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Application of the analytic network process in multi-criteria analysis of sustainable forest management

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Abstract

Over the previous decade, sustainable forest management (SFM) has become a highly relevant topic both in forest and environmental policy. Criteria and indicators (C&I) are primarily used in implementing the principles of SFM at national, regional, and at forest management unit levels. In turning SFM from a conceptual framework into applicable guidelines at the operational scale, several limitations have to be acknowledged: (i) partial lack of knowledge, (ii) deficits about dependencies and feedbacks among system components represented by C&I, and (iii) knowledge gaps regarding impacts and related uncertainties. Several methodologies have been proposed to implement C&I-based SFM. Multi-criteria analysis is often used to analyze and evaluate multiple C&I approaches. This study compares two different multi-criteria analysis approaches: the analytic hierarchy process (AHP) with a hierarchical structure and the analytic network process (ANP) with a network structure. Comparisons are made for evaluating sustainable management strategies at forest management-unit level by using a C&I approach based on the Pan-European guidelines for SFM. AHP and ANP are used to compare four different strategic management options with a set of six criteria and 43 indicators. Differences in evaluation results between AHP and ANP are discussed, as well as strengths and weaknesses of both approaches for SFM. Needs and demands are derived for successful future applications in forestry decision-making.

Keywords: Analytic hierarchy process (AHP); Analytic network process (ANP); Criteria and indicators; Multi-criteria analysis; Sustainable forest management

1. Introduction

Although the concept of forest sustainability has a long tradition in Europe (Farrell et al., 2000), the practice of forestry is currently confronted with an ongoing shift of paradigm from sustained yield and constant forest cover towards sustainability of an increasing diversity of values, goods, and benefits obtained or at least demanded by society from forests. Since the 1990s, sustainable forest management (SFM) has become a highly relevant topic both in forest and environmental policy. In the wake of the UN Conference on Environment and Development in 1992

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(UN, 1992), the concept of sustainability also became a matter of public interest. In Europe, this trend was taken into account at the second Ministerial Conference on the Protection of Forests in Europe (MCPFE) in Helsinki in 1993, when SFM was defined and adopted, binding at the political level (resolutions H1 and H2; MCPFE, 1993). The traditional meaning of ''sustainability'' in terms of sustained yield was radically expanded (Glück, 1995). Sustainable forest management is now defined as ''stewardship and use of forests and forest land in a way, and at a rate, that maintains their biodiversity, productivity, generation capacity, vitality, and their potential to fulfill now and in the future, relevant ecological, economic, and social functions at local, national, and global levels [. . .]'' (MCPFE, 1993).

In the follow-up process of the MCPFE Helsinki Conference, six criteria for SFM in Europe were defined:

(1) maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles (C1);
(2) maintenance of forest ecosystem health and vitality (C2);
(3) maintenance and encouragement of productive functions of forests (wood and non-wood) (C3);
(4) maintenance, conservation, and appropriate enhancement of biological diversity in forest ecosystems (C4);
(5) maintenance and appropriate enhancement of protective functions in forest management (notably soil and water) (C5);
(6) maintenance of other socio-economic functions and conditions (C6).

While progress towards the goals and commitments of the MCPFE is to be measured at the national level by a set of Pan-European indicators, progress in implementing the principles of SFM at the operational level has been widely lacking. Hence, the Pan-European Operational Level Guidelines (PEOLG) have been elaborated by the MCPFE-process to further promote sustainable forest management in Europe by translating international commitments down to the level of forest-management planning and practices. The PEOLG represent a common framework of recommendations that can be used on a voluntary basis and as a complement to national and/or regional policy instruments to further promote sustainable forest management at the operational field level in European forests (MCPFE, 1998). The PEOLG have been developed to cover all relevant measures concerning sustainable forest management planning and practice within European forestry. This implies that they are formulated merely at a quasi-operational level, and thus have to be adapted to specific national, sub-national, and local conditions.

2. Using criteria and indicators and multi-criteria analysis to evaluate sustainable forest management

The demand to evaluate forest-management regimes and alternatives in regards to their specific benefits and to sustainability in general has lead to the use of criteria and indicators (C&I) (Prabhu et al., 1996; Van Bueren and Blom, 1997). According to Prabhu et al. (1999), a criterion is a principle or standard that an issue is judged by, and an indicator is defined as any variable or component of the forest ecosystem used to infer the status of a particular criterion. C&I-approaches appear to be highly capable of measuring aspects of SFM at national, regional, and forest management unit levels. An additional strength of a C&I-approach is that it can be used to collect and report information within a system (e.g., SFM), which is usually characterized by a lack of knowledge, uncertainties, and missing information about impacts, dependencies, and feedbacks (Rametsteiner, 2001; Brang et al., 2002).

The power of C&I is limited when (i) there are unclear definitions involved, (ii) there is lack of reliability, (iii) there are no target or threshold values provided, or (iv) a C&I-system too strongly simplifies a complex item (Brang et al., 2002). However, using C&I has become a common approach to assess or evaluate aspects of SFM. They are custom tools within political (e.g., ITTO, MCPFE, Montreal Process, Tarapoto Proposal, UNEP-FAO Dry Zone Africa) and certification initiatives (e.g., PEFC or FSC; Rametsteiner and Simula, 2003). While some early approaches seemed to be rather intuitive, there has been a recent shift to a more science-based application of C&I-based assessment of SFM (Woodley et al., 1999; Prabhu et al., 1999; Mendoza and Prabhu, 2000a,b, 2003; Franc et al., 2001; Raison et al., 2001; Brang et al., 2002). Among these proposed approaches, multi-criteria analysis (MCA) techniques have been adapted to structure and implement the C&I-based assessment of SFM (Varma et al., 2000; Bousson, 2001; Mendoza and Prabhu, 2003). MCA-methods are the approaches of choice in forest resource planning when:

– there is a need to structure a complex decision problem;
– the problems are multi-objective or have multiple criteria to be considered;
– there are heterogeneous sets of criteria involved;
– there are conflicting objectives involved;
– different management alternatives are to be compared;
– there is need for a more rational, transparent, and comprehensive analysis (e.g., in public participation);
– there are qualitative and quantitative data at different scales included in the decision model.

In this context, MCA methods have proven to be useful tools to deal with C&I sets. Most sets of indicators are represented as hierarchies in which indicators are clustered and subordinated to criteria. The analytic hierarchy process (AHP) introduced by Saaty (1977, 1980) is one of the most widely used and popular techniques for structuring sets of C&I. Although the evaluation of individual indicators in such a structured hierarchy might appear suitable, interactions among indicators may not be apparent (Mendoza and Prabhu, 2003). Designing and investigating a network structure as a feature of an SFM evaluation model tries to compensate for this limitation. The Analytic Network Process (ANP) by Saaty (1999) has been proposed to evaluate the overall cumulative importance of all indicators within an evaluation model by integrating linkages and feedbacks into the decision system. Although potentially a highly relevant tool for the assessment of SFM, so far there are no published applications of ANP in forestry or forestry-related fields. Published applications of ANP deal mainly with strategies and logistics in supply-chain management (Meade and Sarkis, 1998; Sarkis, 2003) and with environment friendly business, and manufacturing practices (Sarkis, 1998, 1999).

In this paper, we compare an application of AHP with a hierarchical structure, and of ANP with a network structure, for evaluating SFM by means of a C&I set. The C&I set is based on the Pan-European guidelines for SFM, which has been implemented in a recent research project for specific situations in managing mountain forest ecosystems in Austria. In particular, we were interested in (a) highlighting methodological differences between AHP and ANP and (b) exploring the implications of using the ANP approach for SFM assessments in terms of model validity and practicality.

3. Methods and material

3.1. The analytic hierarchy process

The AHP is a mathematical theory of value, reason, and judgment, based on ratio scales for the analysis of multiple-criteria decision-making problems (Saaty, 2001). An AHP model typically consists of an overall goal, a set of criteria to specify the overall goal decomposed to subcriteria, and finally, at the lowest level of the hierarchy, the decision alternatives to be evaluated. Beyond the decomposition principle, the AHP is based on pairwise comparisons of elements in a decision hierarchy with respect to the parent element at the next higher hierarchical level (i.e., among criteria and lower level elements). Pairwise comparisons are made on a scale of relative importance where the decision maker has the option to express the preferences between two elements on a ratio scale from equally important (i.e., equivalent to a numeric value of one) to absolute preference (i.e., equivalent to a numeric value of nine) of one element over another (Saaty, 2001).

AHP allows the consistent comparison of both qualitative and quantitative criteria or alternatives, since different scales of input information are transformed to uni-dimensional priorities. Ratings of decision makers are arranged as numerical numbers in a comparison matrix. Based on this, relative weights for all elements of the hierarchy are calculated with the eigenvalue method (Saaty, 2001), indicating the priority level for each element in the hierarchy. Accordingly, priorities for the alternatives are gained by judgments with respect to each above-level element of the hierarchy. Their performances are weighted with the relative weights of criteria and sub-criteria (i.e., indicators), and added to an overall priority for each alternative (i.e., how they contribute to the goal), which allows a cardinal ranking of the alternatives. Moreover, the eigenvalue approach of the AHP provides a measure for the consistency of the judgments (consistency ratio), aiming to improve the coherence among redundant judgments.

AHP has been applied in a large number of practical applications, mainly in economics and conflict resolution. Mendoza and Sprouse (1989) were the first to apply AHP in forest-management planning. More recent applications of AHP in multi-objective forest management and land-use planning included Kangas and Kuusipalo (1993), Mendoza et al. (1999), Vacik and Lexer (2001), Vacik et al. (2001), Schmoldt et al. (2001), and Ananda and Herath (2003). There has been additional research into the further evolution of AHP (e.g., Alho and Kangas, 1997; Leskinen and Kangas, 1998), and the development of hybrid methods incorporating heuristic optimization techniques such as HERO (Kangas et al., 2001), combinations of the AHP with strength–weakness–opportunity–threat (SWOT) analysis (Kurtilla et al., 2000; Pesonen et al., 2001), and expansions of AHP with statistical methods (Alho et al., 2001; Ihalainen et al., 2002; Leskinen et al., 2003).

3.2. The analytic network process

Hierarchical models (e.g., the AHP), premising independent elements, face certain limitations when the complexity of decision problems increases and interactions among criteria and sub-criteria are not implicitly covered. Different approaches have been proposed to consider interaction and dependence among elements. For instance, Leskinen et al. (2003) reported on an application of regression methods to take the effects of interdependent variables into account. In our paper, the emphasis is put on the eigenvalue approach of the ANP, since it is an extension of AHP and therefore of special interest for comparative analysis.

Generally, an ANP model can be designed as a (i) control hierarchy (i.e., a hierarchy of subsystems with inner dependencies) or a (ii) non-hierarchical network, which includes decision alternatives as an original element cluster (Saaty, 1999). The latter approach will be used in this paper.

ANP model building requires the definition of elements and their assignment to clusters, and a definition of their relationships (i.e., the connections between them indicating the flow of influence between the elements). Like AHP, ANP is founded on ratio-scale measurement and pairwise comparisons of elements to derive priorities of selected alternatives. In addition, relations among criteria and sub-criteria are included in evaluations, allowing dependencies both within a cluster (inner dependence) and between clusters (outer dependence) (Saaty, 2001). Pairwise comparison is now done, both for weighting the clusters (i.e., criteria) and for estimating the direction and importance of influences between elements, numerically pictured as ratio scales in a so-called supermatrix.

Mathematically, an ANP model is implemented following a three-step supermatrix calculation (Saaty, 2001). In the first step, the unweighted supermatrix is created directly from all local priorities derived from pairwise comparisons among elements influencing each other. The elements within each cluster are compared with respect to influencing elements outside the cluster. This also yields an eigenvector of influence of all clusters on each cluster (Saaty, 1999). In the second step, the weighted supermatrix is calculated by multiplying the values of the unweighted supermatrix with their affiliated cluster weights. By normalizing the weighted supermatrix, it is made column stochastic.

In the third and final step, the limit supermatrix is processed by raising the entire supermatrix to powers until convergence in terms of a limes (i.e., a Cesaro sum):

$$\lim_k \left(\frac{1}{N}\right)\sum_{k=1}^{N} W^k$$

where W is the weighted supermatrix, N indicates the sequence, and k is the exponent determined by iteration.

Limit priority values within this supermatrix indicate the flow of influence of an individual element towards the overall goal. Since the decision alternatives are elements of an original cluster of the network, their limit priorities are synonymous with their contributions to the goal and are used for the ranking of alternatives, being normalized within the cluster.

3.3. A set of C&I for SFM at forest management unit level

A set of C&I for assessing SFM at the forest management unit level (FMU) in Austria was used for comparing AHP and ANP. Based on the six criteria of the Pan-European guidelines for SFM, 43 indicators were derived from a national Delphi survey (Table 1; Wolfslehner et al., 2003). An expert panel rated the relevance of the indicators to the PEOLG, the practicality of each indicator (i.e., indicating availability of data or ease of obtaining data), and the measurement unit for each indicator (Table 1).

4. Application

4.1. Problem definition

We evaluated four contrasting silvicultural strategies for a private forest-management unit of 250 ha of forest in the south of Austria, to compare AHP and ANP within a realistic setting. The forest consists of secondary Norway spruce (*Picea abies*) stands, with minor portions of admixed Scots pine (*Pinus sylvestris*) and larch (*Larix decidua*), and some occasional, individual sessile oaks (*Quercus robur*), on sites naturally supporting mixed-broadleaved forests (Kilian et al., 1994). The forest represented forest types F1 and F5a of the Pan-European forest biodiversity monitoring scheme (Larsson, 2001). The stands are prone to frequent damage by bark-beetle infestations (*Pityogenes chalcographus, Ips typographus*) and snow breakage. In Austria, forests dominated by secondary coniferous growth comprise about 240,000 ha, which indicates the relevance of this issue for SFM. The management objectives were fairly typical and representative for medium-sized private forest properties in Austria. They included income from timber production as a prerequisite for implementing active forest management, reducing the risk of management as a long-term goal, as well as maintaining site productivity and biodiversity. In the view of the ongoing discussions of potential impacts of a possible climate change (e.g., Lexer et al., 2001), the forest owner is currently reviewing several options as a future forest management strategy.

4.2. Management strategies

The four management strategies (MS1–4) are briefly outlined relative to (i) awareness and incorporation of the principles of SFM, (ii) target species composition and management regime, (iii) forest products (i.e., wood and non-wood), (iv) protection of biodiversity and specific sites, and (v) the game management approaches conducted (Table 2). The expected performances of the indicators for each management strategy were derived either from data directly obtained from an inventory of the forest property (Steiner and Lexer, 1998), or by assuming qualitative preferences. Performance values have been normalized, individually setting the best performances for each indicator equal to one, and the other values in relation to it (Table 3).

4.3. Evaluation of management strategies

The management strategies were evaluated twice, applying both AHP and ANP. To isolate the effects of contrasting model concept and structure between AHP and ANP, we defined equal weights for all criteria in the AHP hierarchy, and all criteria and clusters in the ANP network, respectively. Giving preferences to particular indicators would confound the effects arising from differences in the basic model structure, since with AHP there are pairwise comparisons only among indicators of an individual criterion, but in ANP all indicators could influence all others, even among criteria.

4.3.1. The AHP model

The AHP model uses a hierarchical structure with the goal of ‘‘selecting the best strategy with regard to SFM’’ on top, the six criteria and 43 indicators on the two next lower levels, and the four management strategies at the bottom (Fig. 1). The six criteria are equivalent to those of the MCPFE and 43 indicators have been assigned to one of the six criteria according to their thematic affinity to the criteria (Table 1).

Table 1
List of SFM C&I indicators from the national Delphi survey and associated expert ratings of the relevance, practicality, and measurement units of each indicator (Wolfslehner et al., 2003)

Criterion	No.	Indicator	Relevance	Practicality	Measure
C1	1	Consideration of SFM in FM objectives	Medium	Medium	Cardinal
C1	2	Evaluation of forest management plans	High	High	Cardinal
C1	3	Monitoring of forest resources	High	Medium	Cardinal
C1	4	Mapping of forest resources	High	Medium	Cardinal
C1	5	Controlling of forest resources	Medium	Medium	Cardinal
C1	6	Harvest plans and rotation period	Low	Medium	%
C1	7	Amount and change of growing stock	Medium	High	m^3/ha
C1	8	Balance of growth and harvesting rates	High	High	%
C2	9	Composition of tree species	High	Medium	%
C2	10	Use of suitable tree species	Medium	Medium	%
C2	11	Use of soil-fertilizing methods	Low	Low	Cardinal
C2	13	Amount of damaged wood	Low	Medium	%
C2	14	Use of pesticides and herbicides	Medium	Low	Cardinal
C2	15	Activities of biological pest prevention	Medium	Low	Cardinal
C2	16	Stems damaged by harvest	Medium	Medium	%
C2	17	Stems damaged by bark peeling	Medium	Medium	%
C2	18	Impact of grazing	High	Medium	Cardinal
C3	19	FM practices causing bare forest soil	Medium	Medium	%
C3	20	Amount of full-tree harvesting	Low	Low	%
C3	21	Operating result (EBIT)	Medium	Low	€/ha
C3	22	Returns from wood production	Low	Medium	€/m^3
C3	23	Non-wood products and services	Low	Low	€
C3	24	Access to forests by forest roads	Medium	High	m/ha
C3	25	Final opening up with skid tracks	Medium	Medium	m/ha
C4	26	Laying-out of drainages	High	Medium	Cardinal
C4	27	Amount of natural regeneration	High	Medium	%
C4	28	Use of local provenances	High	Medium	%
C4	29	Vertical structure within stands	Medium	Low	%
C4	30	Number of old trees	Medium	Medium	n/ha
C4	31	Amount of coarse woody debris	High	Medium	m^3/ha
C4	32	Consideration of key ecosystems in FM	High	Medium	Cardinal
C4	33	Consideration of rare species (trees, shrub)	High	Medium	Cardinal
C4	34	Damage of regeneration by browsing	High	Medium	Cardinal
C5	35	Use of soil preparation methods	Low	Low	Cardinal
C5	36	Quality of forest infrastructure	Medium	Low	Cardinal
C6	37	Training of staff with regard to SFM	Medium	Medium	Cardinal
C6	38	Safe working conditions	Medium	Medium	Cardinal
C6	39	Willingness to join co-operations	Medium	Medium	Cardinal
C6	40	Consideration of specific sites in FM	Medium	Medium	Cardinal
C6	41	Use of traditional FM practices	Medium	Medium	Cardinal
C6	42	Role of local staff for regional employment	Low	Medium	Cardinal
C6	43	Meet legal regulations	Medium	High	Cardinal

The AHP is based on pairwise comparisons of elements (i.e., criteria and indicators) in the hierarchy with regard to the parent element at the next higher level. In our example, pairwise comparisons are set equal for all criteria weights and single indicator priorities. Consequently, the weight for each criterion is 1/6 and 1/6 $\times$ 1/j_{1-6} for each individual indicator, where j_{1-6} is the number of indicators for each criterion from one to six. The pairwise comparison of the four management strategies was based on their expected performance for each indicator (Table 3). The AHP model results show that the alternative management strategy MS3 was ranked first, with respect to the SFM goal, with the greatest cumulative priority (Table 4).

Table 2
Characteristics of the management strategies (MS 1–4) used in the comparison of AHP and ANP for MCA

	MS1	MS2	MS3	MS4
Principles of SFM	No explicit consideration of the principles of SFM	No particular consideration of the principles of SFM	Implementation of the principles of SFM	Implementation of the principles of SFM
Management regime	Clear cut system in even-aged, plantation-like secondary coniferous forests (Norway spruce)	Steady transition to mixed broadleaved forests by clearcutting mature spruce stands and subsequent afforestation with species such as *Quercus robur*, *Carpinus betulus*, *Tilia cordata* and *Fraxinus excelsior*	Moderate, extensive transition to mixed broadleaved forests by small-scale fellings and advance planting below the canopy of Norway spruce	Instantaneous shift towards mono-layered Douglas fir stands (*Pseudotsuga menziesii*) with admixed broadleaves such as *Acer pseudoplatanus* by clearcutting mature spruce stands and subsequent afforestation
Forest products	Losses in value of timber assortments by an expected high amount of salvage cuttings (i.e., windthrow, snow breakage, insects) due to tree species not adapted to the prevailing site conditions, providing very few non-wood products or services	Strong emphasis on wood production including the diversification of timber assortments, a decrease of salvage cuttings and higher returns from wood due to tree species better adapted to the site conditions, seeking local/regional (trade) co-operations	Stronger diversification of timber assortments to hedge against market risks considering explicitly a number of non-wood products and services	Elimination of damaged and rot-infested trees to minimize future salvage cuttings and to reach medium-termed the goal of high-quality assortments and maximized returns from timber including Christmas tree production from juvenile stands
Biodiversity and specific sites	No specified measures to protect special ecosystems	Increase of the amount of coarse woody debris and intending to protect and favour rare floral species and specific site types within the FMU	Enhancement of biodiversity elements (dead wood, old trees, biotopes, rare species, specific sites, forest structure) by forest management	Proper amount of woody debris in the wake of cleansing and the support of rare floral species and specific sites
Game management	Reactive game management in terms of bearing a high browsing pressure and only little effort in protective means	Conservative game management in terms of strong efforts in fencing and mono-tree protection measures	Shift towards active game management to negotiate and solve conflicts with hunters, still remaining deficits in conservative aspects leading to present high browsing damage	Conservative game management in terms of strong efforts in fencing and mono-tree protection measures

4.3.2. The ANP model

The ANP retains the idea of criteria, which are now named clusters due to terminology reasons, but replaces the hierarchy of the AHP by a network structure. With ANP, there is a need to indicate all dependences among indicators, and determining the direction of the influence. Connections can be set among elements within a cluster (i.e., inner dependence) and between clusters (i.e., outer dependence). In a cumulative view, a cluster is connected to another when at least one of its elements is connected to at least one element of the other cluster (Fig. 2). Elements and clusters can thus appear as sources, which are origins of paths of influence, as sinks, which are destinations of paths of influence, and as cycles or loops, indicating feedback on themselves, represented by the direction of the arrows (Saaty, 2001).

Table 3
Normalized values of the expected performances of the SFM indicators by the four management strategies (compare Table 1)[a]

Management strategy	SFM indicators													
	I 1	I 2	I 6	I 7	I 8	I 9	I 10	I 13	I 14	I 16	I 17	I 19	I 22	I 23
MS 1	0.5	1.0	1.0	1.0	0.61	0.15	0.25	0.5	1.0	0.71	0.63	0.43	0.8	0.5
MS 2	0.5	1.0	0.23	0.33	0.23	1.0	0.88	1.0	0.5	1.0	1.0	0.3	0.87	0.7
MS 3	1.0	1.0	0.61	1.0	1.0	0.76	0.63	1.0	1.0	0.5	1.0	1.0	1.0	1.0
MS 4	1.0	1.0	0.23	0.33	0.23	0.24	1.0	0.67	0.5	0.71	0.71	0.38	0.93	0.5

	I 26	I 27	I 29	I 30	I 31	I 32	I 33	I 34	I 35	I 36	I 37	I 39	I 40	I 42
MS 1	0.5	1.0	0.2	0.15	0.2	0.5	0.5	0.5	0.5	1.0	0.5	0.5	0.5	1.0
MS 2	0.5	0.13	0.62	0.38	0.6	0.5	1.0	1.0	1.0	0.5	0.5	1.0	1.0	0.5
MS 3	1.0	0.63	1.0	1.0	1.0	1.0	1.0	0.71	0.5	0.5	1.0	1.0	1.0	1.0
MS 4	0.5	0.25	0.4	0.38	0.2	1.0	1.0	0.83	1.0	1.0	1.0	0.5	0.5	0.5

[a] The performances of missing indicators are indifferent between strategies.

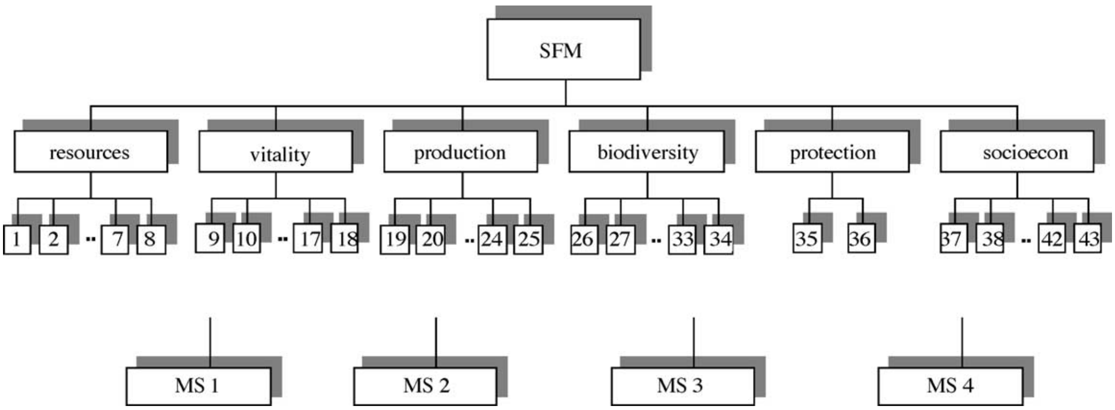

Fig. 1. The organization of C&I for an AHP model for evaluating strategic management alternatives for SFM at the FMU level.

For the ANP model supermatrix calculations, pairwise comparisons are done between clusters, like for criteria in AHP (i.e., cluster comparisons), and between all elements influenced by other elements within a cluster (i.e., node comparisons). The alternatives form a separate cluster, which is embedded in the supermatrix showing connections to each indicator. For instance, indicator I-34, ‘‘the impact of browsing’’ within cluster ‘‘biodiversity’’, has been identified to influence four indicators of criterion C2, ‘‘health and vitality’’. The four indicators, I-9, I-10, I-17, and I-18, are then compared to indicator I-34. Pairwise comparisons ask the following question: ‘‘With regard to the impact of browsing, tree species composition (I-9) is how many times more important then the impact of grazing (I-18)?’’, which in the context of the SFM means ‘‘Which element is more strongly influenced by the impact of browsing, tree species composition or the impact of grazing?’’. Comparisons are no longer made with regard to a next higher level criterion as in AHP, but with regard to influencing elements.

Table 4
Cumulative priorities and ranks of the four management strategies using AHP

Management strategy	Priorities	Rank
1	0.231	4
2	0.241	3
3	0.286	1
4	0.242	2

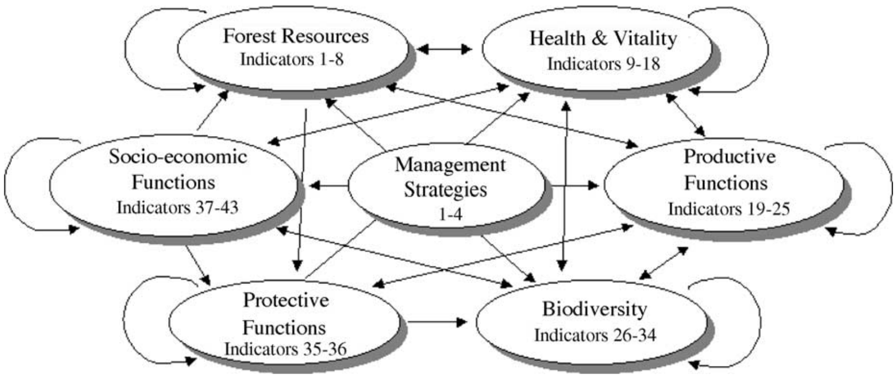

Fig. 2. Network model describing the linkages and feedbacks of the C&I set and management strategies.

Overall priorities of the alternatives are then obtained by supermatrix calculation as well as the single-indicator priorities, which indicate the individual properties with respect to the overall goal. In this case study, all preferences from pairwise comparisons were set equal, unweighted single-indicator priorities will thus remain $1/j$ where j is the number of influenced elements within a cluster with regard to an active element. Clusters are compared with respect to the goal. Given equal preferences, weights are set by the default value of $1/n$ where n is the number of clusters. The cumulative priorities and rankings for the four management strategies, with respect to the goal of forest management (i.e., SFM), resulting from the ANP model again show MS3 to be ranked first, with the greatest cumulative priority (Table 5).

5. Discussion

5.1. Comparing AHP and ANP

AHP and ANP were compared to their effects on prioritisation of alternative management strategies and their representation of elements within the models. By keeping preferences equal for all elements and clusters, both in AHP and ANP, we aimed to isolate differences in outcomes due to structural and methodological reasons. AHP is a widely applied and discussed MCA-technique (e.g., Kangas and Kangas, 2002). Its main features are (a) constructing a hierarchy, (b) establishing priorities (i.e., preferences) by pairwise comparisons on a ratio scale, and (c) securing logical consistency in comparing elements (Saaty and Alexander, 1989). AHP is an intuitive and rather easily used approach, supported by software applications like Expert Choice™, which allows for its popularity in decision-making and participatory planning. The trade-offs required for moderate model-building efforts are that, due to the hierarchical structure, the decision maker might have to accept strong abstractions and homogenization of a complex decision problem. There are also debates on the underlying meaning of pairwise comparisons, such as the properties of the one to nine ratio scale. Leskinen (2000) reported that the measurement scale and the aggregation rule have potentially large impacts on outcomes when using AHP.

Table 5
Cumulative priorities and ranks of the four management strategies using ANP

Management strategy	Priorities	Rank
1	0.238	3
2	0.242	2
3	0.295	1
4	0.225	4

As a basic principle of AHP, the number of elements under each node (i.e., branch of the hierarchic decision tree) should be more or less comparable. Also the elements should be of the same order of magnitude with respect to the basis of comparison. With regard to the principle of hierarchical decomposition, (a) the lower level elements must be outer-dependent on the associated level above, (b) the lower level elements must not be inner-dependent with respect to the elements at the level above, and (c) the higher level elements must not be outer-dependent

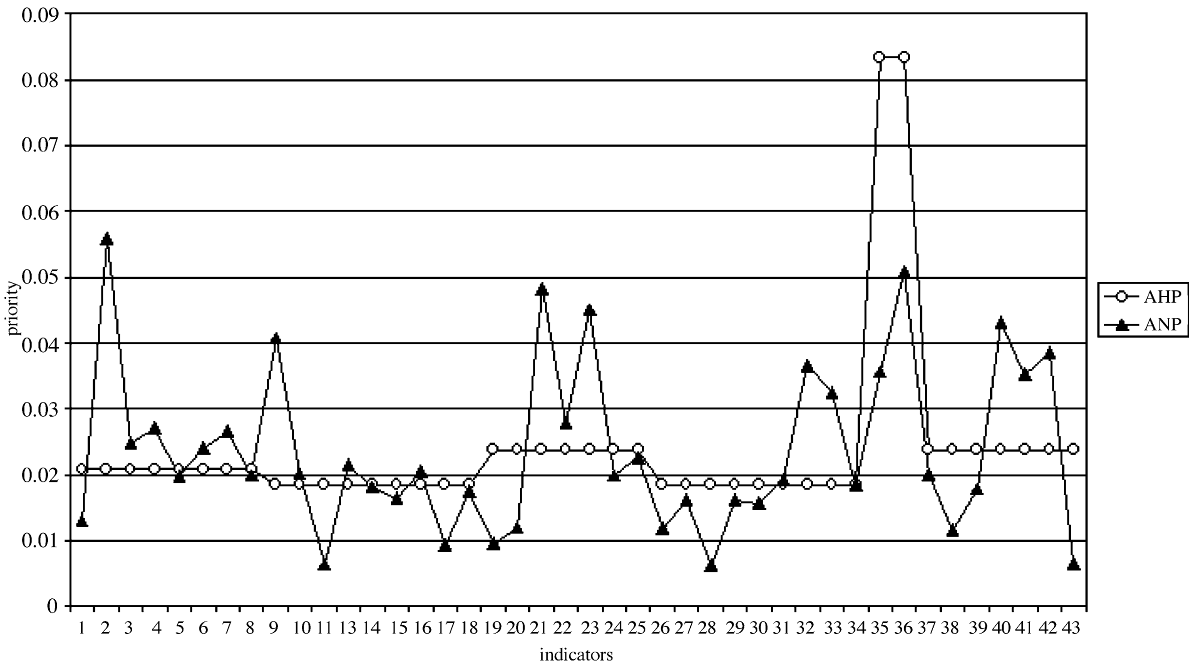

Fig. 3. Priorities of individual indicators as derived from AHP and ANP, given equal preferences in direct pairwise comparisons.

on the level below (Mollaghasemi and Pet-Edwards, 1997). In terms of SFM assessments, these requirements are not satisfied in a strict sense, as the AHP principles of outer and inner dependence do not truly correspond to the holistic understanding of SFM. To use AHP, practical solutions could be a reformulation of the decision problem to better fulfil the prerequisites above, or to statistically assess dependencies within the model (Leskinen et al., 2003).

One should be aware that any modelling of a decision problem causes certain structurally inherent impacts on the evaluation results. In this example of AHP, elements (i.e., indicators) of small clusters (i.e., criteria), which include few elements (e.g., C5; protective functions with two indicators) are over-represented in the overall preference, compared to clusters with greater numbers of elements (e.g., C2; health and vitality with nine indicators). Considering that the priority share of single indicators is $1/n \times 1/j_{1-n}$ of the overall priority at equal weights for clusters and elements, it follows that the larger the number of indicators within a cluster, the smaller is the priority share of an indicator. This may lead to an imbalance among the indicators due to structural inherence before stating any preference for the indicators. Indicators of larger clusters would share less of the overall priority (e.g., indicators of criterion C2 would share 1/54) while those of smaller clusters would share more (e.g., indicators of criterion C5 would share 1/12) (Fig. 3). Although the weighting process could implicitly balance this occurrence, it is still a part of the system. Thus, the model-builder (i.e., the analyst) might have a rather strong influence on the evaluation results, compared to the expressed preferences of the decision maker(s), which may lead to limitations with the conceptual framework of the AHP.

This phenomenon is weakened in ANP. Individual indicator priorities result from the connections to other elements and their respective impacts. This process results in different individual indicator priorities when equal weights are assigned to indicators within a branch of AHP and a cluster in ANP, and for AHP criteria and ANP clusters (Fig. 3). In this example, it becomes apparent that indicators such as ‘‘evaluation of forest management planning’’ (I-2), ‘‘tree species composition’’ (I-9), and others, are highly active elements with strong interdependencies and high structural priorities. The individual indicator priorities in ANP are less affected by the structural preassumptions in building the evaluation model and more by the identification and prioritization of the connections between indicators.

Comparing MCA-methods always leads to some crucial questions. Applying AHP and ANP with the same input, as in our example, resulted in different rankings for three of four alternative management strategies. However, the absolute differences in cumulative priorities among the ranks are fairly small, ranging from 0.001 between ranks 2 and 3 in AHP (Table 4) to as much as 0.053 between ranks 1 and 2 in ANP (Table 5). This raises the question if rankings in MCA are important, when differences in cumulative priorities among alternatives are at the size of a few 0.001 s. It is difficult to judge if a decision maker needs to be concerned about which alternative to choose, due to the differences in cumulative priorities or due to different ranks when using different MCA-approaches. If there is a need to find inherently robust alternatives, it might be useful to apply more sophisticated methods such as ANP, or to compare results of different approaches. We may also have to accept that each method shapes the preferences of the decision maker(s) in a particular way (Lootsma and Schuijt, 1997). The process of evaluation and decision-making might in some cases be more important than the ranking results.

Since the ANP is a generalisation of the AHP, some methodological problems detected in multi-criteria decision analysis apply also to the ANP. Salo and Hämäläinen (1997) remark that the appearance of rank reversals, when adding alternatives, is not eliminated by the supermatrix technique. However, it can be stated that a network model gives a much more realistic view of complex issues such as SFM. Keeping in mind that the ultimate goal of applying MCA-techniques is to arrive at a decision, the confidence of decision makers to rely on ranking and priority information from MCA-applications will depend heavily on the ability of the models to generate reliable and consistent results.

5.2. The potentials of ANP in evaluating SFM

Sustainable forest management is not solely an ecological issue; there are diverse ecological, economic, and socio-economic aspects, which increase problem complexity and analysis of SFM. At a local level, SFM is embedded in a network of external and internal relationships. Due to the intrinsically complex nature of assessing sustainability, it is difficult to develop a framework that has universal applicability (Mendoza and Prabhu, 2003). Desirable characteristics of a well-defined framework could be described as holistic and systematic. The analysis of all system-wide elements should be comprehensive and interactive (Bell and Morse, 1999). Forest-management problems in SFM can hardly be solved or even addressed, when a fragmented approach to indicators is taken. With a network-analysis approach, indicators should refer to the context of practical forest management, measure the quantity and quality of actions taken in forest management, and the response of the forest system to these actions (Duinker, 2001). A systematic framework implies a structured process, employing the principles of dynamic systems analysis. These principles are incorporated in ANP. The process of building an ANP model could be used as an integrative part of systems analysis that leads to a better understanding of the holistic approach that SFM addresses. It could help to link results from MCA and network analysis to a concept for actually implementing SFM. The individual indicator priorities from the ANP supermatrix lead to what we would call a key-indicator concept, not from the biological point of view, but from a systemic and cross-topical one.

There are limited financial resources available for further implementing SFM for the maintenance and enhancement of desired states and processes of forest ecosystems. This applies equally at forest-policy level (e.g., provision of incentives) as at the operational forest-enterprise level. Systems analysis for SFM will be a valuable tool if it serves to identify key issues represented by indicators, where money and effort are most efficiently spent in terms of positive direct and indirect effects and of focused investment.

Finally, it seems appropriate to address weaknesses and potential problems of ANP in SFM assessments, not just from the methodological perspective but also from the application point of view. One of the major drawbacks of ANP is that complexity increases exponentially with the number of indicators and their interdependencies, due both to the numbers of pairwise comparisons and to the dimensions of questionnaires. Based on our experiences, it is therefore recommended to (a) reduce the size of the indicator set as much as possible, (b) put strong emphasis on clear and unambiguous definitions and delineations of indicators, and (c) define only the direct interconnections among system elements, since indirect dependencies are presumably covered by the limit supermatrix calculation procedure (Saaty, 1999). Beside the larger number of questions when using ANP, there are also linguistic problems. The semantics used in pairwise comparison (e.g., "how much more important") often does not keep up with more complex issues when comparing elements in a network structure. Salo and Hämäläinen (1997) claim that the complexity of questions may explain the scarcity of reported supermatrix applications. Dynamic linguistic software approaches are badly needed to further promote the use of ANP as a tool for comprehensive decision-making, systems analysis, and participatory planning. If working with ANP is too laborious in terms of temporal and intellectual efforts, it may simply remain an academic issue. It has to be mentioned that, due to the initial stage of applying ANP in this field, further research is needed, especially in sensitivity and uncertainty analysis of ANP priorities, to learn more about the features and behaviour of a complex ANP model.

Keeping all the fields for improvement and evolution in mind, the enhanced network approach in ANP seems to be an appropriate approach because it incorporates the extended demands of multi-purpose forestry promoted by the MCPFE. In sustainable forest management, network analysis could lead to a new integrated non-linear approach of strategic decision-making, and might be essential to promote and enhance the understanding of the key indicators influencing planning and decision-making in SFM. Abstracting complex issues in overly simple hierarchical structures often means building new 'black boxes' in terms of missing functional understanding. Integrating information about interdependencies within a SFM system could lead to more transparent and comprehensive decision-making in forest management at strategic- and tactical-planning levels.

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