de Castilla la Mancha. Consejería de Agricultura y Medio Ambiente, Toledo.

Muñoz-Rojas, M., Anaya-Romero, M., Zavala, L., Jordan, A., De la Rosa, D.2011. Land Cover change and vegetation carbon stocks in Andalusia region, Southern Spain (1956-2007). Science of the Total Environment. 409, 2796-2806.

Ninyerola M, Pons X, Roure JM 2007a. Objective air temperature mapping forthe Iberian Peninsula using spatial interpolation and GIS.International.Journal of Climatology 27: 1231-1242 DOI: 10.1002/joc.1462.

Ninyerola M, Pons X, Roure JM 2007b. Monthly precipitation mapping of theIberian Peninsula using spatial interpolation tools implemented in aGeographic Information System. Theoretical and AppliedClimatology 89:195-209 DOI (2006) 10.1007/s00704-006-0264-2.

Palahí, M., and Pukkala, T., 2003. Optimising the management of Scots pine (Pinus sylvestris L.) stands in Spain based on individual-tree models. Ann. For. Sci. 60: 105-114.

Palahí, M., Pukkala, T., Pascual, L., Trasobares, A. 2004a. Examining alternative landscape metrics in ecological forest landscape planning: a case for capercaillie in Catalonia. Investigaciones Agrarias: Sist. Recur. For. 13 (3): 527-538.

Palahí, M., Pukkala, T., Pérez, E., Trasobares, A. 2004b.Herramientas de soporte a la decisión en la planificación forestal. Revista forestal MONTES. N-78-IV Trimestre. Page 40.

Palahi, M., Pukkala, T., Bonet, J.A., Colinas, C. Fischer, C.R., Aragón, J.M. 2009 Effect of theInclusion of Mushroom Values on the Optimal Management of Even-Aged Pine Stands of Catalonia. Forest Sci., Volume 55, Number 6: 503-511(9).

Pukkala, T. (ed.). 2002. Multi-objective Forest Planning.Kluwer Academic Publishers.

Río, M., Roig, S., Cañellas, I. and Montero G. 2005. Programación de claras en repoblaciones de Pinus sylvestrisL. Seguimiento de sitios de ensayo en la Comunidadde Madrid. Monografías del INIA: Serie forestal 12, 46pp. [In Spanish].

Rodríguez Soalleiro R., Álvarez González J.G. and Vega G. 1994. Piñeiro do país: modelo dinámicode crecemento de masas regulares de Pinus pinaster Aitonen Galicia (Guía para o usuario do programa PINASTER).Capacitación e Extensión. Serie Manuais Prácticos 8.Consellería de Agricultura, Gandería e Montes, Xunta deGalicia, Santiago de Compostela. 40 pp. [In Galician].

Sánchez-González M., Calama, R., Cañellas I., Montero, G. 2007. Management oriented growthmodels for multifunctional Mediterranean Forests: thecase of Cork Oak (Quercus suber L.). EFI Proceedings 56: 71-84.

SECF Sociedad Española de Ciencias Forestales, 2010. Situación de los Bosques y del Sector Forestal en España. http://www.secforestales.org/web/index.php?option=com_content&task=view&id=58&Itemid=39

Shahbazi; F., De la Rosa, D., Anaya-Romero, M., Jafarzadeh, A., Sarmadian, F., Neyshaboury, M., and Oustan, S. 2008. Land use planning in Ahar area(Iran) using MicroLEIS DSS.International Agrophysics. 22, 3, 277-286.

Trasobares, A. and Pukkala, T. 2004. Optimising the management of uneven-aged Pinus sylvestris L. and Pinus nigra Arn. mixed stands in Catalonia, north-east Spain. Ann. For. Sci. 61 (8): 747-758.

Trasobares, A., Pukkala, T., 2007. Modern tools to support decision-making in forestry. Proceedings of the Ambienta Congress in Zagreb, Croatia, 15th October, 7 pp.