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Review

Making forestry decisions with multiple criteria: A review and an assessment

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Abstract

This paper provides a survey of the literature on multiple criteria decision-making (MCDM) applications to forestry problems undertaken in the last 30 years or so. More than 250 references regarding 9 forestry topics and 9 different MCDM approaches have been categorized and evaluated. This provides a unified source of references that could be useful for forest management students, researchers and practitioners. The paper ends with an assessment of the literature presented, aiming to reach some conclusions, as well as indicate future trends in this line of research.

Keywords: Forestry; Multiple criteria decision-making; Optimization

Contents

1. Introduction

Forest resource planning is a very complex problem mainly due to the multiplicity of wide-ranging criteria involved in the underlying decision-making process. Thus, every decision made affects criteria of different nature like

(a) Economic issues (e.g., timber, forage, livestock, hunting, etc.).
(b) Environmental issues (e.g., soil erosion, carbon sequestration, biodiversity conservation, etc.).
(c) Social issues (e.g., recreational activities, level of employment, population settlement, etc.).

In accordance with these ideas, most public or private decision-makers involved in any type of forest planning problem have a preference structure embedding several

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decision-making criteria such as the ones described above. This is especially true in the case of publicly owned forests. Briefly, the optimization problem underlying most real forest planning problems needs to be formulated within the multiple criteria decision-making (MCDM) paradigm.

What is more, the complexity of most forestry problems is currently increasing because of the way in which different social groups or stakeholders perceive the relative importance of these criteria. Hence, the joint use of MCDM and group decision-making (GDM) approaches and techniques has turned out to be of paramount importance for some forestry problems.

This paper attempts to improve the forestry profession's awareness of the potential role that MCDM and GDM approaches and techniques can play, and have actually played, in solving forestry problems. We shall therefore review MCDM's and GDM's main contributions to the broad field of forest planning over the last 30 years or so. Note that MCDM approaches have long been used in forestry, resulting in a sizeable number of publications, with Field (1973) pioneering work in this direction over 30 years ago. However, the use of GDM approaches and techniques in forest planning does not go very far back. In fact, the first works on this subject were published in the early 1990s (e.g., Kangas, 1994a).

The remainder of the paper has been organized as follows. In Section 2 a double-entry classification scheme has been introduced. The first entry refers to the MCDM technique, whereas the second refers to the forestry area of application. In Section 3, the basic features of the MCDM approaches most widely used in forestry are briefly commented. In the next section, the different contributions in the nine applied areas defined are reviewed. The paper ends with an assessment of the categorized bibliography. In this sense, more than 250 references to papers published in major English-language journals have been categorized following the double-entry scheme defined in Section 2. This section also aims to reach some general conclusions as well as indicate future trends in this line of research.

2. Classification scheme

The following keys were used to define the theoretical procedure or approach used in each paper:

A. Multi-Objective Programming (MOP).
B. Goal Programming (GP).
C. Compromise Programming (CP).
D. Multi-Attribute Utility Theory (MAUT).
E. Fuzzy Multi-Criteria Programming (FMCP).
F. Analytic Hierarchy Process (AHP).
G. Other Discrete Methods (ODM).
H. Data Envelopment Analysis (DEA).
J. Group Decision Making Techniques (GDM) techniques.

The following keys were used to define the forestry area of application for each paper:

I. Harvest scheduling problems.
II. Extended harvest scheduling problems.
III. Forest biodiversity conservation.
IV. Forest sustainability.
V. Forestation.
VI. Regional planning.
VII. Forestry industry.
VIII. Risk and uncertainty.
IX. Miscellaneous topics.

Both keys appear between brackets at the end of each reference in the categorized bibliography. The first symbol refers to the application area and the second to the theoretical procedure used. Thus, [IV, B] would mean that the reference analyzed is a forest sustainability problem by using a GP formulation. Some references include more than one key referring to the theoretical procedure used or to the application area. For example, [III, A;D] corresponds to a forest biodiversity conservation case addressed with the help of MOP and MAUT techniques.

Finally, note that the above topic classification is questionable and does not claim to be a precise ‘‘pigeonhole’’ system. The location of some of the papers appearing in the categorized bibliography is arguable. For instance, some papers classified as ‘‘extended harvest scheduling problems’’ could have been done so as ‘‘forest biodiversity conservation’’ and vice versa. However, this is not an especially relevant matter for the purposes of this paper. The proposed classification actually has the pragmatic goal of building up a sensible classification analyzing different forestry problems, all of which take an MCDM perspective and have been published in one of over 50 major journals. In this review, we have not, like other authors (Porté and Bartelinka, 1998), followed procedures based on searching for keywords in several scientific databases. We have only considered MCDM papers included in the Expanded Web of Science database and no other papers or MCDM books have been included.

3. A brief review of the main MCDM approaches

Readers are assumed to know something about the basic aspects of the different MCDM/GDM approaches. However, in order to provide for a self-contained paper, the following are some brief comments explaining the basic ideas underlying each approach. The brief explanation of the several approaches will be referenced with key sources, where readers can consult detailed technical presentations.

MOP addresses the issue of optimizing several objectives subject to a set of constraints. Given any level of conflict among the objectives, which is a commonplace occurrence, not all of them can be simultaneously optimized. Instead of searching for a non-existent optimum, the MOP approach seeks to find a set of efficient solutions (i.e., the pareto-optimal set). Efficient solutions are those in which no other feasible solution can improve one objective without degrading at least one other (Steuer, 1989).

Within a GP context, a target has been established that represents a desirable level of achievement for each of the criteria considered. GP minimizes, by defining an achievement function, unwanted deviations between the target values and the actual figures achieved by the respective criteria (Tamiz et al., 1998; Ignizio and Romero, 2003).

CP defines the ideal point as a vector whose components are given by the optimum values of the criteria considered. The ideal point is obviously infeasible, and it is only used as a point of reference. Within CP, the ‘‘most suitable’’ or ‘‘best-compromise’’ solution is defined as the efficient solution closest to the ideal point. By using different distance measures (metrics), a set of compromise solutions can be established as the ‘‘most suitable solutions’’ (Yu, 1973; Zeleny, 1974).

MAUT attempts to define a cardinal utility function comprising all the relevant criteria. This multi-attribute utility function is optimized subject to its respective constraints (Keeney and Raiffa, 1976). FMCP is any type of MCDM approach (MOP, GP, etc.), for which some of the model parameters (e.g., right-hand sides, coefficients of the objective functions, etc.) are fuzzy rather than crisp numbers with a definite mathematical structure (triangular, trapezoidal, etc.). The main purpose of FMCP approaches is to introduce into the model the imprecision usually inherent in the information available (Zimmerman, 1996).

Within an AHP context, decision-maker preferences are represented by a ‘‘pairwise’’ comparison procedure of criteria and alternatives based on a linguistic scale and within a hierarchical structure. A set of weights at each level of the hierarchy are elicited from the ‘‘pairwise’’ comparison matrices in order to obtain the respective ranking of alternatives (Saaty, 1980; Forman and Gass, 2001).

DEA is a well-known, linear-programming-based, non-parametric approach (Charnes et al., 1978) that is widely used to analyze the efficiency of a set of organizational units like a set of forest districts. The links between DEA and MCDM are clear and strong, because of that many authors now include DEA within the MCDM paradigm (e.g., Stewart, 1996; Joro et al., 1998).

The GDM discipline has a really impressive arsenal of tools. Within a forestry context, the tools used up to now have been based on ordinal scales, like the multi-criteria approval method (e.g., Laukkanen et al., 2004) or on cardinal valuations like the MAUT-based HERO method (Pukkala and Kangas, 1993). In any case, the application of GDM approaches to forest planning problems is a promising, relatively new area of research.

4. Forest topics

4.1. Harvest scheduling problems

Timber harvest scheduling is the first area in the forestry field where the MCDM paradigm has been widely applied. Let us start the review of this section with papers using MOP techniques. Thus, de Kluyver et al. (1980) formulated a two-stage model, combining MOP and dynamic programming, for determining optimum management regimes, first at a stand level, and second at the whole forest level. Hallefjord et al. (1986) combined an MOP model with a growth simulation system for solving a strategic planning problem in a Swedish forest. Mendoza et al. (1987b) formulated several MOP problems for addressing an agro-forestry problem with two objectives: the maximizations of the net present value (NPV) and of the black walnut volume. Roise (1990) proposed an MOP model with two objectives in order to integrate the adjacency constraint within a harvest scheduling problem. Krcmar-Nozic et al. (1998) designed a two-stage methodology incorporating an interactive MOP model with a heuristic procedure in order to determine the best management alternatives in a Canadian forest. Following a similar line, Ducheyne et al. (2004) combined the MOP with genetic algorithms for addressing a harvest scheduling problem in a Scottish forest.

GP has also been widely used for tackling harvest scheduling problems. Thus, Kao and Brodie (1979) formulated a linear GP model for reconciling economic, even-flow and regulation criteria. Field et al. (1980) and Hotvedt et al. (1982) proposed different extensions of this approach by resorting to a weighted GP model and interactive GP. Kangas and Pukkala (1992) formulated a GP model, in which AHP was used for eliciting the preferential weights of the decision-maker. Diaz-Balteiro and Romero (1998) combined GP, CP and AHP to obtain harvest schedules representing good compromises between NPV, even-flow, area control and ending inventory. Finally, Gómez et al. (2006) proposed a fractional lexicographic GP model for determining the optimum harvest schedule of a plantation of *Pinus caribaea* and *Pinus tropicallis* in Cuba.

Howard and Nelson (1993) resorted to a MAUT model with three attributes for solving a specific harvest scheduling problem. Pykäläinen (2000) has proposed a variant of the HERO method with strong interactive elements for integrating forest owner goals. Heinonen and Pukkala (2004) used this type of approach for addressing harvest scheduling issues integrating spatial aspects. Finally, Bare and Mendoza (1992) and Pickens and Hof (1991) addressed this type of problem with the help of fuzzy GP models.

4.2. Extended harvest scheduling problems

This section reviews harvest scheduling problems including timber as well as non-timber criteria (hunting, recreation, carbon sequestration, etc.). We shall start with problems of a continuous nature formulated as MOP models. Thus, Steuer and Schuler (1978) formulated an interactive MOP model that includes criteria related to hunting, recreation and grazing. Mendoza et al. (1987a), and Campbell and Mendoza (1988) explored the usefulness of two MOP approaches for coping with forestry problems in which one relevant criterion was water production. Harrison and Rosenthal (1988) proposed an MOP method with objectives like habitat suitability indexes for several wildlife species. Bare and Mendoza (1988, 1990), employed the interactive method known as STEM to solve harvest schedule problems that included timber criteria plus other criteria related to wildlife management, sediment and forage production. Liu and Davis (1995) formulated an interactive MOP model supported by shadow values for a problem, with several criteria including grazing and recreational camping. This modeling effort has been applied by Hjortsø and Straede (2001) for assessing several forestry policies in Lithuania. Turner et al. (2002) tackled a forestry problem in Australia that included criteria like water yields, wildlife and sediment production with the help of linear programming (LP) and MOP models. Zhou and Gong (2004) resorted to the NISE method for obtaining an optimum mix of ecosystems use in Sweden by considering NPV, dead wood, lichen production and recreation. Finally, Toth et al. (2006) formulated an MOP model with two criteria: NPV and habitat patches associated with wildlife species.

Let us move on to cases addressed with the help of GP models. The pioneer work in this direction is due to Field (1973), who proposed a lexicographic GP model for a harvest schedule. The goals considered included income, recreational and timber targets. Bottoms and Bartlett (1975) turned again to a lexicographic GP including goals related to timber, grazing and recreation. Schuler and Meadows (1975), Dane et al. (1977), and Schuler et al. (1977) proposed different weighted GP models to the management of National Forests by considering timber and non-timber criteria. Kahalas and Groves (1978) also included this technique in a hypothetical example with several non-timber criteria. At a theoretical level, Dyer et al. (1979) compared LP and GP within the context of forestry multiple use. Chang and Buongiorno (1981) showed how GP and input-output analysis could be successfully unified in a forestry context. Arp and Lavigne (1982) proposed a weighted GP model that included goals related to timber, recreation, hunting and wildlife. Lonergan and Cocklin (1988), and Cornett and Williams (1991) employed lexicographic GP formulations including goals related to timber and livestock production as well as to recreation and deer population management. de Oliveira et al. (2003) used a weighted GP formulation for addressing a planning problem in a Brazilian farm by considering criteria like wildlife, flora biodiversity, erva-mate leaves and pasture, among others. Finally, Diaz-Balteiro and Romero (2003) incorporated carbon sequestration into a harvest scheduling issue by formulating several lexicographic GP models.

Within this forestry topic, very few papers have adopted the CP approach. Thus, only Tecle et al. (1998) and Kazana et al. (2003) formulated different CP models for harvest scheduling problems that incorporated timber and non-timber criteria like recreation, aesthetical values, deer stalking, etc.

The MAUT approach has been extensively used for tackling this type of problem. The pioneer work is due to Hyberg (1987) who formulated a MAUT model with two attributes: timber production and aesthetical values. Pukkala and Kangas (1993) proposed the HERO method jointly with AHP for a problem in Finland, where criteria like scenic beauty were considered. Pukkala et al. (1995, 1997) proposed different MAUT functions applied to planning problems in Finnish forests by considering timber and non-timber criteria like biodiversity and aesthetical values. Vacik and Lexer (2001) combined MAUT and AHP to design a decision support system for the management of several forests near Vienna. Jumppanen et al. (2003) integrated the non-spatial analysis with spatial ecological criteria into a MAUT model in order to establish the optimum allocation of mature forests. Kurttila and Pukkala (2003) formulated an additive MAUT model within a hierarchical process for a forest management problem related to the protection of the flying squirrel in a Finnish forest. Pukkala et al. (2003), by using a MAUT approach, predicted the impact on the timber supply due to future changes in objectives like recreation or nature values pursued by forestry policy. Lexer et al. (2005) combined an additive MAUT model with AHP in a computer-based decision support system in order to compare several alternatives assessed in terms of timber production, nature conservation and biodiversity, and sustainable site productivity. Fürstenau et al. (2007) and Briceño-Elizondo et al. (2008) also resorted to a MAUT approach to evaluate different management alternatives within a climate change scenario. Both papers included timber and non-timber objectives, like biodiversity and carbon sequestration.

Fuzzy multi-criteria techniques have also been applied in this field. Thus Mendoza and Sprouse (1989), through a fuzzy technique, generated several management alternatives that were evaluated with the help of the AHP method. Mendoza et al. (1993) formulated a MOP model in which the coefficients of the objective functions were fuzzy numbers. Tecle et al. (1994) set up a MOP model for which objectives like herbage production, water runoff, sediment yield, and recreation were formulated in a fuzzy fashion. Kangas et al. (2006a) unified a fuzzy multi-criteria model with the approval voting method for addressing several forestry planning problems with a single decision-maker or several of them. Finally, Zadnik Stirn (2006) also use a hybrid approach that combined fuzzy theory with AHP associated with a dynamic context in a Slovenian forest.

The AHP as a single decision-making tool has been used by Kangas (1992) and Kangas et al. (1993a) to establish optimum harvest schedules in Finland including criteria like scenic beauty and game management. In the same direction, Rauscher et al. (2000) also applied AHP to evaluate four management alternatives taking into consideration non-timber criteria like visual quality, water production, wildlife or ecology. Riedl et al. (2000) used the same type of approach for a case near the town of Vienna. Finally, Leskinen (2007) used AHP for comparing four different scoring techniques for a ratio-scale assessment of several criteria in a forest management case.

Let us now turn to applications based on discrete MCDM methods. Thus, Pesonen et al. (2001) proposed a merger of strengths, weaknesses, opportunities and threats (SWOT) and AHP for evaluating four management alternatives in Finnish forests according to several criteria, some of them related to protection and recreation. Kangas et al. (2003a, 2005) joined stochastic multicriteria acceptability analysis with ordinal criteria (SMAA-O) to SWOT for the assessment of forest management alternatives by integrating recreational and ecological criteria. Leskinen et al. (2004) used this method to compare the results provided by a statistical model which integrated mixed data with ordinal and ratio scale information in an extended harvest scheduling example. Finally, Pauwels et al. (2007) resorted to ELECTRE for comparing several silvicultural alternatives of *Larix* stands in Belgium taking into account criteria related to biodiversity and stability when the stands faced potential windstorm damage.

Finally, we shall review cases addressed with the help of GDM techniques. Thus, Pykäläinen et al. (2001) applied the HERO method for forest management problems in Finland with several stakeholders that took into account criteria like landscape, recreation and the preservation of old forest areas. Hytönen et al. (2002) proposed a method able to incorporate qualitative information provided by several individuals into a geographical information system (GIS). Laukkanen et al. (2002), Laukkanen et al. (2004), and Laukkanen et al. (2005) applied different voting systems (multi-criteria approval, Borda's rule and cumulative voting) to several extended harvest scheduling problems in Finland. Pasanen et al. (2005) proposed an Internet-based forest decision support system based on multi-criteria approval for comparing several forestry plans. Pykäläinen et al. (2007) combined voting methods with an interactive utility analysis for the management of public forests in Finland involving 42 stakeholders. Finally, Vainikainen et al. (in press) applied approval voting, the Borda's rule and the cumulative voting rule to a forest management problem in Finland, involving nine criteria and several stake holders.

4.3. Forest biodiversity conservation

The management of forest biodiversity from the perspective of wildlife species and their habitat has been recently addressed from an MCDM angle. Linked to the biodiversity problem is the management of national parks, reserves and any type of protected land. In these cases, the selection of activities for achieving management objectives leads to an MCDM problem. The main efforts in both directions are presented in this section.

Starting with cases using continuous MCDM methods, Mendoza (1988) resorted to MOP techniques for integrating wildlife with several management alternatives oriented towards timber production. Rothley (1999) proposed a method joining MOP to MAUT for the optimum design of a biodiversity network in Canada, by considering three criteria: connectedness, area of each reserve and number of rare plant species. Memtsas (2003) applied a similar method for a selection problem of nature reserves on the island of Crete in Greece. Hjortsø et al. (2006) developed a method based on MOP and GP for a land use planning case in a protected area-buffer zone in Nepal. On the other hand, Jordi and Peddie (1988), Ludwin and Chamberlain (1989), and Berbel and Zamora (1995) proposed different MOP and GP formulations for dealing with problems exclusively related to game management.

An alternative way of dealing with forest biodiversity is based on the right management of the structural diversity of a forest stand. This structural diversity is usually described by means of the distribution of trees per species-size classes, and the classic Shannon index is used to measure the respective relative abundance. A key paper in this direction is that of Buongiorno et al. (1995), in which a GP model was proposed for the management of uneven-aged stands in France, by considering one economic criterion and another one minimizing the difference between the actual distribution of trees according to site and age classes and an ideal distribution. Bertomeu and Romero (2001, 2002) proposed the integration of the maximization of the edge contrast, as an operational measurement of habitat diversity, with other relevant forest management criteria. The exercise was undertaken by formulating several GP models. Finally, in this direction, Bojórquez-Tapia et al. (2003) combined CP and AHP for the redesigning of a biosphere reserve in Mexico.

Another line of research, closely related to the one mentioned above, consists of making biodiversity operational by breaking it down into diversity indicators measuring the characteristics of individual stands. These indicators are treated as decision-making criteria and the respective individual utility functions are elicited according to the MAUT approach. Some applications in this direction have been done by Kangas and Pukkala (1996) and Kangas et al. (1998).

Store and Kangas (2001) integrated MAUT and HERO into a GIS system to evaluate the habitat suitability for a polypore in some forestry ecosystems. Store and Jokimäki (2003) extended the previous idea by showing how it is possible to obtain geographical information on the habitat for two birds and a fungus species in the same ecosystem. Kurttila et al. (2002) tested three spatial objectives for certain zones meeting a habitat suitability index in Finland.

To continue with MAUT models for biodiversity conservation, McDaniels and Roessler (1998) employed a MAUT model for eliciting judgment values for an appraisal exercise in a Canadian forest oriented towards wilderness preservation. Leskinen et al. (2003) used MAUT and statistical modeling techniques to integrate into the management plan ecological values like the amount of old forests, of dead wood and of deciduous trees. Finally, Kurttila et al. (2006) again resorted to a MAUT methodology in order to establish the optimum subsidy to compensate a forest owner in Finland for orienting its management towards biodiversity conservation.

Let us move to biodiversity conservation cases addressed within an AHP format. In this context, the hierarchy included biodiversity as a whole at the objective level. At lower levels of the hierarchy, the biodiversity criterion was broken down into different components, such as the richness, rarity and vulnerability of species. The outcome of the process was a priority index for each feasible forest plan. Some works in this direction are those of Kangas and Kuusipalo (1993) and Kuusipalo and Kangas (1994). Following a similar direction, Kangas et al. (1993b) proposed an AHP framework for defining the most suitable hunting areas, by using expert judgments. Kangas (1994a) applied the same method to the management of a nature conservation area in Finland from a group decision-making perspective.

The AHP method has also been used for addressing several aspects related to the conservation of protected spaces. Thus, Schmoldt et al. (1994) and Peterson et al. (1994) combined AHP and integer programming for tackling a capital budgeting problem in a natural park in the United States. Bantayan and

Bishop (1998) employed AHP to define feasible alternatives for land assessment in a forest reserve in the Philippines. Bojórquez-Tapia et al. (2004) also utilized AHP in a study to determine the best design of nature reserves inside a park in order to maximize their conservation value.

Moreover, Mau-Crimmins et al. (2005) assessed the usefulness of AHP for improving social participation in the management of national forests in the U.S. Strager and Rosenberger (2005), using AHP, analyzed the influence of stakeholders' preferences in order to prioritize areas devoted to conservation. Finally, Kangas and Leskinen (2005) criticized some potential weaknesses inherent to the AHP approach, when the experts' judgments have to be aggregated to deal with problems related to habitat and species conservation.

Moving to other approaches, Hjortsø (2004) used GDM techniques to aggregate stakeholders' preferences in a tactical planning exercise in a Danish forest managed with a conservation orientation. Moffett et al. (2005), by taking elements from AHP and MAUT, developed software able to rank non-dominated plans within a forest management issue in Ecuador directed towards conservation planning. Following a similar line, Fuller et al. (2006) proposed and applied a discrete MCDM method for dealing with a conservation planning problem in a forestry region in Mexico. Finally, Oliver et al. (2007) used GDM techniques based on AHP, to identify the most important ecological criteria for defining the status of patch-scale species-level biodiversity within forest ecosystems.

4.4. Forest sustainability

The current view of sustainability comprises not only timber production persistence, but also sustainability (i.e., persistence over time) of several attributes demanded by society and produced by forest systems. One of the most widely used orientations to measure the sustainability of a system is the so-called "indicators approach". From this perspective, a key question is to aggregate the different indicators used into a single index measuring the sustainability of the forest system as a whole, which leads to an MCDM problem. Efforts to connect the forest sustainability issue to the MCDM paradigm are very recent and can be summarized as follows. Ducey and Larson (1999) resorted to a fuzzy MOP to evaluate a discrete set of forest management plans. Mendoza and Prabhu (2003a) showed how the imprecision underlying the measurement of many sustainability indicators justified the use of different fuzzy MCDM approaches. Maness and Farrell (2004) also used a fuzzy approach to evaluate several management alternatives according to different sustainability indicators for a strategy planning exercise in a Canadian forest. Phua and Minowa (2005) addressed a forest conservation plan at a landscape level in a national park by integrating, into a GIS-based approach that embraced CP and AHP, three criteria and eight indicators.

Diaz-Balteiro and Romero (2004a) proposed a binary extended GP model to establish the forest system with a higher level of achievement with respect to the targets than any expert or panel of experts have attached to each sustainability indicator. Following up this idea, Diaz-Balteiro and Romero (2004b) proposed a flexible formula for measuring the overall sustainability of natural systems. Both papers have utilized a case study regarding a strategic forest management planning exercise in a Spanish forest.

Moving to the use of discrete MCDM methods in forest sustainability, the following efforts will be reviewed. For instance, Varma et al. (2000) used MAUT within a GIS context in order to determine sustainable forest management units. Huth et al. (2004) resorted to a similar method in order to build a model to evaluate the degree of sustainability associated with different logging strategies in a rainforest in Malaysia. Huth et al. (2005) analyzed the same problem with the help of the PROMETHEE method. Mendoza and Prabhu (2000a) combined expert judgements with several indicators, with the help of AHP, for the management of an Indonesian forest. The same authors (Mendoza and Prabhu, 2000b) addressed a similar problem from a group decision-making perspective. Mendoza and Dalton (2005) proposed a model based on AHP within a web platform in order to evaluate the sustainability of a forest management plan, in which the views of several stakeholders were taken into consideration. Finally, in this direction, Wolfslehner et al. (2005), on a comparative basis, resorted to AHP and to an extension of this approach known as the analytic network process (ANP) for measuring the sustainability of four strategies evaluated according to 6 criteria and 43 indicators in an Austrian forest.

Mendoza and Prabhu (2003b) used qualitative soft multi-criteria techniques for the assessment of forest sustainability indicators. Thus, they proposed and applied cognitive mapping to the sustainable management of a forest in Zimbabwe, where 10 experts gave their judgments on 6 criteria and 49 indicators. Mrosek et al. (2006) turned to a multi-criteria rating method to evaluate the sustainability of forest management plans at a disaggregated level.

Finally, some authors have used GDM techniques for addressing several aspects of forest sustainability. Thus, Kant and Lee (2004) modified the classic Borda method in order to obtain an ordinal ranking of forest plans in terms of sustainability, while Sheppard and Meitner (2005) proposed a group decision-making model for a sustainable forest management, involving local communities in Canada.

4.5. Forestation

In this section, we have incorporated those applications in which MCDM methods have been used to deal with cases primarily related to forestation/reforestation/afforestation problems. The first work on this topic is by Walker (1985), who developed a GP methodology for planning activities linked to a reforestation case by considering several species, silvicultural treatments, etc. Mendoza (1986) extended the previous methodology by applying a heuristic approach to the same case study. Gilliams et al. (2005b) used GP to design a spatial decision support system to cope with several environmental requirements associated with an afforestation problem in agricultural lands. Romero et al. (1998) applied a CP model in order to determine the optimal forest rotation age, by considering a compromise between the two optimal solutions associated with timber production and carbon sequestration. This theoretical framework was applied to a beech afforestation case in Spain.

In relation to forestation exercises solved with the help of multi-criteria discrete methods, several of them have joined the MAUT theory to the AHP approach. Thus, Kangas (1993) applied this type of procedure to a reforestation problem in Finland. The author defined a three-level hierarchical structure encompassing three main objectives: timber production, amenity, and impact on water. The same author (Kangas, 1994b), in this previous methodology, included the attitude towards risk, and used the same example to illustrate how this approach worked. Finally, Nousiainen et al. (1998) employed these methods to include scenic values in a two-stage forest management application in Finland. Afforestation in this example was a key element, since it is the most important activity involved in landscape change.

Other works have used the AHP approach to deal with forestation projects. Thus, Liu et al. (1998) used this method in order to evaluate four alternatives regarding regional forestation projects in China by taking into account four criteria. Gilliams et al. (2005a) compared AHP with other discrete multi-criteria methods (i.e., ELECTRE, and three types of the PROMETHEE approach) in a case where the purpose of the research was to choose the best afforestation alternative in Belgium. These alternatives were different afforestation practices, locations and the length of the afforestation period. The authors concluded that, for some issues, PROMETHEE worked slightly better than the other two methods.

Van Elegem et al. (2002) proposed an MCDM method in order to deal with the allocation of new urban forests. This method was composed of three stages, and in the last one 14 criteria were defined. These criteria were evaluated by using an ordinal scale. To illustrate this method, a Belgian case study was analyzed. Finally, Espelta et al. (2003) applied a discrete multi-criteria method in order to choose the best alternatives in a post-fire reforestation problem in Spain. Five criteria were defined, and a preference intensity index was calculated in order to rank the eight alternatives proposed.

4.6. Regional planning

In this section, several studies presenting a national or regional spatial dimension are described. It is necessary to indicate that these papers cover case studies on the planning of diverse forests outputs, or studies related to the efficiency of the forest management practices, often linked to several forest services.

Lets us start with applications using continuous MCDM methods. Thus, Buongiorno and Svanquist (1982), and Buongiorno et al. (1981) built GP models in order to plan the Indonesian forestry sector. These models included aspects like timber supply, operational costs, demand scenarios, the firm's capacity and interregional forest product trade. Davis and Liu (1991) also applied this technique in a multiple owner planning case study in California. Njiti and Sharpe (1994) developed a weighted GP model for land use allocation in Cameroon taking into account different uses like forestry, wildlife, agriculture and livestock. This kind of application is relatively frequent in the literature, but in this review only the studies where forestland is the predominant use have been included. van Kooten (1995) resorted to GP formulations in a Canadian case study in Vancouver. From the information derived from several surveys, six goals in order of importance were defined for four different scenarios. Yin et al. (1995) used a GP model in order to illustrate the correct allocation of land uses at a regional level in Canada. By using the same technique, Nhantumbo et al. (2001) created a model for integrating different demands from Miombo woodlands in Mozambique. The stakeholders who originated these demands were local communities, the state, and other investors. Other MCDM applications in developing countries can be seen in Allen (1986). In this work, a bi-objective model with a function minimizing two categories of costs was proposed and solved by using the NISE method, within the context of a regional forest planning problem in Tanzania. Finally, Krcmar et al. (2005) applied a CP model in a Canadian boreal region with two main land uses: forestry and agriculture. The model includes three different objectives: economic performance, carbon sequestration and structural diversity.

On the other hand, for addressing this type of problem, other researchers have resorted to discrete MCDM methods. Thus, Faith et al. (1996) employed a discrete multi-criteria method to deal with a regional case study in Australia associated with biodiversity conservation. As indicated in the previous section, Liu et al. (1998) applied AHP to a regional forestation case in China. Pykäläinen et al. (1999) used the MAUT approach for analyzing a forest management case in an eastern region of Finland, by defining four criteria and several sub-criteria for six different strategies. These MCDM exercise elements have been evaluated by different interest groups. Kangas et al. (2001) used the same case study in order to compare three multi-criteria techniques: MAUT, ELECTRE and PROMETHEE. It should be noted that the final ranking of strategies is highly sensitive to the technique used. Some of these methods are described in Schlaepfer et al. (2002), showing an exercise in the management of forested mountainous landscapes in a Swiss Canton. Ananda and Herath (2003a) used a methodology that combined an additive multi-attribute utility function and group decision-making techniques, in order to solve a regional forest management problem in Australia. On that occasion, three attributes were defined and 36 responses from 5 groups of stakeholders were obtained. The same authors (Ananda and Herath, 2003b) applied the AHP method in an analogous exercise, in which five management plans were evaluated by a group of stakeholders according to the three objectives defined in the previous study. Ananda (2007) described another AHP application to a forest planning case study in the same Australian region, with the same objectives and considering three management plans. In Leskinen et al. (2006b) an A'WOT methodology was proposed, in order to deal with the strategic planning of a regional forest research unit in Finland. Finally, Hiltunen et al. (2008) proposed the use of GDM techniques in participatory strategic forest planning in state-owned forests in Finland. Five voting methods, including Borda's rule and voting approval were applied.

Other applications deal with the planning of forest services in order to improve the efficiency of forest management. Thus, Kao and Yang (1991, 1992) and Kao et al. (1993) used a methodology based on DEA with the purpose of studying the efficiency of Taiwanese forests. They defined 3 inputs and 4 outputs, including services like recreation and soil protection, to calibrate technical and scale efficiency throughout the 13 forest districts. The results provided a measurement of the improvement in the performance of each district. Kao (1998) applied the same methodology to Taiwanese forest districts, which were divided into working circles or sub-districts. The proposed model calculated the production frontier for the working circles of each district, and then the aggregate forest production frontier was derived. Two extensions of this model have been described. First, Kao (2000) measured the efficiency and productivity of each district at two different points in time by using DEA and the Malmquist productivity index. Second, Kao and Hung (2005) proposed a compromise solution method for generating common weights within the context of a DEA problem. Another application following this direction can be found in Viitala and Hänninen (1998), where DEA was applied to measure the efficiency of 19 regional forestry boards in Finland. In this case study, six inputs and three outputs were defined, within an input-oriented model, in which, finally, a Tobit composite efficiency model was included. Joro and Viitala (2004) used this example to explain a weight-restricted DEA model. Another exercise with a DEA approach oriented towards public forest services can be seen in Zhang (2002), where one input and three outputs were considered for a Chinese case study. Bogetoft et al. (2003) resorted again to a DEA in order to calculate the efficiency and to evaluate possible merger gains of the 14 offices comprising the Danish forestry service. Hof et al. (2004) applied a DEA methodology in order to identify areas with a maximum potential for improving forest and rangeland conditions. In that work, there were no inputs or outputs as in a usual DEA model. In fact, a group of indicators of forest and rangeland conditions performed as inputs, and some measurements of human activity as outputs. This method has been applied to more than 3000 counties in the United States, showing up those areas where natural resources were not efficiently managed. By using distance function models and the DEA approach together, Liu and Yin (2004) measured the productivity growth of rural and poor households during a period of 20 years in a Chinese province. Six inputs regarding several expenditures and four outputs concerning production values were defined. Additionally, Vennesland (2005) applied this technique in order to measure the efficiency of a regional development support scheme in Norway.

4.7. Forestry Industry

It should be noted that, although several multi-criteria methods have been used to study different aspects of the forest industry, the impressive rate of progress achieved in recent years has been remarkable, in relation to applications of DEA methods for evaluating the efficiency of this type of industry. Thus, Yin (1998) applied DEA to analyze the efficiency of 44 paper companies in the United States, by considering seven inputs and one output (annual production). The same author (Yin, 1999) used the same procedure to study the production efficiency and cost competitiveness of seventy pulp firms located in 10 countries on the Pacific Rim. This work was expanded in Yin (2000), in order to study technical and allocative efficiency measures for 102 pulp mills in the world by using DEA as well as a parametric method such as the stochastic frontier analysis (SFA). Nyrud and Baardsen (2003) and Nyrud and Bergseng (2002) employed a DEA analysis to measure production efficiency in approximately 200 Norwegian sawmills. Hseu and Shang (2005) applied DEA models in order to construct a Malmquist index in the pulp and paper industry. Other papers have used parametric and non-parametric techniques (DEA and Malmquist index) together in paper industries in a sample of OCDE countries (Hseu and Shang, 2005), or Canadian wood product industries (Sowlati and Vahid, 2006). Lee (2005a,b) analyzed the efficiency in the most important global forest and paper companies by using DEA. In Lee (2005a) these results were compared with an SFA analysis. In order to provide a better representation of the technology related to these industries, undesirable outputs have been incorporated into DEA models (see Hailu and Veeman, 2001; Hua et al., 2007). Besides, in recent years, these methodologies frequently include two levels of analysis; thus, in the first level, a DEA model is introduced, and in the second stage a statistical analysis is undertaken. In this direction, Salehirad and Sowlati (2005) developed a statistical comparison of the efficiency of sawmills in British Columbia forest regions by using two non-parametric statistical tests. Furthermore, Diaz-Balteiro et al. (2006) analyzed the link between Spanish wood-based enterprise efficiency and innovation activities, by using DEA methods jointly with a logistic regression analysis. Finally, Vahid and Sowlati (2007) resorted to DEA techniques to study changes in efficiency among six wood product sub-sectors in Canada.

Other authors have applied other multi-criteria methods to study several aspects of forestry industries. Thus, Mikkila et al. (2005) used AHP in order to evaluate an indicator of the corporate social performance in pulp and paper industries of four different countries. Renaud et al. (2007) employed two discrete multi-criteria methods with the purpose of evaluating the paper manufacturing process in Canada using only pulp from jack pine.

Several studies have also applied multi-criteria techniques in problems associated with the obtention, logistics and transportation of timber flows to industries. Although some of these studies might have been placed in the preceding sections, it has been preferred to include them in the forestry industry. Thus, Palander (1999), with the help of GP model, explained a timber procurement problem. Dodson Coulter et al. (2006) used AHP and two heuristic methods to build maintenance projects for low-volume forest roads, in order to minimize environmental and economic costs. Three studies have included DEA models in this kind of application: Hailu and Veeman (2003) analyzed the efficiency in logging industries of six Canadian provinces; Ulmer et al. (2004) used DEA to calculate efficiency in the wood purchases of mills in the southern states of United States, and Marinescu et al. (2005) set up a timber allocation model employing DEA in order to allocate forest stands to different forest industries in British Columbia, and compared the results obtained with other strategies to allocate timber in these firms. Finally, Salo et al. (2003) and Salo and Liesio (2006) proposed discrete MCDM methods in order to plan several aspects of research programs in Finnish forest industries.

4.8. Risk and uncertainty

Taking into consideration risk and uncertainty elements in many forest management models would seem to be of an unquestionable importance. In this sense, it is important to note that important literature, mainly developed in the last 10 years, has attempted to integrate risk and uncertainty elements into MCDM models in forestry. Let us start with problems with a continuous structure. Thus, Gong (1992) proposed a MOP dynamic programming model for dealing with a harvest scheduling issue where two objectives were considered: timber sales revenue and owner utility derived from the timber stand composition. Chen et al. (2001) showed how key risk elements could be introduced by jointly using GIS and CP. They applied the theoretical proposal in the determination of priority areas in order to establish a prescribed burning plan.

Some authors have resorted to the theory of fuzzy sets, to address problems related to uncertainty in forest management. Thus, Ells et al. (1997) proposed a fuzzy programming model to deal with uncertainty in a forest management case in Canada, in which six objectives were proposed. Kangas et al. (2007) resorted to two methods for dealing with uncertainty in forest management. One was a fuzzy multi-criteria model, and the other an additive MAUT model. Both methods were applied to a forestry case in Finland, from a multiple use perspective.

The most widely used MCDM approach for dealing with risk and uncertainty in forestry are the MAUT techniques. Thus, Teeter and Dyer (1986) with the help of a bi-criteria utility function evaluated seven feasible strategies in a forest fire context in the United States. Pukkala and Miina (1997) turned again to MAUT techniques for optimising the treatment schedule in a mixed forest in Finland within a risky context. Pukkala (1998) extended the previous research by considering the risks associated with inventory data, future states of nature and decision-maker's preferences. Continuing with the use of MAUT techniques, Lexer et al. (2000) proposed a model to evaluate risks in a large-scale exercise in Austria forests, in which climate change effects were taken into account.

Following a slightly different direction, Levy et al. (2000b) proposed an interactive method based on MAUT and AHP, for dealing with a forest management problem in Canada, in which the different stands were affected by a forest disease. The same authors (Levy et al., 2000a) addressed a similar problem, where three feasible forest alternatives were assessed with the help of a pure MAUT model. Ananda and Herath (2005) again used a MAUT model, in order to integrate social attitudes towards risk into a forest management model formulated on a regional scale. Finally, in this direction, Ohlson et al. (2006) proposed a MAUT variant, known as multi-attribute trade-off analysis (see Keeney and Raiffa, 1976, Chapter 6), for dealing with a wildlife management problem in Canada within a risk context.

Let us now move in the direction of other discrete MCDM methods. Thus, Reynolds and Holsten (1994) applied AHP to aggregate several experts' judgments, in order to evaluate the risks associated with forest diseases in Alaska. Pukkala and Kangas (1996) integrated the risk associated with management alternatives and with the decision-maker's attitude in a case study in Finland. Alho et al. (1996) analyzed the uncertainty associated with the judgments provided by several experts in the AHP approach with the help of regression techniques. The case study referred to a Finnish forest with a hunting orientation, where the opinions of 15 experts were considered. Alho and Kangas (1997) tackled a similar problem, by incorporating Bayesian analysis techniques to regression models. Following this line, Leskinen and Kangas (1998) proposed a method based on a statistics analysis for dealing with the uncertainty associated with the parameters defining an AHP model. Kangas et al. (2000) applied these methods to evaluate the uncertainty associated with the precise quantification of the values of the ecological objectives, defined in a tactical forest planning exercise. In this sense, 10 management alternatives were evaluated in relation to a criterion of an ecological nature and according to another criterion based on timber production. Finally, in this direction Leskinen et al. (2006a) used a ''pairwise'' comparison scheme, transformed into a geometric scale, in order to evaluate the uncertainty associated with the preferences of a sample of forest owners in Finland.

Kangas et al. (2003b) used the approach known as stochastic multicriteria acceptability analysis (SMAA), for dealing with the management of an ecosystem, where cardinal and ordinal criteria were jointly considered. Kangas et al. (2000) addressed a similar problem, by now including a new criterion measuring environmental risks in riparian areas. Kangas et al. (2006c) used a similar method for addressing the uncertainty attached to the measurement errors usually committed in forest management. Finally, Kangas (2006) used this type of method to evaluate the risks associated with the actual decision-making process. The risks were evaluated by obtaining the probability of deriving a correct recommendation by using this method, as well as the expected losses due to making incorrect recommendations.

4.9. Miscellaneous topics

This section is of a miscellaneous nature, since its aim is to include forestry MCDM papers that do not fit into the preceding categories, starting with papers with a clearly applied orientation, and, after that, presenting papers with a more theoretical orientation.

One of the first papers applying MCDM methods in forestry issues was written by Bertier and Montgolfier (1974). These authors applied the ELECTRE method to the choice of a suburban highway design inside a forest area. Porterfield et al. (1975) and Porterfield (1976) proposed a GP approach in order to evaluate tree-improvement programs, where the goals were genetic traits, such as straightness or fusiform resistance. In the same direction, MOP was used in the tree-improvement field (Mattheiss and Land, 1984; Ivkovich and Koshy, 2002).

Some papers focusing on forest measurements have followed a certain line of research using MCDM methods. Thus, Mitchell and Bare (1981) employed a GP method to select an allocation for a stratified random sampling oriented towards multiple objectives in a forest inventory. This methodology was illustrated by a case study in the United States with 6 objectives (1 relative to economic cost, 5 related to sample estimation precision), and 14 strata. Kangas and Maltamo (2000) also applied a GP model to calibrate a predicted diameter distribution of a forest growing stock with additional information. Angelis and Stamatellos (2004) described a methodology based on MOP, in which the cost of the inventory and the variance in the sample estimations were the objectives to be minimized. A simulated annealing algorithm was used to find optimal solutions. Finally, a discrete multi-criteria method to reassign the pixels of satellite images to field plot data of a Finnish forest inventory can be seen in Halme and Tomppo (2001).

Some papers dealing with situations where the production of non-timber goods and services play a primary role are now commented. Thus, Cocklin et al. (1988) developed a GP model to assess options in a land-use change to forest energy plantations in Canada. Janssen and Padilla (1999) suggested a discrete MCDM method for mangrove management in the Philippines, including objectives related to aquaculture production. Hjortsø and Straede (2001) included fruit and mushrooms jointly with timber and other objectives in a Lithuanian forest management problem. Ihalainen et al. (2002) proposed a method that included ‘‘pairwise’’ comparisons, within an AHP format, and regression analyzes to evaluate bilberry and cowberry yield prediction functions in a Finnish forest.

Let us now review papers where several forestry cases have been addressed with the help of GDM techniques with an MCDM orientation. First, we shall introduce the type of work in which non-renewable resources have been integrated into forestry models. Thus, Martin et al. (1996) wrote one of the first studies on the application of GDM techniques in managing forest lands. In this paper, two systems of voting rules (Condorcet and Borda) were applied in a case study of oil and gas leasing on public forest lands in the United States. Seven stakeholders and seven alternatives were defined in order to choose the best option for applying this methodology. The same case study was analyzed in Shields et al. (1999) by using a GDM methodology. Thus, multi-objective techniques, voting methods, the Nash-Harsanyi solution, and the Shapley value were applied. Finally, Martin et al. (2000) employed MAUT techniques in a similar problem, where stakeholder preferences for the development of leasable minerals (oil and gas) in a national forest were explored. Four attributes and six alternatives were evaluated for the three stakeholders previously defined.

Kurttila et al. (2000) described a method which merged SWOT and AHP in a forest certification case in Finland. Silvennionen et al. (2001) applied an AHP approach for eliciting preferential weights in a landscape forestry management exercise. Some authors have applied GDM techniques for the management of common property forests. Thus, Purnomo et al. (2004) applied a ‘‘soft system’’ approach in the management of a common property forest covering an area of 30,000 ha in Indonesia. They selected 6 indicators related to the management plan, as well as several strategies defined in 15 scenarios evaluated by a set of stakeholders. On these lines, Mendoza and Prabhu (2005) applied a similar methodology for the management of a communal forest in Zimbabwe. Following a slightly different direction, Schmoldt and Peterson (2000) used a GDM technique based on AHP for a forest fire problem. Tikkanen et al. (2006) analyzed the actual objectives followed by a sample of forest owners, by resorting to a cognitive map approach.

This miscellaneous section will be completed by papers with a more theoretical orientation. Thus, Romero (1997) justified theoretically the use of CP in forest management within a context of joint production. Bertrand and Martel (2002) reflected on some questions related to GDM techniques, when they were defined with the help of discrete MCDM methods. Leskinen and Kangas (2005) analyzed, at a theoretical level, the use of MCDM methods when the criteria involved were interdependent. These authors proposed using statistical models, in order to avoid the uncritical acceptance of the hypothesis of independence among criteria.

Let us finish this section by commenting on surveys and review papers, devoted in one way or another to forestry problems from a multi-criteria perspective. We have the following contributions by chronological order. Romero and Rehman (1987) in a paper reviewing natural resources management with an MCDM perspective, comment around 30 papers with a forestry orientation. Rehman and Romero (1993) presented a critical assessment of the MCDM paradigm in the field of agricultural systems. Following another direction, Howard (1991) reviewed several multi-criteria methods, in order to evaluate the problems associated with the elicitation of decision-makers' preferences. Tarp and Helles (1995) analyzed the main MCDM methods and their applications in forestry. Mendoza and Martins (2006) undertook an exhaustive review of the MCDM methods used in natural resource management, emphasizing the forestry case.

It should be noted that there are other review papers, focusing on a profound analysis of a single MCDM approach. Thus, Mendoza (1987) analyzed the different formulations and extensions of the GP model, reviewing their actual and potential applications in forestry. Kangas and Kangas (2005) focused their review on discrete MCDM methods already applied in forestry. Recently, some papers have appeared reviewing the use of GDM techniques in forestry. Thus, Palander et al. (2002) discussed the interest of using these techniques within the context of wood procurement organizations. Sheppard (2005) reviewed the different techniques with a multi-criteria orientation, used from a participatory decision-making angle in forestry. The paper was oriented towards a tactical planning context where forest sustainability was of paramount importance. Kangas et al. (2006b) evaluated the different voting techniques and their applicability in forestry, when the views of several stakeholders were taken into consideration. Mendoza and Prabhu (2006) reviewed the importance of some "soft methods" like crisp and fuzzy cognitive mapping and qualitative system dynamics in participatory forestry decision-making. Finally, in this direction Martins and Borges (2007) reviewed different GDM approaches with an MCDM orientation and their potential use in forest management problems in Portugal.

Other review papers are by Sowlati (2005), and Salehirad and Sowlati (2006), in which several efficiency studies on the forest industry, by using parametric and non-parametric methods were made. Kangas and Kangas (2004) reviewed valid MCDM methods for introducing uncertainty elements into forest management models. Finally, Moffett and Sarkar (2006) reviewed 26 MCDM methods, most of them of a discrete nature, able to be applied to problems related to forest biodiversity.

5. A general assessment

There are currently an impressive number of applications of MCDM approaches to forestry problems. An assessment of each application in terms of its originality or its innovativeness is beyond the scope of this paper, whose purpose, in fact, was to bring these applications to the attention of forest management students, researchers and practitioners, as a single source, as well as to provide a general assessment of the MCDM paradigm's potential in the forestry field.

However, there are some general conclusions and some future trends that are worth pointing out, and Tables 1 and 2 and Figs. 1–3 were put together with this aim in mind. Table 1 shows paper frequency dealing with the MCDM approach and forestry topics. Note that the sum of the figures for the nine columns (302 items) does not match the figure under the column measuring the total number of papers (255 items), since some papers used two or three MCDM techniques. Table 2 shows the reference number of the papers on a particular MCDM approach and forestry topic.

On the other hand, Fig. 1 shows how the numbers of forestry MCDM papers have evolved over 5-year periods and their growth rate is really significant. In fact, around 86% of the compiled papers were published after 1989.

Fig. 2 shows the temporal breakdown of the different MCDM approaches used in forestry in percentage terms. The increasing importance of approaches like GDM, DEA and ODM is worthy of note (50% of the total throughout 2000–2007). On the other hand, there is a relative decline in the use of some continuous methods, like GP and MOP.

Fig. 3 shows the temporal breakdown of the different MCDM forestry topics analyzed from an MCDM perspective in percentage terms. There is a significant increase in forestry industry issues, as well as forest sustainability topics. The sizeable decline in harvest scheduling problems is also noteworthy, while the extended harvest scheduling topic, despite a slight fall, is still the most prolific area. Finally, the trend in the other forestry topics remains fairly stable.

Let us conclude this assessment by raising the following three points:

1. MCDM is a sound and well-established paradigm for addressing many problems within the broad field of forest management. There has been a notable increase in the use of approaches like DEA, GDM and ODM over time. This is due to two reasons. First, the theory underlying these approaches was developed much later than other methods like MOP and GP. Moreover, these approaches were specifically designed to tackle discrete problems, and foresters only started to consider these forestry problems in the second half of the period of time considered.
2. The concept and measurement of forest sustainability is still an open problem. Similarly, the incorporation of MCDM methods for addressing this type of problems has been very tentative. However, the development of further efforts to structure new methods based on multi-criteria analyses to characterize and measure forest sustainability seems especially promising.
3. The application of GDM methods in forestry from a multi-criteria perspective is a relatively new area of research. The adaptation of the great arsenal of ordinal and cardinal

Table 1
Paper frequency by MCDM approach and forestry topic

	Total	A (MOP)	B (GP)	C (CP)	D (MAUT)	E (FMCP)	F (AHP)	G (ODM)	H (DEA)	J (GDM)
I-Harvest scheduling	17	6	7	1	3	2	2	0	0	0
II-Extended harvest scheduling	61	11	14	2	14	5	12	5	0	10
III-Forest biodiversity	34	6	5	2	9	0	15	2	0	7
IV-Forest sustainability	17	0	2	1	2	3	5	3	0	6
V-Forestation	11	0	3	1	1	0	2	3	0	1
VI-Regional planning	30	1	7	1	2	0	4	3	13	7
VII-Forestry industry	23	0	1	0	1	0	2	3	18	2
VIII-Risk and uncertainty	22	1	0	1	10	1	9	5	0	1
IX-Miscellaneous	40	3	6	1	1	1	5	5	2	12
	255	28	45	10	43	12	56	29	33	46

Table 2
Double-entry classification: references by MCDM approach and forestry topic

	I	II	III	IV	V	VI	VII	VIII	IX
MOP	de Kluyver et al. (1980), Ducheyne et al. (2004), Hallefjord et al. (1986), Krcmar-Nozic et al. (1998), Mendoza et al. (1987b), Roise (1990)	Bare and Mendoza (1988,1990), Campbell and Mendoza (1988), Harrison and Rosenthal (1988), Hjortsø and Straede (2001), Liu and Davis (1995), Mendoza et al. (1987a), Steuer and Schuler (1978), Toth et al. (2006), Turner et al. (2002), Zhou and Gong (2004)	Berbel and Zamora (1995), Hjortsø et al. (2006), Jordi and Peddie (1988), Memtsas (2003), Mendoza (1988), Rothley (1999)			Allen (1986)		Gong (1992)	Angelis and Stamatellos (2004), Ivkovich and Koshy (2002), Mattheiss and Land (1984)
GP	Diaz-Balteiro and Romero (1998), Field et al. (1980), Gómez et al. (2006), Hotvedt et al. (1982), Kangas and Pukkala (1992), Kao and Brodie (1979), Mendoza et al. (1987b)	Arp and Lavigne (1982), Bottoms and Bartlett (1975), Buongiorno and Svanquist (1982), Chang and Buongiorno (1981), Cornett and Williams (1991), Dane et al. (1977), de Oliveira et al. (2003), Diaz-Balteiro and Romero (2003), Dyer et al. (1979), Field (1973), Kahalas and Groves (1978), Lonergan and Cocklin (1988), Schuler and Meadows (1975), Schuler et al. (1977)	Berbel and Zamora (1995), Bertomeu and Romero (2001, 2002), Hjortsø et al. (2006), Ludwin and Chamberlain (1989)	Diaz-Balteiro and Romero (2004a,b)	Gilliams et al. (2005b), Mendoza (1986), Walker (1985)	Buongiorno et al. (1981, 1995), Davis and Liu (1991), Nhantumbo et al. (2001), Njiti and Sharpe (1994), van Kooten (1995), Yin et al. (1995)	Palander (1999)		Cocklin et al. (1988), Kangas and Maltamo (2000), Mendoza (1987), Mitchell and Bare (1981), Porterfield (1976), Porterfield et al. (1975)
CP	Diaz-Balteiro and Romero (1998)	Kazana et al. (2003), Tecle et al. (1998)	Bojórquez-Tapia et al. (2004), Memtsas (2003)	Phua and Minowa (2005)	Romero et al. (1998)	Krcmar et al. (2005)		Chen et al. (2001)	Romero (1997)
MAUT	Heinonen and Pukkala (2004), Howard and Nelson (1993), Pykäläinen (2000)	Briceño-Elizondo et al. (2008), Fürstenau et al. (2007), Harrison and Rosenthal (1988), Hyberg (1987), Jumppanen et al. (2003), Kurttila and Pukkala (2003), Lexer et al. (2005), Nousiainen et al. (1998), Pukkala and Kangas (1993), Pukkala et al. (1995, 1997, 2003), Pykäläinen et al. (2001), Vacik and Lexer (2001)	Kangas and Pukkala (1996), Kangas et al. (1998), Kurttila et al. (2002, 2006), Leskinen et al. (2003), McDaniels and Roessler (1998), Rothley (1999), Store and Jokimäki (2003), Store and Kangas (2001)	Huth et al. (2004), Varma et al. (2000)	Kangas (1993, 1994b), Nousiainen et al. (1998)	Ananda and Herath (2003a), Pykäläinen et al. (1999)	Palander (1999)	Ananda and Herath (2005), Chen et al. (2001), Kangas (1994b), Levy et al. (2000a,b), Lexer et al. (2000), Ohlson et al. (2006), Pukkala (1998), Pukkala and Miina (1997), Teeter and Dyer (1986)	Martin et al. (2000)
FMCP	Bare and Mendoza (1992), Pickens and Hof (1991)	Kangas et al. (2006a), Mendoza et al. (1993), Tecle et al. (1994), Zadnik Stirn (2006)		Ducey and Larson (1999), Maness and Farrell (2004), Mendoza and Prabhu (2003a), Phua and Minowa (2005)				Kangas et al. (2007)	Mendoza and Prabhu (2006), Mendoza and Sprouse (1989)

Table 2 (*Continued*)

	I	II	III	IV	V	VI	VII	VIII	IX
AHP	Diaz-Balteiro and Romero (1998), Kangas and Pukkala (1992)	Fürstenau et al. (2007), Kangas (1992), Kangas et al. (1993a), Leskinen (2007), Lexer et al. (2005), Nousiainen et al. (1998), Pukkala and Kangas (1993), Pukkala et al. (1997), Rauscher et al. (2000), Riedl et al. (2000), Vacik and Lexer (2001), Zadnik Stirn (2006)	Bantayan and Bishop (1998), Bojórquez-Tapia et al. (2003, 2004), Kangas (1994a), Kangas and Kuusipalo (1993), Kangas and Leskinen (2005), Kangas and Pukkala (1996), Kangas et al. (1993b), Kuusipalo and Kangas (1994), Mau-Crimmins et al. (2005), Oliver et al. (2007), Peterson et al. (1994), Schmoldt et al. (1994), Store and Kangas (2001), Strager and Rosenberger (2005)	Mendoza and Dalton (2005), Mendoza and Prabhu (2000a,b), Wolfslehner et al. (2005)	Gilliams et al. (2005a), Kangas (1993, 1994b), Liu et al. (1998), Nousiainen et al. (1998)	Ananda (2007), Ananda and Herath (2003b), Ells et al. (1997), Liu et al. (1998)	Dodson Coulter et al. (2006), Mikkila et al. (2005)	Alho et al. (1996), Alho and Kangas (1997), Ells et al. (1997), Kangas (1994b), Kangas et al. (2000), Leskinen and Kangas (1998), Pukkala and Kangas (1996), Reynolds and Holsten (1994)	Ihalainen et al. (2002), Kangas and Kangas (2005), Kurttila et al. (2000), Mendoza and Sprouse (1989), Schmoldt and Peterson (2000), Silvennionen et al. (2001)
ODM		Kangas et al. (2003a, 2005), Leskinen et al. (2004), Pauwels et al. (2007), Pesonen et al. (2001)	Fuller et al. (2006), Moffett et al. (2005)	Huth et al. (2005), Mrosek et al. (2006)	Espelta et al. (2003), Gilliams et al. (2005a), Mendoza and Prabhu (2003b)	Faith et al. (1996), Kangas et al. (2001), Leskinen et al. (2006b), Schlaepfer et al. (2002)	Renaud et al. (2007), Salo and Liesio (2006), Salo et al. (2003)	Kangas (2006), Kangas et al. (2001, 2003b, 2006c), Leskinen et al. (2006a), Lexer et al. (2000)	Bertier and Montgolfier (1974), Halme and Tomppo (2001), Janssen and Padilla (1999), Kangas and Kangas (2005), Leskinen and Kangas (2005)
DEA						Bogetoft et al. (2003), Hof et al. (2004), Joro and Viitala (2004), Kao (1998, 2000), Kao and Hung (2005), Kao and Yang (1991, 1992), Kao et al. (1993), Liu and Yin (2004), Vennesland (2005), Viitala and Hänninen (1998), Zhang (2002)	Diaz-Balteiro et al. (2006), Hailu and Veeman (2001, 2003), Hseu and Shang (2005), Hua et al. (2007), Lee (2005a,b), Marinescu et al. (2005), Nyrud and Baardsen (2003), Nyrud and Bergseng (2002), Renaud et al. (2007), Salehirad and Sowlati (2005), Sowlati and Vahid (2006), Ulmer et al. (2004), Vahid and Sowlati (2007), Yin (1998, 1999, 2000)		Salehirad and Sowlati (2006), Sowlati (2005)
GDM		Hytönen et al. (2002), Kangas et al. (2006a), Laukkanen et al. (2002, 2004, 2005), Pasanen et al. (2005), Pykäläinen et al. (2001, 2007), Tecle et al. (1994, 1998), Vainikainen et al. (in press)	Hjortsø (2004), Kangas (1994a), Kant and Lee (2004), Leskinen et al. (2003), Mau-Crimmins et al. (2005), Oliver et al. (2007), Strager and Rosenberger (2005)	Hiltunen et al. (2008), Mendoza and Dalton (2005), Mendoza and Prabhu (2000a,b), Phua and Minowa (2005), Sheppard and Meitner (2005)	Gilliams et al. (2005a), Mendoza and Prabhu (2003b), Van Elegem et al. (2002)	Ananda (2007), Ananda and Herath (2003a,b), Hiltunen et al. (2008), Kangas et al. (2001), Leskinen et al. (2006b), Pykäläinen et al. (1999, 2007)	Palander (1999), Salo et al. (2003)	Kangas et al. (2001)	Bertrand and Martel (2002), Kangas et al. (2006b), Kangas and Kangas (2005), Martin et al. (1996), Mendoza and Prabhu (2005, 2006), Palander et al. (2002), Purnomo et al. (2004), Schmoldt and Peterson (2000), Sheppard (2005), Shields et al. (1999), Tikkanen et al. (2006)

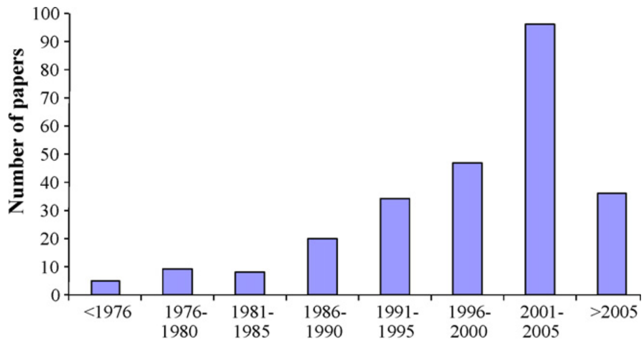

Fig. 1. Trends in the number of MCDM forestry papers published.

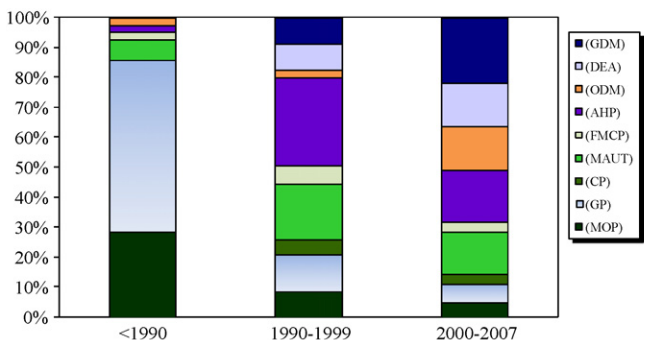

Fig. 2. Temporal composition of the different MCDM approaches used in forestry.

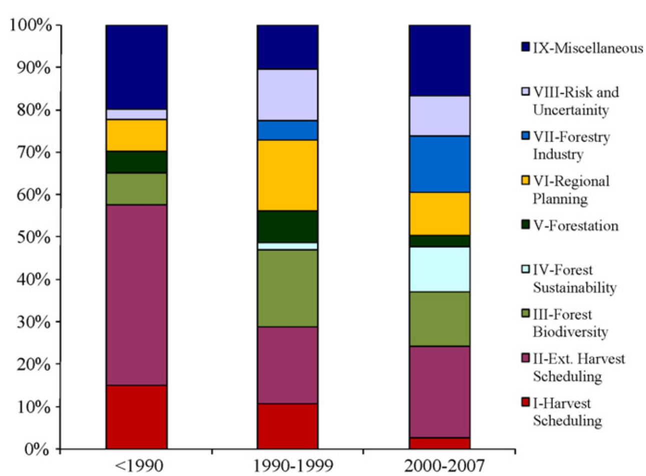

Fig. 3. Temporal composition of the different forestry topics analyzed within an MCDM perspective.

methods for GDM as well as its connections with MCDM would seem to be an extremely attractive research area for forestry.

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References

(Not included in the categorized bibliography)

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2, 429–444.

Forman, E.H., Gass, S.I., 2001. The analytic hierarchy process – an exposition. Oper. Res. 49, 469–486.

Ignizio, J.P., Romero, C., 2003. Goal programming. In: Bidgoli, H. (Ed.), Encyclopedia of Information Systems, vol. 2. Academic Press, San Diego, CA, pp. 489–500.

Joro, T., Korhonen, P., Wallenius, J., 1998. Structural comparison of data envelopment analysis and multiple objective linear programming. Manage. Sci. 44, 962–970.

Keeney, R.L., Raiffa, H., 1976. Decisions with Multiple Objectives: Preferences and Value Tradeoffs. John Wiley and Sons, New York.

Porté, A., Bartelinka, H.H., 1998. Modelling mixed forest growth: a review of models for forest management. Ecol. Model. 150, 141–188.

Saaty, T.L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting, and Resource Allocation. McGraw-Hill, New York.

Steuer, R.E., 1989. Multiple Criteria Optimization: Theory, Computation and Application. John Wiley and Sons, New York.

Stewart, T.J., 1996. Relationship between data Envelopment Analysis and Multicriteria Decision Analysis. J. Oper. Res. Soc. 47, 654–665.

Tamiz, M., Jones, D.F., Romero, C., 1998. Goal Programming for decision making: an overview of the current state-of-the-art. Eur. J. Oper. Res. 111, 569–581.

Yu, P.L., 1973. A class of solutions for group decision problems. Manage. Sci. 19, 936–946.

Zeleny, M., 1974. A concept of compromise solutions and the method of the displaced ideal. Comput. Oper. Res. 1, 479–496.

Zimmerman, H.J., 1996. Fuzzy Set Theory and its Applications. Kluwer, Boston.

(Categorized bibliography)

Alho, J.M., Kangas, J., 1997. Analyzing uncertainties in experts' opinions of forest plan performance. For. Sci. 43, 521–528 [VIII, F].

Alho, J., Kangas, J., Kolehmainen, O., 1996. Uncertainty in the expert predictions of the ecological consequences of forest plans. Appl. Stat. 45, 1–14 [VIII, F].

Allen, J.C., 1986. Multiobjective regional forest planning using the noninferior set estimation (NISE) method in Tanzania and the United States. For. Sci. 32, 517–533 [VI, A].

Ananda, J., 2007. Implementing participatory decision making in forest planning. Environ. Manage. 39, 534–544 [VI, F;J].

Ananda, J., Herath, G., 2003a. Incorporating stakeholder values into regional forest planning: a value function approach. Ecol. Econ. 45, 75–90 [VI, D;J].

Ananda, J., Herath, G., 2003b. The use of analytic hierarchy process to incorporate stakeholder preferences into regional forest planning. For. Policy Econ. 5, 13–26 [VI, F;J].

Ananda, J., Herath, G., 2005. Evaluating public risk preferences in forest land-use choices using multi-attribute utility theory. Ecol. Econ. 55, 408–419 [VIII, D].

Angelis, L., Stamatellos, G., 2004. Multiple objective optimization of sampling designs for forest inventories using random search algorithms. Comput. Electron. Agric. 42, 129–148 [IX, A].

Arp, P.A., Lavigne, D.R., 1982. Planning with goal programming: a case study for multiple-use of forested land. For. Chron. 58, 225–232 [II, B].

Bantayan, N.C., Bishop, I.D., 1998. Linking objective and subjective modelling for landuse decision-making. Landsc. Urban Plann. 43, 35–48 [III, F].

Bare, B.B., Mendoza, G.A., 1988. Multiple objective forest land management planning: an illustration. Eur. J. Oper. Res. 34, 44–55 [II, A].

Bare, B.B., Mendoza, G.A., 1990. Designing forest plans with conflicting objectives using de Novo programming. J. Environ. Manage. 31, 237–246 [II, A].

Bare, B.B., Mendoza, G.A., 1992. Timber harvest scheduling in a fuzzy decision environment. Can. J. For. Res. 22, 423–428 [I, E].

Berbel, J., Zamora, R., 1995. An application of MOP and GP to wildlife management (deer). J. Environ. Manage. 44, 29–38 [III, A;B].

Bertier, P., Montgolfier, J.D., 1974. Multicriteria analysis—application to a forest management problem. Metra 13, 33–45 [IX, G].

Bertomeu, M., Romero, C., 2001. Managing forest biodiversity: a zero-one goal programming approach. Agric. Syst. 68, 197–213 [III, B].

Bertomeu, M., Romero, C., 2002. Forest management optimisation models and habitat diversity: a goal programming approach. J. Oper. Res. Soc. 53, 1175–1184 [III, B].

Bertrand, L., Martel, J.M., 2002. Multicriteria collaborative approach to integrated forest management. INFOR 40, 223–239 [IX, J].

Bogetoft, P., Thorsen, B.J., Strange, N., 2003. Efficiency and merger gains in the Danish Forestry Extension Service. For. Sci. 49, 585–595 [VI, H].

Bojórquez-Tapia, L.A., Brower, L.P., Castilleja, G., Sánchez-Colón, S., Hernández, M., Calvert, W., Díaz, S., Gómez-Priego, P., Alcantar, G., Melgarejo, E.D., Solares, M.J., Gutiérrez, L., Juárez, M.L., 2003. Mapping expert knowledge: redesigning the Monarch Butterfly Biosphere Reserve. Conserv. Biol. 17, 367–379 [III, C;F].

Bojórquez-Tapia, L.A., de la Cueva, H., Díaz, S., Melgarejo, D., Alcantar, G., Solares, M.J., Grobet, G., Cruz-Bello, G., 2004. Environmental conflicts and nature reserves: redesigning Sierra San Pedro Mártir National Park, Mexico. Biol. Conserv. 117, 111–126 [III, F].

Bottoms, K.E., Bartlett, E.T., 1975. Resource allocation through goal programming. J. Range Manage. 28, 442–447 [II, B].

Briceño-Elizondo, E., Jäger, D., Lexer, M.J., Garcia-Gonzalo, J., Peltola, H., Kellomäki, S., 2008. Multi-criteria evaluation of multi-purpose stand treatment programmes for Finnish boreal forests under changing climate. Ecol. Indic. 8, 26–45 [II, D].

Buongiorno, J., Peyron, J.L., Houllier, F., Bruciamacchie, M., 1995. Growth and management of mixed-species, uneven-aged forests in the French Jura: implications for economic returns and tree diversity. For. Sci. 41, 397–429 [II, B].

Buongiorno, J., Svanquist, N.H., 1982. A separable goal programming model of the Indonesian forestry sector. For. Ecol. Manage. 4, 67–78 [VI, B].

Buongiorno, J., Svanquist, N.H., Wiroatmodjo, P., 1981. Forestry sector development planning: a model for Indonesia. Agric. Syst. 7, 113–135 [VI, B].

Campbell, G.E., Mendoza, G.A., 1988. Adapting modeling to generate alternatives (MGA) techniques to forest level planning. J. Environ. Manage. 26, 151–161 [II, A].

Chang, S., Buongiorno, J., 1981. A programming for multiple use forestry. J. Environ. Manage. 13, 45–58 [II, B].

Chen, K., Blong, R., Jacobson, C., 2001. MCE-RISK: integrating multicriteria evaluation and GIS for risk decision-making in natural hazards. Environ. Modell. Software 16, 387–397 [VIII, C;D].

Cocklin, C., Lonerganb, S., Smit, B., 1988. Assessing conflicts in the use of rural resources: an analytical framework. J. Rural Stud. 4, 9–20 [IX, B].

Cornett, D., Williams, W.A., 1991. Goal programming for multiple land-use planning at Mineral King, California. J. Soil Water Conserv. 46, 373–376 [II, B].

Dane, C.W., Meador, N.C., White, J.B., 1977. Goal programming in land use planning. J. For. 75, 325–329 [II, B].

Davis, L.S., Liu, G., 1991. Integrated forest planning across multiple ownerships and decision makers. For. Sci. 37, 200–226 [VI, B].

de Kluyver, C.A., Daellenbach, H.G., Whyte, A.G.D., 1980. A two-stage, multiple objective mathematical programming approach to optimal thinning and harvesting. For. Sci. 26, 674–686 [I, A].

de Oliveira, F., Volpi, N.M.P., Sanquetta, C.R., 2003. Goal programming in a planning problem. Appl. Math. Comput. 140, 165–178 [II, B].

Diaz-Balteiro, L., Casimiro Herruzo, A., Martinez, M., González-Pachón, J., 2006. An analysis of productive efficiency and innovation activity using DEA: an application to Spain's wood-based industry. For. Policy Econ. 8, 762–773 [VII, H].

Diaz-Balteiro, L., Romero, C., 1998. Modeling timber harvest scheduling problems with multiple criteria: an application in Spain. For. Sci. 44, 47–57 [I, B;C;F].

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

Diaz-Balteiro, L., Romero, C., 2004a. Sustainability of forest management plans: a discrete goal programming approach. J. Environ. Manage. 71, 351–359 [IV, B].

Diaz-Balteiro, L., Romero, C., 2004b. In search of a natural systems sustainability index. Ecol. Econ. 49, 401–405 [IV, B].

Dodson Coulter, E., Sessions, J., Wing, M.G., 2006. Scheduling forest road maintenance using the analytic hierarchy process and heuristics. Silva Fenn. 40, 143–160 [VII, F].

Ducey, M.J., Larson, B.C., 1999. A fuzzy set approach to the problem of sustainability. For. Ecol. Manage. 115, 29–40 [IV, E].

Ducheyne, E.I., De Wulf, R.R., De Baets, B., 2004. Single versus multiple objective genetic algorithms for solving the even-flow forest management problem. For. Ecol. Manage. 201, 259–273 [I, A].

Dyer, A.A., Hof, J.G., Kelly, J.W., Crim, S.A., Alward, G.S., 1979. Implications of goal programming in forest resources allocation. For. Sci. 25, 535–543 [II, B].

Ells, A., Bulte, E., van Kooten, G.C., 1997. Uncertainty and forest land use allocation in British Columbia: vague priorities and imprecise coefficients. For. Sci. 43, 509–520 [VIII;VI, F].

Espelta, J.M., Retana, J., Habrouk, A., 2003. An economic and ecological multicriteria evaluation of reforestation methods to recover burned *Pinus nigra* forests in NE Spain. For. Ecol. Manage. 180, 185–198 [V, G].

Faith, O.P., Walker, P.A., lve, J.R., Belbin, L., 1996. Integrating conservation and forestry production: exploring trade-offs between biodiversity and production in regional land-use assessment. For. Ecol. Manage. 251–260 [VI, G].

Field, D.B., 1973. Goal programming for forest management. For. Sci. 19, 125–135.

Field, R.C., Dress, P.E., Fortson, J.C., 1980. Complementary linear and goal programming procedures for timber harvest scheduling. For. Sci. 26, 121–133 [I, B].

Fuller, T., Munguía, M., Mayfield, M., Sánchez-Cordero, V., Sarkar, S., 2006. Incorporating connectivity into conservation planning: a multi-criteria case study from central Mexico. Biol. Conserv. 133, 131–142 [III, G].

Fürstenau, C., Badeck, F.W., Lasch, P., Lexer, M.J., Lindner, M., Mohr, P., Suckow, F., 2007. Multiple-use forest management in consideration of climate change and the interests of stakeholder groups. Eur. J. For. Res. 126, 225–239 [II, D;F;].

Gilliams, S., Raymaekers, D., Muys, B., Van Orshoven, J., 2005a. Comparing multiple criteria decision methods to extend a geographical information system on afforestation. Comput. Electron. Agric. 49, 142–158 [V, F;G;J].

Gilliams, S., Van Orshoven, J., Muys, B., Kros, H., Heil, G.W., Van Deursen, W., 2005b. AFFOREST sDSS: a metamodel based spatial decision support system for afforestation of agricultural land. New For. 30, 33–53 [V, B].

Gómez, T., Hernández, M., León, M.A., Caballero, R., 2006. A forest planning problem solved via a linear fractional goal programming model. For. Ecol. Manage. 227, 79–88 [I, B].

Gong, P., 1992. Multiobjective dynamic programming for forest resource management. For. Ecol. Manage. 48, 43–54 [VIII, A].

Hailu, A., Veeman, T.S., 2001. Non-parametric productivity analysis with undesirable outputs: an application to the Canadian pulp and paper industry. Am. J. Agric. Econ. 83, 605–616 [VII, H].

Hailu, A., Veeman, T.S., 2003. Comparative analysis of efficiency and productivity growth in Canadian regional boreal logging industries. Can. J. For. Res. 33, 1653–1660 [VII, H].

Hallefjord, A., Jörnsten, K., Eriksson, O., 1986. A long range forestry planning problem with multiple objectives. Eur. J. Oper. Res. 26, 123–133 [I, A].

Halme, M., Tomppo, E., 2001. Improving the accuracy of multisource forest inventory estimates by reducing plot location error—a multicriteria approach. Remote Sens. Environ. 78, 321–327 [IX, G].

Harrison, T.P., Rosenthal, R.E., 1988. An implicit/explicit approach to multiobjective optimization with an application to forest management planning. Decis. Sci. 19, 190–210 [II, A;D].

Heinonen, T., Pukkala, T., 2004. A comparison of one- and two-compartment neighbourhoods in heuristic search with spatial forest management goals. Silva Fenn. 38, 319–332 [I, D].

Hiltunen, V., Kangas, J., Pykäläinen, J., 2008. Voting methods in strategic forest planning—experiences from Metsähallitus. For. Policy Econ. 10, 117–127 [IV;VI, J].

Hjortsø, C.N., 2004. Enhancing public participation in natural resource management using Soft OR—an application of strategic option development and analysis in tactical forest planning. Eur. J. Oper. Res. 152, 667–683 [III, J].

Hjortsø, C.N., Straede, S., 2001. Strategic multiple-use forest planning in Lithuania: applying multi-criteria decision-making and scenario analysis for decision support in an economy in transition. For. Policy Econ. 3, 175–188 [II, A].

Hjortsø, C.N., Straede, S., Helles, F., 2006. Applying multi-criteria decision-making to protected areas and buffer zone management: a case study in the Royal Chitwan National Park, Nepal. J. For. Econ. 12, 91–108 [III, A;B].

Hof, J., Flather, C., Baltic, T., King, R., 2004. Forest and rangeland ecosystem condition indicators: identifying national areas of opportunity using data envelopment analysis. For. Sci. 50, 473–494 [VI, H].

Hotvedt, J.E., Leuschner, W.A., Buhyoff, G.J., 1982. A heuristic weight determination procedure for goal programs used for harvest scheduling models. Can. J. For. Res. 12, 292–298 [I, B].

Howard, A.F., 1991. A critical look at multiple criteria decision making techniques with reference to forestry applications. Can. J. For. Res. 21, 1649–1659 [IX, –].

Howard, A.F., Nelson, J.D., 1993. Area-based harvest scheduling and allocation of forest land using methods for multiple-criteria decision making. Can. J. For. Res. 23, 151–158 [I, D].

Hseu, J.S., Shang, J.K., 2005. Productivity changes of pulp and paper industry in OECD countries 1991–2000: a non-parametric Malmquist approach. For. Policy Econ. 7, 411–422 [VII, H].

Hua, Z., Bian, Y., Liang, L., 2007. Eco-efficiency analysis of paper mills along the Huai River: an extended DEA approach. Omega 35, 578–587 [VII, H].

Huth, A., Drechsler, M., Köhler, P., 2004. Multicriteria evaluation of simulated logging scenarios in a tropical rain forest. J. Environ. Manage. 71, 321–333 [IV, D].

Huth, A., Drechsler, M., Köhler, P., 2005. Using multicriteria decision analysis and a forest growth model to assess impacts of tree harvesting in Dipterocarp lowland rain forests. For. Ecol. Manage. 207, 215–232 [IV, G].

Hyberg, B.T., 1987. Multiattribute decision theory and forest management: a discussion and application. For. Sci. 33, 835–845 [II, D].

Hytönen, L.A., Leskinen, P., Store, R., 2002. A spatial approach to participatory planning in forestry decision making. Scand. J. For. Res. 17, 62–71 [II, J].

Ihalainen, M., Alho, J., Kolehmainen, O., Pukkala, T., 2002. Expert models for bilberry and cowberry yields in Finnish forests. For. Ecol. Manage. 157, 15–22 [IX, F].

Ivkovich, M., Koshy, M., 2002. Optimization of multiple trait selection in western hemlock (*Tsuga heterophylla* (Raf) Sarg.) including pulp and paper properties. Ann. For. Sci. 59, 577–582 [IX, A].

Janssen, R., Padilla, J.E., 1999. Preservation or conversion? Valuation and evaluation of a mangrove forest in the Philippines. Environ. Resour. Econ. 14, 297–331 [IX, G].

Jordi, K., Peddie, D., 1988. A wildlife management problem: a case study in multiple-objective linear programming. J. Oper. Res. Soc. 39, 1011–1020 [III, A].

Joro, T., Viitala, E.-J., 2004. Weight-restricted DEA in action: from expert opinions to mathematical models. J. Oper. Res. Soc. 55, 814–821 [VI, H].

Jumppanen, J., Kurttila, M., Pukkala, T., Uuttera, J., 2003. Spatial harvest scheduling approach for areas involving multiple ownership. For. Policy Econ. 5, 27–38 [II, D].

Kahalas, H., Groves, D.L., 1978. Modeling for organizational decision-making: profits vs. social values in resource management. J. Environ. Manage. 6, 73–84 [II, B].

Kangas, A., Maltamo, M., 2000. Calibrating predicted diameter distribution with additional information. For. Sci. 46, 390–396 [IX, B].

Kangas, A., Kangas, J., Pykäläinen, J., 2001. Outranking methods as tools in strategic natural resources planning. Silva Fenn. 35, 215–227 [VI;VIII, G;J].

Kangas, A.S., Kangas, J., 2004. Probability, possibility and evidence: approaches to consider risk and uncertainty in forestry decision analysis. For. Policy Econ. 6, 169–188 [IX;VIII, –].

Kangas, A., 2006. The risk of decision making with incomplete criteria weight information. Can. J. For. Res. 36, 195–205 [VIII, G].

Kangas, A., Kangas, J., Laukkanen, S., 2006a. Fuzzy multicriteria approval method and its application to two forest planning problems. For. Sci. 52, 232–242 [II, E;J].

Kangas, A., Laukkanen, S., Kangas, J., 2006b. Social choice theory and its applications in sustainable forest management—a review. For. Policy Econ. 9, 77–92 [IX, J].

Kangas, A., Kangas, J., Lahdelma, R., Salminen, P., 2006c. Using SMAA-2 method with dependent uncertainties for strategic forest planning. For. Policy Econ. 9, 113–125 [VIII, G].

Kangas, A., Leskinen, P., Kangas, J., 2007. Comparison of fuzzy and statistical approaches in multicriteria decisionmaking. For. Sci. 53, 37–44 [VIII, E].

Kangas, J., 1992. Multiple-use planning of forest resources by using the analytic hierarchy process. Scand. J. For. Res. 7, 259–268 [II, F].

Kangas, J., Pukkala, T., 1992. A decision theoretic approach applied to goal programming of forest management. Silva Fenn. 26, 169–176 [I, B;F].

Kangas, J., 1993. A multi-attribute preference model for evaluating the reforestation chain alternatives of a forest stand. For. Ecol. Manage. 59, 271–288 [V, D;F].

Kangas, J., Kuusipalo, J., 1993. Integrating biodiversity into forest management planning and decision-making. For. Ecol. Manage. 61, 1–15 [III, F].

Kangas, J., Laasonen, L., Pukkala, T., 1993a. A method for estimating forest landowners landscape preferences. Scand. J. For. Res. 8, 408–417 [II, F].

Kangas, J., Karsikko, J., Laasonen, L., Pukkala, T., 1993b. A method for estimating the suitability function of wildlife habitat for forest planning on the basis of expertise. Silva Fenn. 27, 259–268 [III, F].

Kangas, J., 1994a. An approach to public participation in strategic forest management planning. For. Ecol. Manage. 70, 75–88 [III, F;J].

Kangas, J., 1994b. Incorporating risk attitude into comparison of reforestation alternatives. Scand. J. For. Res. 9, 297–304 [V;VIII, D;F].

Kangas, J., Pukkala, T., 1996. Operationalization of biodiversity as a decision objective in tactical forest planning. Can. J. For. Res. 26, 103–111 [III, D;F].

Kangas, J., Alho, J.M., Kolehmainen, O., Mononen, A., 1998. Analyzing consistency of experts' judgements-case of assessing forest biodiversity. For. Sci. 44, 610–617 [III, D].

Kangas, J., Store, R., Leskinen, P., Mehtatalo, L., 2000. Improving the quality of landscape ecological forest planning by utilising advanced decision-support tools. For. Ecol. Manage. 132, 157–171 [VIII, F].

Kangas, J., Kurttila, M., Kajanus, M., Kangas, A., 2003a. Evaluating the management strategies of a forestland estate—the S-O-S approach. J. Environ. Manage. 69, 349–358 [II, G].

Kangas, J., Hokkanen, J., Kangas, A.S., Lahdelma, R., Salminen, P., 2003b. Applying stochastic multicriteria acceptability analysis to forest ecosystem management with both cardinal and ordinal criteria. For. Sci. 49, 928–937 [VIII, G].

Kangas, J., Kangas, A., 2005. Multiple criteria decision support in forest management—the approach, methods applied, and experiences gained. For. Ecol. Manage. 207, 133–143 [IX, F;G;J].

Kangas, J., Leskinen, P., 2005. Modelling ecological expertise for forest planning calculations-rationale, examples, and pitfalls. J. Environ. Manage. 76, 125–133 [III, F].

Kangas, J., Store, R., Kangas, A., 2005. Socioecological landscape planning approach and multicriteria acceptability analysis in multiple-purpose forest management. For. Policy Econ. 7, 603–614. [II, G].

Kant, S., Lee, S., 2004. A social choice approach to sustainable forest management: an analysis of multiple forest values in Northwestern Ontario. For. Policy Econ. 6, 215–227. [III, J].

Kao, C., 1998. Measuring the efficiency of forest districts with multiple working circles. J. Oper. Res. Soc. 49, 583–590 [VI, H].

Kao, C., 2000. Measuring the performance improvement of Taiwan forests after reorganization. For. Sci. 46, 577–584 [VI, H].

Kao, C., Brodie, J.D., 1979. Goal programming for reconciling economic, even flow, and regulation objectives in forest harvest scheduling. Can. J. For. Res. 9, 525–531 [I, B].

Kao, C., Chang, P.-L., Hwang, S.N., 1993. Data envelopment analysis in measuring the efficiency of forest management. J. Environ. Manage. 38, 73–83 [VI, H].

Kao, C., Hung, H.-T., 2005. Data envelopment analysis with common weights: the compromise solution approach. J. Oper. Res. Soc. 56, 1196–1203 [VI, H].

Kao, C., Yang, Y.C., 1991. Measuring the efficiency of forest management. For. Sci. 1239 [VI, H].

Kao, C., Yang, Y.C., 1992. Reorganization of forest districts via efficiency measurement. Eur. J. Oper. Res. 58, 356–362 [VI, H].

Kazana, V., Fawcett, R.H., Mutch, W.E.S., 2003. A decision support modelling framework for multiple use forest management: the Queen Elizabeth forest case study in Scotland. Eur. J. Oper. Res. 148, 102–115 [II, C].

Krcmar, E., van Kooten, G.C., Vertinsky, I., 2005. Managing forest and marginal agricultural land for multiple tradeoffs: compromising on economic, carbon and structural diversity objectives. Ecol. Model. 185, 451–468 [VI, C].

Krcmar-Nozic, E., van Kooten, G.C., Vertinksy, I., Brumelle, S., 1998. An interactive multiobjective approach to harvest decisions in forest planning. Scand. J. For. Res. 13, 357–369 [I, A].

Kurttila, M., Pesonen, M., Kangas, J., Kajanus, M., 2000. Utilizing the analytic hierarchy process (AHP) in SWOT analysis—a hybrid method and its application to a forest-certification case. For. Policy Econ. 1, 41–52 [IX, F].

Kurttila, M., Pukkala, T., 2003. Combining holding-level economic goals with spatial landscape-level goals in the planning of multiple ownership forestry. Landsc. Ecol. 18, 529–541 [II, D].

Kurttila, M., Pukkala, T., Loikkanen, T., 2002. The performance of alternative spatial objective types in forest planning calculations: a case for flying squirrel and moose. For. Ecol. Manage. 166, 254–260 [III, D].

Kurttila, M., Pykäläinen, J., Leskinen, P., 2006. Defining the forest landowner’s utility–loss compensative subsidy level for a biodiversity object. Eur. J. For. Res. 125, 67–78 [III, D].

Kuusipalo, J., Kangas, J., 1994. Managing biodiversity in a forest environment. Conserv. Biol. 8, 450–460 [III, F].

Laukkanen, S., Kangas, A., Kangas, J., 2002. Applying voting theory in natural resource management: a case of multiple-criteria group decision support. J. Environ. Manage. 64, 127–137 [II, J].

Laukkanen, S., Palander, T., Kangas, J., 2004. Applying voting theory in participatory decision support for sustainable timber harvesting. Can. J. For. Res. 34, 1511–1524 [II, J].

Laukkanen, S., Palander, T., Kangas, J., Kangas, A., 2005. Evaluation of the multicriteria approval method for timber-harvesting group decision support. Silva Fenn. 39, 249–264 [II, J].

Lee, J.Y., 2005a. Comparing SFA and DEA methods on measuring production efficiency for forest and paper companies. For. Prod. J. 55, 51–56 [VII, H].

Lee, J.Y., 2005b. Using DEA to measure efficiency in forest and paper companies. For. Prod. J. 55, 58–66 [VII, H].

Leskinen, P., 2007. Comparison of alternative scoring techniques when assessing decision maker’s multi-objective preferences in natural resource management. J. Environ. Manage. 85, 363–370 [II, F].

Leskinen, P., Kangas, J., 1998. Analysing uncertainties of interval judgment data in multiple-criteria evaluation of forest plans. Silva Fenn. 32, 363–372 [VIII, F].

Leskinen, P., Kangas, J., 2005. Multi-criteria natural resource management with preferentially dependent decision criteria. J. Environ. Manage. 77, 244–251 [IX, G].

Leskinen, P., Kangas, A., Kangas, J., 2004. Rank-based modelling of preferences in multi-criteria decision making. Eur. J. Oper. Res. 158, 721–733 [II, G].

Leskinen, P., Kangas, J., Pasanen, A.M., 2003. Assessing ecological values with dependent explanatory variables in multi-criteria forest ecosystem management. Ecol. Model. 170, 1–12 [III, D;J].

Leskinen, L.A., Leskinen, P., Kurttila, M., Kangas, J., Kajanus, M., 2006b. Adapting modern strategic decision support tools in the participatory strategy process—a case study of a forest research station. For. Policy Econ. 8, 267–278 [VI, G;J].

Leskinen, P., Viitanen, J., Kangas, A., Kangas, J., 2006a. Alternatives to incorporate uncertainty and risk attitude in multicriteria evaluation of forest plans. For. Sci. 52, 304–312 [VIII, G].

Levy, J.K., Hipel, K.W., Kilgour, D.M., 2000a. Using environmental indicators to quantify the robustness of policy alternatives to uncertainty. Ecol. Model. 130, 79–86 [VIII, D].

Levy, J.K., Kilgour, D.M., Hipel, K.W., 2000b. Web-based multiple criteria decision analysis: Web-HIPRE and the management of environmental uncertainty. INFOR 38, 221–244 [VIII, D].

Lexer, M.J., Hönninger, K., Scheifinger, H., Matulla, C., Groll, N., Kromp-Kolb, H., 2000. The sensitivity of central European mountain forests to scenarios of climatic change: methodological frame for a large-scale risk assessment. Silva Fenn. 34, 113–129 [VIII, D;F].

Lexer, M.J., Vacik, H., Palmetzhofer, D., Oitzinger, G., 2005. A decision support tool to improve forestry extension services for small private landowners in southern Austria. Comput. Electron. Agric. 49, 81–102 [II, D;F].

Liu, A., Collins, A., Yao, S., 1998. A multi-objective and multi-design evaluation procedure for environmental protection forestry. Environ. Resour. Econ. 12, 225–240 [V;VI, F].

Liu, G., Davis, L.S., 1995. Interactive resolution of multi-objective forest planning problems with shadow price and parametric analysis. For. Sci. 41, 452–469 [II, A].

Liu, C., Yin, R., 2004. Poverty dynamics revealed in production performance and forestry in improving livelihoods: the case of West Anhui, China. For. Policy Econ. 6, 391–401 [VI, H].

Lonergan, S.C., Cocklin, C., 1988. The use of lexicographic goal programming in economic/ecological conflict analysis. Socio Econ. Plan. Sci. 22, 83–92 [II, B].

Ludwin, W.G., Chamberlain, P.A., 1989. Habitat management decisions with goal programming. Wildl. Soc. B 17, 20–23 [III, B].

Maness, T., Farrell, R., 2004. A multi-objective scenario evaluation model for sustainable forest management using criteria and indicators. Can. J. For. Res. 34, 2004–2017 [IV, E].

Marinescu, M.V., Sowlati, T., Maness, T.C., 2005. The development of a timber allocation model using data envelopment analysis. Can. J. For. Res. 35, 2304–2315 [VII, H].

Martin, W.E., Shields, D.J., Tolwinski, B., Kent, B., 1996. An application of social choice theory to U.S.D.A. Forest Service decision making. J. Policy Model. 18, 603–621 [IX, J].

Martin, W.E., Wise Bender, H., Shields, D.J., 2000. Stakeholder objectives for public lands: rankings of forest management alternatives. J. Environ. Manage. 58, 21–32 [IX, D].

Martins, H., Borges, J.G., 2007. Addressing collaborative planning methods and tools in forest management. For. Ecol. Manage. 248, 107–118 [IX, –].

Mattheiss, T.H., Land, S.B., 1984. A tree breeding strategy based on multiple objective linear programming. Interfaces 14, 96–104 [IX, A].

Mau-Crimmins, T., de Steiguer, J.E., Dennis, D., 2005. AHP as a means for improving public participation: a pre–post experiment with university students. For. Policy Econ. 7, 501–514 [III, F;J].

McDaniels, T.L., Roessler, C., 1998. Multiattribute elicitation of wilderness preservation benefits: a constructive approach. Ecol. Econ. 27, 299–312 [III, D].

Memtsas, D.P., 2003. Multiobjective programming methods in the reserve selection problem. Eur. J. Oper. Res. 150, 640–652 [III, A;C].

Mendoza, G.A., 1986. A heuristic programming approach in estimating efficient target levels in goal programming. Can. J. For. Res. 16 [V, B].

Mendoza, G.A., 1987. Goal programming formulations and extensions: an overview and analysis. Can. J. For. Res. 17, 575–581 [IX, B].

Mendoza, G.A., 1988. A multiobjective programming framework for integrating timber and wildlife management. Environ. Manage. 12, 163–171 [III, A].

Mendoza, G.A., Bare, B.B., Campbell, G.E., 1987a. Multiobjective programming for generating alternatives: a multiple-use planning example. For. Sci. 33 [II, A].

Mendoza, G.A., Bare, B.B., Zhou, Z., 1993. A fuzzy multiple objective linear programming approach to forest planning under uncertainty. Agric. Syst. 41, 257–274 [II, E].

Mendoza, G.A., Campbell, G.E., Rolfe, G.L., 1987b. Multiple objective programming: an approach to planning and evaluation of agroforestry systems. Part 2. An illustrative example and analysis. Agric. Syst. 23, 1–18 [I, A;B].

Mendoza, G.A., Dalton, W.J., 2005. Multi-stakeholder assessment of forest sustainability: multi-criteria analysis and the case of the Ontario forest assessment system. For. Chron. 81, 222–228 [IV, F;J].

Mendoza, G.A., Martins, H., 2006. Multi-criteria decision analysis in natural resource management: a critical review of methods and new modelling paradigms. For. Ecol. Manage. 230, 1–22 [IX, –].

Mendoza, G.A., Prabhu, R., 2000a. Development of a methodology for selecting criteria and indicators of sustainable forest management: a case study on participatory assessment. Environ. Manage. 26, 659–673 [IV, F;J].

Mendoza, G.A., Prabhu, R., 2000b. Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study. For. Ecol. Manage. 131, 107–126 [IV, F;J].

Mendoza, G.A., Prabhu, R., 2003a. Fuzzy methods for assessing criteria and indicators of sustainable forest management. Ecol. Indic. 3, 227–236 [IV, E].

Mendoza, G.A., Prabhu, R., 2003b. Qualitative multi-criteria approaches to assessing indicators of sustainable forest resource management. For. Ecol. Manage. 174, 329–343 [IV, G;J].

Mendoza, G.A., Prabhu, R., 2005. Combining participatory modeling and multi-criteria analysis for community-based forest management. For. Ecol. Manage. 207, 145–156 [IX, J].

Mendoza, G.A., Prabhu, R., 2006. Participatory modeling and analysis for sustainable forest management: overview of soft system dynamics models and applications. For. Policy Econ. 9, 179–196 [IX, E;J].

Mendoza, G.A., Sprouse, W., 1989. Forest planning and decision making under fuzzy environments: an overview and illustration. For. Sci. 35, 481–502 [II, E;F].

Mikkila, M., Kolehmainen, O., Pukkala, T., 2005. Multi-attribute assessment of acceptability of operations in the pulp and paper industries. For. Policy Econ. 7, 227–243 [VII, F].

Mitchell, B.R., Bare, B.B., 1981. A separable goal programming approach to optimizing multivariate sampling designs for forest inventory. For. Sci. 27, 147–162 [IX, B].

Moffett, A., Garson, J., Sarkar, S., 2005. MultCSync: a software package for incorporating multiple criteria in conservation planning. Environ. Modell. Software 20, 1315–1322 [III, G].

Moffett, A., Sarkar, S., 2006. Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations. Divers. Distrib. 12, 125–137 [IX, –].

Mrosek, T., Balsillie, D., Schleifenbaum, P., 2006. Field testing of a criteria and indicators system for sustainable forest management at the local level. Case study results concerning the sustainability of the private forest Haliburton Forest and Wild Life Reserve in Ontario, Canada. For. Policy Econ. 8, 593–609 [IV, G].

Nhantumbo, I., Dent, J.B., Kowero, G., 2001. Goal programming: application in the management of the Miombo woodland in Mozambique. Eur. J. Oper. Res. 133, 310–322 [VI, B].

Njiti, C.F., Sharpe, D.M., 1994. A goal-programming approach to the management of competition and conflict among land uses in the tropics: the Cameroon example. Ambio 23, 112–119 [VI, B].

Nousiainen, I., Tahvanainen, L., Tyrväinen, L., 1998. Landscape in farm-scale land-use planning. Scand. J. For. Res. 13, 477–487 [V;II, D;F].

Nyrud, A.Q., Baardsen, S., 2003. Production efficiency and productivity growth in Norwegian sawmilling. For. Sci. 49, 89–97 [VII, H].

Nyrud, A.Q., Bergseng, E.R., 2002. Production efficiency and size in Norwegian sawmilling. Scand. J. For. Res. 17, 566–575 [VII, H].

Ohlson, D.W., Berry, T.M., Gray, R.W., Blackwell, B.A., Hawkes, B.C., 2006. Multi-attribute evaluation of landscape-level fuel management to reduce wildfire risk. For. Policy Econ. 8, 824–837 [VIII, D].

Oliver, I., Jones, H., Schmoldt, D.L., 2007. Expert panel assessment of attributes for natural variability benchmarks for biodiversity. Aust. Ecol. 32, 453–475 [III, J;F].

Palander, T., 1999. A hierarchical participatory methodology for tactical decision-making based on a decision-analytic model for balancing timber stock. Scand. J. For. Res. 14, 567–580 [VII, B;D;J].

Palander, T., Toivonen, M., Laukkanen, S., 2002. Groupware and group decision support systems for wood procurement organisation. A review. Silva Fenn. 36, 585–600 [IX, J].

Pasanen, K., Kurttila, M., Pykäläinen, J., Kangas, J., 2005. MESTA—non industrial private forest owners' decision-support environment for the evaluation of alternative forest plans over the Internet. Int. J. Inform. Technol. Decis. Making 4, 601–620 [II, J].

Pauwels, D., Lejeune, P., Rondeux, J., 2007. A decision support system to simulate and compare silvicultural scenarios for pure even-aged larch stands. Ann. For. Sci. 64, 345–353 [II, G].

Pesonen, M., Kurttila, M., Kangas, J., Kajanus, M., Heinonen, P., 2001. Assessing the priorities using A'WOT among resource management strategies at the Finnish Forest and Park Service. For. Sci. 47, 534–541 [II, G].

Peterson, D.L., Silsbee, D.G., Schmoldt, D.L., 1994. A case study of resources management planning with multiple objectives and projects. Environ. Manage. 18, 729–742 [III, F].

Phua, M., Minowa, M., 2005. A GIS-based multi-criteria decision making approach to forest conservation planning at a landscape scale: a case study in the Kinabalu Area, Sabah, Malaysia. Landsc. Urban Plann. 71, 207–222 [IV, C;F;J].

Pickens, J.B., Hof, J.G., 1991. Fuzzy goal programming in forestry—an application with special solution problems. Fuzzy Set Syst. 39, 239–246 [I, E].

Porterfield, R.L., 1976. A goal programming model to guide and evaluate tree improvement programs. For. Sci. 22, 417–430 [IX, B].

Porterfield, R.L., Zobel, B.J., Ledig, F.T., 1975. Evaluating the efficiency of tree improvement programs. Silvae Genet. 24, 33–44 [IX, B].

Pukkala, T., 1998. Multiple risks in multi-objective forest planning integration and importance. For. Ecol. Manage. 111, 265–284 [VIII, D].

Pukkala, T., Kangas, J., 1993. A heuristic optimisation method for forest planning and decision-making. Scand. J. For. Res. 8, 560–570 [II, D;F].

Pukkala, T., Kangas, J., 1996. A method for incorporating risk and risk attitude into forest planning. For. Sci. 42, 198–205 [VIII, F].

Pukkala, T., Kangas, J., Kniivilä, M., Tiainen, A.-M., 1997. Integrating forest-level and compartment-level indices of species diversity with numerical forest planning. Silva Fenn. 31, 417–429 [II, D;F].

Pukkala, T., Ketonen, T., Pykäläinen, J., 2003. Predicting timber harvests from private forests—a utility maximization approach. For. Policy Econ. 5, 285–296 [II, D].

Pukkala, T., Miina, J., 1997. A method for stochastic multiobjective optimization of stand management. For. Ecol. Manage. 98, 189–203 [VIII, D].

Pukkala, T., Nuutinen, T., Kangas, J., 1995. Integrating scenic and recreational amenities of forest area into numerical forest management planning. Landsc. Urban Plann. 32, 185–195 [II, D].

Purnomo, H., Mendoza, G., Prabhu, R., 2004. Model of collaborative planning of community-managed resources based on qualitative soft systems approach. J. Trop. For. Sci. 16, 106–131 [IX, J].

Pykäläinen, J., 2000. Defining forest owner's forest-management goals by means of a thematic interview in interactive forest planning. Silva Fenn. 34 [I, D].

Pykäläinen, J., Hiltunen, V., Leskinen, P., 2007. Complementary use of voting methods and interactive utility analysis in participatory strategic forest planning: experiences gained from western Finland. Can. J. For. Res. 37, 853–865 [II;VI, J].

Pykäläinen, J., Kangas, J., Loikkanen, T., 1999. Interactive decision analysis in participatory strategic forest planning: experiences from state owned boreal forests. J. For. Econ. 5 [VI, D;J].

Pykäläinen, J., Pukkala, T., Kangas, J., 2001. Alternative priority models for forest planning on the landscape level involving multiple ownership. For. Policy Econ. 2, 293–306 [II, D;J].

Rauscher, H.M., Lloyd, F.T., Loftis, D.L., Twery, M.J., 2000. A practical decision-analysis process for forest ecosystem management. Comput. Electron. Agric. 27, 195–226 [II, F].

Rehman, T., Romero, C., 1993. The application of the MCDM paradigm to the management of agricultural systems: some basic considerations. Agric. Syst. 41, 239–255 [IX, –].

Renaud, J., Thibault, J., Lanouette, R., Kiss, L.N., Zaras, K., Fonteix, C., 2007. Comparison of two multicriteria decision aid methods: net flow and rough set methods in a high yield pulping process. Eur. J. Oper. Res. 177, 1418–1432 [VII, G;H].

Reynolds, K.M., Holsten, E., 1994. Relative importance of risk factors for spruce beetle outbreaks. Can. J. For. Res. 24, 2089–2095 [VIII, F].

Riedl, L., Vacik, H., Kalasek, R., 2000. MapModels: a new approach for spatial decision support in silvicultural decision making. Comput. Electron. Agric. 407–412 [II, F].

Roise, J.P., 1990. Multicriteria nonlinear programming for optimal spatial allocation of stands. For. Sci. 36, 487–501 [I, A].

Romero, C., 1997. Multicriteria decision analysis and environmental economics: an approximation. Eur. J. Oper. Res. 96, 81–89 [IX, C].

Romero, C., Rehman, T., 1987. Natural resource management and the use of multiple criteria decision-making techniques: a review. Eur. Rev. Agric. Econ. 14. [IX, –].

Romero, C., Rios, V., Diaz-Balteiro, L., 1998. Optimal forest rotation age when carbon captured is considered: theory and applications. J. Oper. Res. Soc. 49, 121–131 [V, C].

Rothley, K.D., 1999. Designing bioreserve networks to satisfy multiple, conflicting demands. Ecol. Appl. 9, 741–750 [III, A;D].

Salehirad, N., Sowlati, T., 2005. Performance analysis of primary wood producers in British Columbia using data envelopment analysis. Can. J. For. Res. 35, 285–294 [VII, H].

Salehirad, N., Sowlati, T., 2006. Productivity and efficiency assessment of the wood industry: a review with a focus on Canada. For. Prod. J. 56, 25–32 [IX, H].

Salo, A., Gustafsson, T., Ramanathan, R., 2003. Multicriteria methods for technology foresight. J. Forecasting 22, 235–255 [VII, G].

Salo, A., Liesio, J., 2006. A case study in participatory priority setting for a Scandinavian research program. Int. J. Inform. Technol. Decis. Making 5, 65–88 [VII, G;J].

Schlaepfer, R., Iorgulescu, I., Glenz, C., 2002. Management of forested landscapes in mountain areas: an ecosystem-based approach. For. Policy Econ. 4, 89–99 [VI, G].

Schmoldt, D.L., Peterson, D.L., 2000. Analytical group decision making in natural resources: methodology and application. For. Sci. 46, 62–75 [IX, F;J].

Schmoldt, D.L., Peterson, D.L., Silsbee, D.G., 1994. Developing inventory and monitoring programs based on multiple objectives. Environ. Manage. 18, 707–727 [III, F].

Schuler, A., Meadows, J.C., 1975. Planning resource use on national forests to achieve multiple objectives. J. Environ. Manage. 3, 351–366 [II, B].

Schuler, A.T., Webster, H.H., Meadows, J.C., 1977. Goal programming in forest management. J. For. 75, 320–324 [II, B].

Sheppard, S.R.J., 2005. Participatory decision support for sustainable forest management: a framework for planning with local communities at the landscape level. Can. J. For. Res. 35, 1515–1526 [IX, J].

Sheppard, S.R.J., Meitner, M., 2005. Using multi-criteria analysis and visualisation for sustainable forest management planning with stakeholder groups. For. Ecol. Manage. 207, 171–187 [IV, J].

Shields, D.J., Tolwinski, B., Kent, B.M., 1999. Models for conflict resolution in ecosystem management. Socio Econ. Plan. Sci. 33, 61–84 [IX, J].

Silvennionen, H., Alho, J., Kolehmainen, O., et al., 2001. Prediction models of landscape preferences at the forest stand level. Landsc. Urban Plann. 56, 11–20 [IX, F].

Sowlati, T., 2005. Efficiency studies in forestry using data envelopment analysis. For. Prod. J. 55, 49–57 [IX, H].

Sowlati, T., Vahid, S., 2006. Malmquist productivity index of the manufacturing sector in Canada from 1994 to 2002, with a focus on the wood manufacturing sector. Scand. J. For. Res. 21, 424–433 [VII, H].

Steuer, R.E., Schuler, A.T., 1978. An interactive multiple objective linear programming approach to a problem in forest management. Oper. Res. 26, 254–269 [II, A].

Store, R., Jokimäki, J., 2003. A GIS-based multi-scale approach to habitat suitability modeling. Ecol. Model. 169, 1–15 [III, D].

Store, R., Kangas, J., 2001. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. Landsc. Urban Plann. 55, 79–93 [III, D;F].

Strager, M.P., Rosenberger, R.S., 2005. Incorporating stakeholder preferences for land conservation: weights and measures in spatial MCA. Ecol. Econ. 57, 627–639 [III, F;J].

Tarp, P., Helles, F., 1995. Multi-criteria decision-making in forest management planning—an overview. J. For. Econ. 1, 273–306 [IX, –].

Tecle, A., Duckstein, L., Korhonen, P., 1994. Interactive, multiobjective programming for forest resources management. Appl. Math. Comput. 63, 75–93 [II, E;J].

Tecle, A., Shrestha, B.P., Duckstein, L., 1998. A multiobjective decision support system for multiresource forest management. Group Decis. Negot. 7, 23–40 [II, C;J].

Teeter, L., Dyer, A.A., 1986. A multiattribute utility model for incorporating risk in fire management planning. For. Sci. 32, 1032–1048 [VIII, D].

Tikkanen, J., Isokaänta, T., Pykäläinen, J., Leskinen, P., 2006. Applying cognitive mapping approach to explore the objective–structure of forest owners in a Northern Finnish case area. For. Policy Econ. 9, 139–152 [IX, J].

Toth, S.F., McDill, M.E., Rebain, S., 2006. Finding the efficient frontier of a bi-criteria, spatially explicit, harvest scheduling problem. For. Sci. 52, 93–107 [II, A].

Turner, B.J., Chikumbo, O., Davey, S.M., 2002. Optimisation modelling of sustainable forest management at the regional level: an Australian example. Ecol. Model. 153, 157–179 [II, A].

Ulmer, J.R., Greene, W.D., Clutter, M.L., Mayo, J.H., 2004. Consistency ratings for assessing the impact of variations in mill demand on logging crew production and cost. For. Prod. J. 54, 57–63 [VII, H].

Vacik, H., Lexer, M.J., 2001. Application of a spatial decision support system in managing the protection forests of Vienna for sustained yield of water resources. For. Ecol. Manage. 143, 65–76 [II, D;F].

Vahid, S., Sowlati, T., 2007. Efficiency analysis of the Canadian wood-product manufacturing subsectors: a DEA approach. For. Prod. J. 57, 71–77 [VII, H].

Vainikainen, N., Kangas, A., Kangas, J., in press. Empirical study on voting power in participatory forest planning. J. Environ. Manage. [II, J].

Van Elegem, B., Embo, T., Muys, B., Lust, N., 2002. A methodology to select the best locations for new urban forests using multicriteria analysis. Forestry 75, 13–23 [V, G].

van Kooten, G.C., 1995. Modeling public forest land use tradeoffs on Vancouver island. J. For. Econ. 1, 191–217 [VI, B].

Varma, V.K., Ferguson, I., Wild, I., 2000. Decision support system for the sustainable forest management. For. Ecol. Manage. 128, 49–55 [IV, D].

Vennesland, B., 2005. Measuring rural economic development in Norway using data envelopment analysis. For. Policy Econ. 7, 109–119 [VI, H].

Viitala, E.-J., Hänninen, H., 1998. Measuring the efficiency of public forestry organizations. For. Sci. 44, 298–307 [VI, H].

Walker, H.D., 1985. An alternative approach to goal programming. Can. J. For. Res. 15, 319–325 [V, B].

Wolfslehner, B., Vacik, H., Lexer, M.J., 2005. Application of the analytic network process in multi-criteria analysis of sustainable forest management. For. Ecol. Manage. 207, 157–170 [IV, F].

Yin, R., 1998. DEA: a new methodology for evaluating the performance of forest products producers. For. Prod. J. 48, 29–34 [VII, H].

Yin, R., 1999. Production efficiency and cost competitiveness of pulp producers in the Pacific Rim. For. Prod. J. 49, 43–49 [VII, H].

Yin, R., 2000. Alternative measurements of productive efficiency in the global bleached softwood pulp sector. For. Sci. 46, 558–569 [VII, H].

Yin, Y.Y., Pierce, J.T., Love, E., 1995. Designing a multisector model for land conversion study. J. Environ. Manage. 44, 249–266 [VI, B].

Zadnik Stirn, L., 2006. Integrating the fuzzy analytic hierarchy process with dynamic programming approach for determining the optimal forest management decisions. Ecol. Model. 194, 296–305 [II, E;F].

Zhang, Y., 2002. The impacts of economic reform on the efficiency of silviculture: a non-parametric approach. Environ. Dev. Econ. 7, 107–122 [VI, H].

Zhou, W., Gong, P., 2004. Multiple-use tradeoffs in Swedish mountain region forests. For. Policy Econ. 7, 39–52 [II, A].