Aggregation of preferences in participatory forest planning with multiple criteria: an application to the urban forest in Lycksele, Sweden

Eva-Maria Nordström, Carlos Romero, Ljusk Ola Eriksson, and Karin Öhman

Abstract: A promising approach for participatory forest management planning is the combination of multiple-criteria decision-making and group decision making. A crucial part of the participatory multiple-criteria decision-making process is the aggregation of individual stakeholder preferences into a collective preference. In this study, an approach based on the determination of cardinal compromise consensus was applied to a real case of participatory forest planning. Consensus matrices for four different social groups were established from stakeholder preferences in the form of pairwise comparisons of different sets of criteria. Criteria weights were obtained for each social group and used to determine rankings of 12 forest management plans. The rankings of the social groups were aggregated to determine consensus solutions for the choice of the best forest management plan from a collective perspective. In the procedure, control parameters and a distance metric were employed to find solutions that balance the points of view of the majority and the minority. This approach makes it possible to aggregate preferences of different stakeholders and produces a range of different solutions. Furthermore, certain values of the control parameters and the distance metric generate solutions that are promising to present in a participatory situation where stakeholders have very differing preferences.

Résumé : La combinaison de l'analyse multicritère de décision et de la prise de décision en groupe est une approche prometteuse pour la planification participative en aménagement forestier. Une partie cruciale du processus d'analyse multicritère est l'agrégation des préférences de chacun des intervenants pour obtenir une préférence collective. Dans cette étude, une approche basée sur la détermination d'un consensus pour lequel des compromis sont essentiels a été appliquée à un cas réel de planification forestière participative. Des matrices de consensus pour quatre groupes sociaux différents ont été établies à partir des préférences des intervenants sous la forme de comparaisons jumelées de différents ensembles de critères. Le poids des critères a été obtenu pour chaque groupe social et utilisé pour déterminer le classement de 12 plans d'aménagement forestier. Les classements des groupes sociaux ont été regroupés pour déterminer les solutions consensuelles pour le choix du meilleur plan d'aménagement dans une perspective collective. Dans la procédure, des paramètres témoins et une métrique de distance ont été utilisés pour trouver des solutions qui équilibrent les points de vue majoritaires et minoritaires. Avec cette approche, il est possible de regrouper les préférences de différents intervenants et de produire une gamme de solutions différentes. De plus, certaines valeurs des paramètres témoins et de la métrique de distance génèrent des solutions qui vaudraient la peine d'être présentées dans un contexte participatif où les intervenants ont des préférences très divergentes.

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1. Introduction

Traditionally, the main focus of forest management planning has been the production of timber. However, today, forests are regarded as a source for a wide range of commodities and services, some of them without well-defined markets. This results in planning situations where a multiplicity of criteria of very different natures must be considered. Moreover, these multiple-criteria situations often involve several stakeholders or social groups with different perceptions of the criteria considered, which can make the planning process very complicated. An approach that has been proposed for situations like these is the combination of multiple-criteria decision-making and group decision making. This type of merger has been applied to an increasing number of cases related to forestry during recent years (for a recent review, see Diaz-Balteiro and Romero 2008).

A crucial part of a participatory multiple-criteria decision-making process is the aggregation of individual stakeholder preferences into a social or collective preference. The aggregation problem is essentially twofold: aggregation is a philosophical problem as well as a mathematical or technical problem. For example, within the Analytic Hierarchy Process (Saaty 1990), one of the most frequently used multiple-criteria decision-making methods in forestry applications, two widely used methods for aggregation of individual preferences are the geometric mean and the weighted arithmetic mean (Ramanathan and Ganesh 1994). The mathematical

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properties of these methods have been debated (Ramanathan and Ganesh 1994; Van Den Honert and Lootsma 1997; Forman and Peniwati 1998), and a number of other aggregation methods have been proposed (e.g., Bryson and Joseph 1999; Escobar and Moreno-Jiménez 2007; Cho and Cho 2008). However, many of the methods proposed, though sound from a methodological point of view, are rather mechanistic in the sense that it is difficult to interpret the preferential meaning of the solutions derived. This can be a problem when applying the methods in real participatory planning cases, because from an applied point of view, the philosophical aspect of aggregation is at least as important as the mathematical aspect. If the solutions derived from a participatory process are to be accepted as legitimate by the stakeholders, the mechanisms of aggregation have to be understandable, equitable, and transparent (Munda 2004; Sheppard and Meitner 2005).

In a real participatory planning situation, the aggregation method must be chosen such that consideration is given to the characteristics of the planning situation. One important characteristic is the degree of consensus or the conflict of interest among stakeholders. Belton and Stewart (2002) described a gradient of general approaches to group decision making based on this degree of consensus:

(1) At one extreme end there is a situation where individuals consider an issue from their own perspectives and use their own procedures for evaluating courses of action.
(2) Independent expert groups evaluate a common set of alternatives possibly using a common approach to modeling, but incorporate criteria and judgments that reflect their individual perspectives. The independent views are then synthesized by an overarching decision-making group or individual.
(3) The group defines a common model (an agreed criteria structure and a set of alternatives, or an agreed specification of objectives and constraints), and then individuals or subgroups independently use that model to evaluate alternatives or explore possible solutions, coming together again to compare results.
(4) At the other extreme end there is a situation when a group seeks to work together throughout and defines a common model and shared judgments.

One aspect to consider in the choice of approach is the degree to which preferences and criteria agree. Preferences will certainly not be the same for all stakeholders; otherwise there would be no need for a participatory process. The participatory process gets more difficult when both the preferences and the criteria diverge (Dyer and Forman 1992; Ramanathan and Ganesh 1994; Salo 1995; Belton and Pictet 1997; Belton and Stewart 2002; Munda 2004). In some cases where interests are polarized or controversial, methods that avoid confrontation between stakeholders with conflicting interests may be more effective than participatory methods demanding stakeholder interaction (Sheppard and Meitner 2005).

A new aggregation method based upon the determination of cardinal compromise consensus has been proposed by González-Pachón and Romero (2007). This method is both understandable and transparent insofar as it offers a clear preferential interpretation of the consensus solutions that are established. Interaction between stakeholders is feasible but not required. As for the question of fairness, the method has very interesting properties because it can generate solutions for consensus based on the majority principle, for consensus minimizing the disagreement of the most displaced stakeholder, or for intermediate consensus balancing the majority and minority. In this paper, González-Pachón and Romero's (2007) aggregation method is applied to an urban forest planning situation in northern Sweden, involving multiple criteria and multiple stakeholders. The case presented corresponds to the second approach described by Belton and Stewart (2002), because each social group has its preferences defined by its own set of criteria. The objectives of this paper are to (*i*) adapt the method to the peculiarities of a real case of participatory forest planning, (*ii*) explore possible consensus solutions for choice of forest management plan, and (*iii*) evaluate the usefulness of the aggregation method in participatory forest planning problems.

2. Analytical framework

Formally, the problem to be addressed can be summarized as follows. A finite number of forestry strategies must be evaluated according to the point of view of several social groups. Moreover, each social group evaluates each alternative according to a set of criteria that differs among the respective groups. The proposed methodology is formalized as follows. We have $i = 1, 2, \ldots, q$ social groups involved in the assessment of $j = 1, 2, \ldots, m$ forest plan alternatives. Each social group assesses the m alternatives according to a different set of criteria. Let us represent by $n_1, \ldots, n_i, \ldots, n_q$, the number of criteria considered by each social group, and by $N_1, \ldots, N_i, \ldots, N_q$, the number of members of each group. Through a pairwise comparison procedure, the ratio values $m_{r,s}^{k,i}$ are obtained. These figures represent the quantification of the assessment or judgments made by the kth member of the ith group, when criteria r and s are compared. The quantification of the ratio values $m_{r,s}^{k,i}$ implies the consideration of N_i square matrices of $n_i \times n_i$ dimension for the generic ith social group.

Once the above information has been quantified, the proposed methodology covers the following phases. Firstly, from the pairwise comparison matrices, a consensus matrix is obtained for each social group. Secondly, from this matrix, the group weights for the criteria are derived. Thirdly, by using the group weights, the respective forest plans are evaluated to establish the group rankings of the alternative forest plans. Fourthly, from the group rankings, the final aggregated or social rankings are obtained. In the subsections that follow, the four phases are described in detail.

2.1. Phase 1: Elicitation of the consensus matrix

From the pairwise comparison matrices defined above, we determine an aggregated or consensus matrix for each of the q social groups involved. The q consensus matrices searched for in this phase can be obtained by adapting an Extended Goal Programming (EGP) model proposed by González-Pachón and Romero (2007). Thus, for the generic ith group, the respective consensus matrix is obtained by solving the following EGP model:

Model 1 (eqs. 1–5)

Achievement function

$$[1] \qquad \mathrm{MIN}(1-\lambda)D+\lambda\sum_{k=1}^{N_i}\sum_{r=1}^{n_i}\sum_{s=1}^{n_i}(n_{r,s}^{k,i}+p_{r,s}^{k,i})$$

Goals and constraints

$$[2] \qquad m_{r,s}^{c,i}+n_{r,s}^{k,i}-p_{r,s}^{k,i}=m_{r,s}^{k,i}$$

where $r,s \in (1, ..., n_i)$, $r \neq s$, $k \in (1, ..., N_i)$.

$$[3] \qquad \sum_{r=1}^{n_i}\sum_{s=1}^{n_i}(n_{r,s}^{k,i}+p_{r,s}^{k,i})-D\leq 0$$

where $k \in (1, ..., N_i)$.

$$[4] \qquad t_1 \leq m_{r,s}^{c,i} \leq t_2$$

$$[5] \qquad \lambda \in [0, 1] (\text{user-defined control parameter})$$

where $m_{r,s}^{c,i}$ represents the consensus ratio values for the group i (i.e., the unknown of the models), and $m_{r,s}^{k,i}$, as was indicated above, represents the preferences provided by the N_i members of the ith group (i.e., the data of the model). In eq. 1, D represents the maximum disagreement; i.e., the quantification of the disagreement of the social group with perceptions more displaced with respect to the consensus obtained. Moreover, the last part of eq. 1,

$$[6] \qquad \sum_{k=1}^{N_i}\sum_{r=1}^{n_i}\sum_{s=1}^{n_i}(n_{r,s}^{k,i}+p_{r,s}^{k,i})$$

represents the aggregated disagreement. Therefore, for $\lambda = 0$, the best solution from the point of view of the minority is obtained, whereas for $\lambda = 1$, the best solution from the point of view of the majority is obtained. For values of the control parameter λ belonging to the open interval (0,1), compromise consensuses, if they exist, can be derived. Hence, λ plays the role of a compensatory parameter (marginal rate of transformation) between minority and majority consensuses. A detailed explanation of the preferential meaning of a similar type of model can be seen in González-Pachón and Romero (2007). The variables $n_{r,s}^{k,i}$ and $p_{r,s}^{k,i}$ of model 1 are the typical negative and positive deviation variables and now play the role of auxiliary variables. Equation 4 represents scale conditions, thus, if we resort to the well-known Saaty's (1977) scale, we have $t_1 = 0.111$ and $t_2 = 9$. In short, we need to formulate q EGP models, i.e., one EGP model for each social group.

2.2. Phase 2: Elicitation of the group weights

From the consensus matrices, the respective group weights W_r^i are derived. Note that W_r^i represents the weight or relative importance attached by the ith group to the rth criterion. These weights can be derived by solving the following simple GP problem (see González-Pachón and Romero 2004):

Model 2 (eqs. 7–9)

Achievement function

$$[7] \qquad \mathrm{MIN}\sum_{r=1}^{n_i}\sum_{\substack{s=1\\ r\neq s}}^{n_i}(n_{r,s}^{i}+p_{r,s}^{i})$$

Goals and constraints

$$[8] \qquad W_r^i - m_{r,s}^{c,i}W_s^i + n_{r,s}^i - p_{r,s}^i = 0$$

where $r,s \in (1, ..., n_i)$, $r \neq s$.

$$[9] \qquad \sum_{r=1}^{n_i} W_r^i = 1$$

Again, the deviation variables $n_{r,s}^i$ and $p_{r,s}^i$ play an auxiliary role. By solving model 2, the group weights W_r^i for each criterion are derived. Hence, we will need to formulate and to solve q GP problems like model 2. In short, at the end of phase 2, we have a number of group weights equal to the total number of criteria considered by all the groups, i.e., $n_1 + n_2, \ldots, n_q$.

2.3. Phase 3: Elicitation of the group rankings of alternatives

Once the group weights W_r^i for each criterion have been defined, the m forest plan alternatives are evaluated to obtain a ranking of them for each social group. To undertake this task, we need to obtain the outcomes $O_j^{r,i}$, i.e., the result obtained when alternative j is assessed according to criterion r by the ith social group. From this information, a ranking of alternatives for each social group is obtained by considering two different (opposite) situations. Firstly, the rankings are derived by using the metric $\pi = 1$. Thus, the best consensus ranking is determined by maximizing the weighted average of the outcomes. Secondly, the rankings are derived by using the metric $\pi = \infty$. Thus, the best consensus ranking from the point of view of minimizing the most displaced result is established. For the first case ($\pi = 1$), the numerical assessment $(A_{ij})_{\pi = 1}$ of the generic jth alternative for the ith generic group is straightforwardly obtained by applying the following formula:

$$[10] \qquad (A_{ij})_{\pi=1} = \sum_{r=1}^{n_r} W_r^i O_j^{r,i}$$

For the case $\pi = \infty$, the numerical assessment $(A_{ij})_{\pi = \infty}$ of the generic jth alternative for the ith generic group is straightforwardly obtained by applying the following formula:

$$[11] \qquad (A_{ij})_{\pi=\infty} = \mathrm{MAX}_{\forall r}[W_r^i O_j^{r,i}]$$

In short, the output provided in phase 3 implies $2 \times q$ rankings for the m forest plan alternatives considered, i.e., q rankings for the metric $\pi = 1$ and other q rankings for the metric $\pi = \infty$.

2.4. Phase 4: Elicitation of the final consensus rankings

Once the group rankings have been obtained, the next and final phases of the procedure consists of determining the social rankings that reflect the best orderings from an aggregated or social perspective. This task is undertaken by adapting an EGP model proposed by González-Pachón and Romero (1999), valid for aggregating individual preferences shown in an ordinal way. Thus, by solving the following EGP model, the final consensus rankings are obtained:

Model 3 (eqs. 12–17)

Achievement function

$$[12] \quad \mathrm{MIN}(1-\mu)D + \mu\sum_{i=1}^{q}\sum_{j=1}^{m} W_i(n_{ij}+p_{ij})$$

Goals and constraints

$$[13] \quad R_j^c + n_{ij} - p_{ij} = R_{ij}$$

where $i \in (1, ..., q)$ and $j \in (1, ..., m)$.

$$[14] \quad W_i(n_{ij}+p_{ij}) - D \leq 0$$

where $i \in (1, ..., q)$ and $j \in (1, ..., m)$.

$$[15] \quad 1 \leq R_j^c \leq m$$

$$[16] \quad \sum_{j=1}^{m} R_j^c = \frac{(m+1)m}{2}$$

$$[17] \quad \mu \in [0,1] \text{ (user-defined control parameter)}$$

where R_j^c is the unknown of the model, i.e., the consensus ordinal value attached by all the groups to the jth alternative, and R_{ij} are the data of the model, i.e., the ordinal values given by the ith social group to the jth alternative when applying either eqs. 10 or 11. W_i represents the relative importance or social weight attached to the ith social group. Again, the control parameter μ plays a role similar to that of parameter λ in model 1, i.e., as a compensatory mechanism between the interests of the majority and that of the minority. Thus, for $\mu = 0$ the maximum disagreement D in eq. 12 is minimized, and consequently, the interest of the minority is optimized. For $\mu = 1$, the value of

$$[18] \quad \sum_{i=1}^{q}\sum_{j=1}^{m} W_i(n_{ij}+p_{ij})$$

(i.e., the last part of eq. 12) is minimized, and consequently, the interest of the majority is optimized. For intermediate values of μ, compromise consensuses, if they exist, can be obtained. Again negative and positive deviation variables play the role of auxiliary variables. Equations 15 and 16 represent the formalization of Borda's convention, i.e., to assign the maximum number m to the "best" alternative and the minimum number 1 to the "worst" one.

We need to apply model 3 twice: firstly, to the set of rankings derived from the metric $\pi = 1$ (eq. 10) and, secondly, to the set of rankings derived from the metric $\pi = \infty$ (eq. 11). The first solution will represent the "best" consensus ranking from the point of view of the majority, while the second solution will represent the "best" consensus ranking from the point of view of the minority (i.e., the group with perceptions most displaced with respect to the consensus obtained).

In the presentation of the methodology, two sets of parameters (λ and μ) and π have played a crucial role; hence, some clarifications on the meaning of these parameters are necessary. Parameter π, mathematically speaking, is the metric that defines the family of distance functions. On the other hand, from a preferential point of view, π plays the role of a "balancing factor" between the "group utility" (majority principle) obtained for $\pi = 1$ and the "maximum discrepancy" (minority principle) obtained for $\pi = \infty$. The control parameters (λ and μ) can be interpreted in a rather similar way — as trade-offs or marginal rates of substitution between "group utility" and the "utility of the stakeholder most displaced with respect to the consensus obtained". It is obvious that (λ and μ) = 1 and $\pi = 1$ lead to the same "group utility" consensus, while (λ, μ) = 0 and $\pi = \infty$ lead to the same "minority consensus" (see Yu (1973) for a treatment of the preferential properties underlying metric π). If we want to obtain compromises between these two opposite solutions, either we can vary the value of π, which generally leads to unsolvable complex nonlinear and nonconvex programming problems, or we can vary the value of (λ and μ), which leads to solving simple linear programming problems. For a thorough study of the relationships between control parameters (λ and μ) and metric π within a compromise programming context see André and Romero (2008).

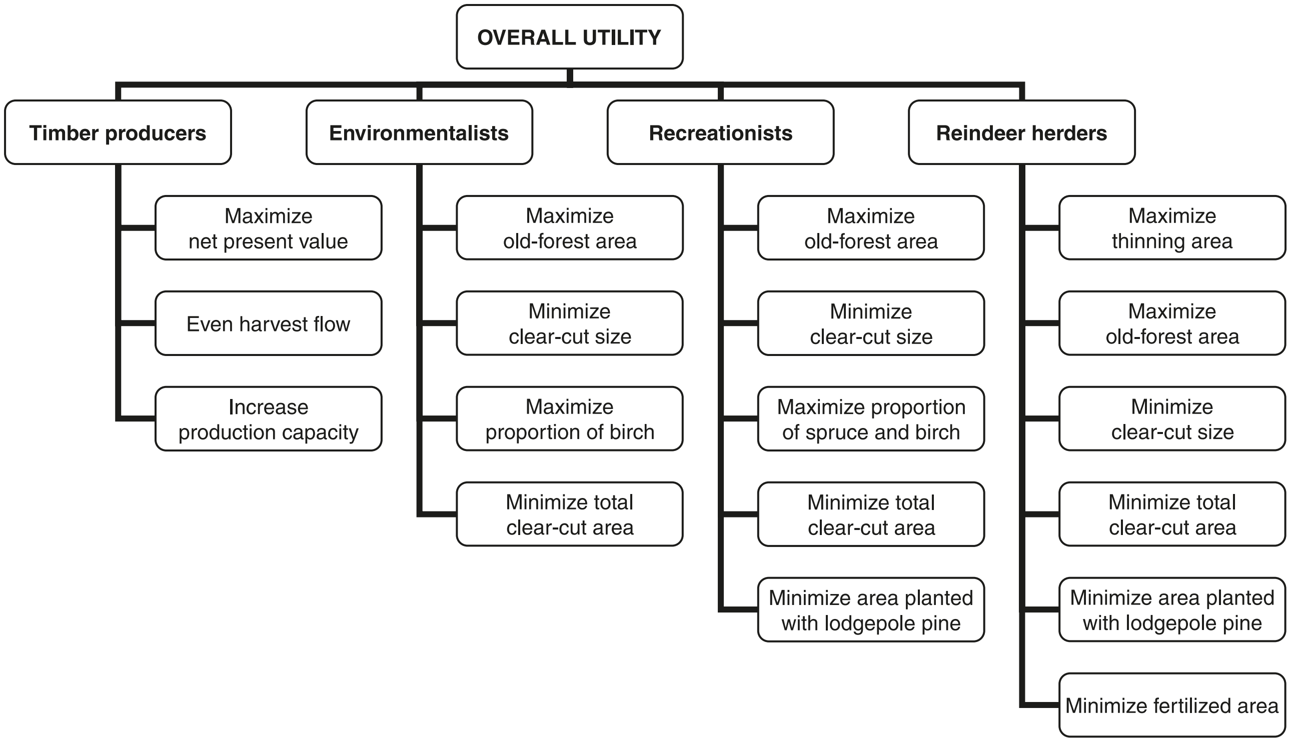
3. The case study

3.1. Description of the Lycksele case

To validate the approach and to illustrate what happens when the approach is applied to an actual participatory planning situation, the methodology was applied to a case of forest management planning of a 13 000 ha landscape around the town of Lycksele, Sweden. Lycksele is the regional centre in a forest landscape area in northern Sweden where commercial forestry is an important industry. However, the urban forest holds other values and is important to the inhabitants of the town for purposes other than timber production, e.g., for the reindeer herding industry; for preserving biodiversity; and for providing forest suitable for recreation, hunting, and fishing opportunities (see Rydberg and Falck (2000) for a definition of urban forest). The wide range of activities may cause conflicts of interest, which is an increasingly common situation concerning forests close to densely populated areas. Furthermore, at the larger scale, there are often several different decision makers; the urban forests surrounding Lycksele are owned not only by the municipality but also by commercial forest companies.

Because of the complexity of the situation with several decision makers, many stakeholders, and conflicting objectives, the planning process was designed to be a participatory process using multiple-criteria decision-making. Among the stakeholders, including the forest owners, four major social groups were identified: timber producers, reindeer herders, environmentalists, and recreationists, i.e., q was set to four. A number of representatives from each social group were interviewed. The number of representatives

Fig 1. Objective hierarchy with the criteria identified by the different social groups.



varied among the social groups because of the character of their situation. All the forest-owning companies and the municipality were included in the group of timber producers, resulting in five representatives, while the reindeer herders' group was represented by only one person (the representative of the local reindeer husbandry district). The environmentalists were represented by two people from nongovernmental organizations and one person each from the municipality and the County Board. The recreation group was represented by 14 people; this great number was partly due to the existence of many concerned associations and was partly a consequence of the emphasis on including recreationists, because knowledge about the criteria of this group in this particular area was insufficient. Using information collected from interviews, we identified criteria and arranged them in a hierarchical structure (Fig. 1). Note that each social group has its own set of criteria. These are the criteria that the stakeholders stated as relevant to their social group in the interviews.

The representatives of the different social groups were asked to make judgments on the identified criteria by the pairwise comparisons procedure of the Analytic Hierarchy Process (Saaty 1990). The comparisons were made using the verbal statements of the nine-point Saaty's scale of the Analytic Hierarchy Process to determine the strength of preference for one criterion over another (see Appendix A, Table A1 shows a basic summary of Saaty's scale). The respondents gave their judgments by filling in inquiry forms. Each respondent was considered to be a member of one of the four social groups and answered questions relating to the criteria for that particular social group. Thus, the stakeholders were only requested to make judgments on the criteria relevant to them. The advantage of this procedure is that it facilitates the judgment process for the stakeholders and that the risk of strategic behavior influencing judgments is reduced. However, there was one exception: municipality representatives made judgments on all criteria. As a local government institution, the municipality is concerned with the interest of all social groups. It could be argued that the municipality should be treated as a fifth group, separate from the four social groups. However, we chose to include the municipality as a member in each of the four social groups because the municipality comprises sections with diverging interests that each can be regarded as a stakeholder in itself.

The following numbers of completed inquiry forms were obtained: five from the timber producers ($N_1 = 5$), one from the reindeer herders ($N_2 = 1$), four from the environmentalists ($N_3 = 4$), and seven from the recreationists ($N_4 = 7$). Appendix B (Fig. B1) shows the pairwise comparison matrices with judgments on the criteria made by the different individuals belonging to the four social groups.

Maps of areas important to reindeer herders, environmentalists, and recreationists were created from interview information combined with information from inventories and from the results of a questionnaire administered during a public day. The maps of important areas were used to create a zonal map where the forest land was divided into four different zones based on the silvicultural management. The four zones were as follows: (1) zone with no commercial management, (2) zone with no clearcuts, (3) zone with reinforced consideration to other objectives than timber production, and (4) zone with standard forest management.

3.2. Generation of alternatives

The starting point of the generation of alternatives was the forest data on stand level, i.e., data that traditionally are found in the forest management plan of a Swedish forest

Table 1. Matrix of outcomes when the 12 alternative forest plans are evaluated according to 11 criteria.

Forest plan	C_1: NPV (10^3 Swedish Crowns)	C_2: Even harvest flow (m^3)	C_3: Increased production capacity (ha)	C_4: Thinning area (ha)	C_5: Old-forest area (ha)	C_6: Clearcut size (ha)
A1	87 136.66 (0.86)	921 911 (0.59)	6 135 (0.64)	6019 (0.91)	3473 (0.27)	**6.7 (0)**
A2	75 118.31 (1)	558 463 (0.31)	6 050 (0.66)	5659 (1)	3628 (0.21)	15.5 (0.95)
A3	98 567.93 (0.72)	1 462 032 (1)	6 132 (0.64)	6947 (0.68)	3472 (0.27)	9.8 (0.33)
A4	112 897.03 (0.56)	284 432 (0.10)	3 860 (1)	7707 (0.50)	**4253 (0)**	16.0 (1)
A5	128 591.08 (0.37)	412 515 (0.20)	8 987 (0.20)	9099 (0.16)	2150 (0.72)	12.0 (0.57)
A6	102 258.24 (0.68)	459 701 (0.23)	8 976 (0.20)	8416 (0.32)	2617 (0.56)	13.4 (0.72)
A7	128 842.17 (0.37)	1 459 114 (1)	9 035 (0.19)	8874 (0.21)	2142 (0.72)	12.0 (0.57)
A8	146 713.32 (0.16)	329 799 (0.13)	6 797 (0.54)	7366 (0.58)	2677 (0.54)	11.4 (0.51)
A9	144 735.50 (0.18)	282 617 (0.10)	**10 249 (0)**	**9734 (0)**	1414 (0.97)	11.7 (0.54)
A10	122 076.04 (0.45)	307 438 (0.12)	10 199 (0.01)	9386 (0.09)	1866 (0.82)	10.7 (0.43)
A11	145 103.35 (0.18)	866 197 (0.54)	10 190 (0.01)	9356 (0.09)	1337 (1)	14.3 (0.82)
A12	**160 202.92 (0)**	**156 497 (0)**	7 517 (0.43)	7312 (0.59)	1781 (0.85)	11.7 (0.54)

Note: Normalized values are shown within parentheses. The ideal value is 0 (in boldface) and the anti-ideal value is 1 (underlined), and consequently, the

owner. Based on which zone the stand belonged to, each stand was assigned a treatment class defining the set of allowed treatment schedules. The first treatment class, defining the treatment in zone 1, contained stands and buffer zones that should be left for undisturbed growth. The second treatment class, defining the treatments in zone 2, contained stands that are never to be clear-cut; instead a shelter of 200 stems per hectare is established. In zone 3, the treatment class contained stands where 20 years are added to the minimum age of final felling to prolong the rotation time. Zone 4 contained stands where the full range of standard treatments could be applied. A number of these stands would not accept stand establishment with lodgepole pine because of stand characteristics and, in a few cases, because of restrictions in the Forestry Act of Sweden (SNBF 1994). After a stand was assigned a treatment class, the stand data were exported to the GAYA stand simulation system, which simulated all permissible treatment schedules under the given treatment class (Eriksson 1983; Hoen and Eid 1990). Each schedule consists of a sequence of silvicultural treatments for the stand over a 100 year planning horizon. Standard treatments include precommercial thinning of the young forest, thinning, fertilization, and final felling. The minimum age for final felling for each stand is set according to the Forestry Act (corresponding to site productivity) (SNBF 1994). Thinning treatment has an intensity of 30% removal of the basal area. Stand establishment activities after clear-cutting follow one of two fixed programs: one with pine or spruce as the dominant species and the other with lodgepole pine. These settings resulted in the generation of 116 740 schedules, corresponding to an average of almost 100 schedules per stand. The GAYA simulator used growth functions by Ekö (1985). Revenues were computed with functions from Ollas (1980) and the autumn 2007 Norra Skogsägarna Umeå region timber price list. Silvicultural costs were set according to Johansson (2001), and harvesting machine costs were computed based on functions by Nurminen et al. (2006), with the cost per hour set to 750 and 650 Swedish Crowns for harvester and forwarder, respectively.

Based on the generated treatment schedules and the identified objectives (see Fig. 1), 12 forest plan alternatives were generated — m was set to 12. Each alternative consists of different combinations of treatment schedules for all stands in the landscape, which then results in different values for the objectives in the identified hierarchy. The generation of alternatives was based on compromise programming with the $\pi = \infty$ metric (Zeleny 1982). Ideally, compromise programming and other versions of goal programming should be applied in an interactive manner. However, the planning situation in Lycksele involved a large number of stakeholders belonging to many different organizations, which made it infeasible to discuss and present solutions to each of the stakeholders in turn. Because it was not possible to work in an iterative way with the stakeholders in this study, compromise programming was used to create alternatives by varying the ideal values for the different objectives. In this way, we were able to generate a finite set of nondominated solutions that explore the solution space sufficiently.

The 12 forest plan alternatives were then evaluated with regard to the 11 previously defined criteria; the outcomes are shown in Table 1. To compare the outcomes of different criteria, the elements of this matrix were normalized in the following way:

$$[19] \qquad \frac{O^{r*} - O^r_j}{O^{r*} - O^r_*}$$

where O^{r*} and O^r_* are the ideal and the anti-ideal values, respectively, for the rth criterion within the set of alternatives (j); O^r_j is the outcome that corresponds to the jth alternative when it is evaluated according to the rth criterion. In this way, the normalized matrix of outcomes (numbers in parentheses) in Table 1 was obtained. It should be noted that according to this system of normalization, all the elements of the matrix are bound between 0 (ideal value) and 1 (anti-ideal value).

4. Results

4.1. Phase 1: Elicitation of the consensus matrix

In the application of the proposed methodology to the Lycksele case, the first phase comprises the aggregation of the individual pairwise comparison matrices to obtain consensus matrices for each of the social groups. When model 1, described in Section 2: Analytical Framework, is applied to the individual pairwise comparison matrices with different values for the control parameter λ, four consensus matri-

C_7: Proportion of birch (%)	C_8: Proportion of birch and spruce (%)	C_9: Total clearcut area (ha)	C_{10}: Area planted with lodgepole pine (ha)	C_{11}: Fertilized area (ha)
3.3 (0.30)	13.9 (0.35)	2784 (0.49)	1953 (0.49)	4182 (0.25)
3.3 (0.30)	14.0 (0.32)	3246 (0.50)	1980 (0.50)	4070 (0.21)
3.5 (0.10)	**15.0 (0)**	3699 (0.50)	1968 (0.50)	4164 (0.24)
3.6 (0)	14.6 (0.13)	**3653 (0)**	**540 (0)**	**3320 (0)**
2.6 (1)	12.0 (0.97)	4748 (0.83)	2935 (0.83)	6052 (0.78)
2.7 (0.90)	11.9 (1)	4329 (0.81)	2870 (0.81)	6106 (0.79)
2.7 (0.90)	12.4 (0.84)	5437 (0.84)	2965 (0.84)	6070 (0.78)
3.4 (0.20)	13.5 (0.48)	6515 (0.68)	2482 (0.68)	4315 (0.28)
2.8 (0.80)	13.2 (0.58)	5650 (1)	3416 (1)	6833 (1)
2.8 (0.80)	12.9 (0.68)	5145 (0.99)	3378 (0.99)	6821 (1)
2.9 (0.70)	13.9 (0.35)	7206 (0.99)	3390 (0.99)	6800 (0.99)
3.3 (0.30)	12.9 (0.68)	7831 (0.92)	3196 (0.92)	4321 (0.28)

different numbers represent distances or degrees of discrepancy from the ideal value.

ces are found for the timber producers (Table 2A), three are found for the environmentalist group (Table 2B), and four for the recreationist group (Table 2C). Because the reindeer herders' group has only one member, no consensus matrix has to be produced.

It should be noted that the solutions in the first rows of Tables 2A–2C, where $\lambda = 0$, have the same maximum disagreement as the solutions in the second row of the same table, whereas the aggregated disagreement is higher for the solution of the first row compared with the second row. Consequently, the solutions in the first rows of the tables are inferior in a Paretian sense to the solutions in the second rows. Hence, the solutions in the first rows are not considered further.

4.2. Phase 2: Elicitation of the group weights

The next phase of the procedure is to derive a vector of group priority weights for the criteria involved in each of the consensus matrices previously determined. By applying model 2, the group priority weights shown in Table 3 are obtained. The reindeer herders' group weights are the criteria weights provided by the single member of this group.

For the environmentalist group, the two nondominated solutions for the consensus matrix produce the same vector of priority weights (see Table 3). However, from the consensus matrices for the timber producers, two different vectors of weights can be derived; this is also the case for the recreationist group (see Table 3). For $\lambda = 1$, the solutions obtained imply the smallest possible aggregated disagreement, while the maximum disagreement is the largest. When the value of λ decreases, the aggregated disagreement increases and the maximum disagreement decreases. The importance of this is that with $\lambda = 1$, the best solution from the perspective of the majority is found because the overall disagreement is minimized. On the other hand, with $\lambda = 0$, the disagreement of the most displaced individual with respect to the consensus solution is minimized. In this situation, using the vector that corresponds to the best solution for the majority is justified because it is the preferences of individuals belonging to the same social group that are aggregated. According to the reflection made at the end of the analytical framework section, $\lambda = 0.5$ can to some extent represent something like the frontier between consensus solutions biased towards the interest of the majority ($\lambda > 0.5$) and consensus solutions biased towards the interest of the minority ($\lambda < 0.5$). This reflection might be useful for the preferential interpretation to solutions shown from Table 2 to Table 3.

4.3. Phase 3: Elicitation of the group rankings of alternatives

In the third phase, eqs. 10 and 11 are applied by using the following two sets of information: the normalized outcomes of the alternatives evaluated for each criterion (see Table 1) and the group priority weights attached to the different criteria by the four social groups. In this way, two rankings for the 12 forest plan alternatives are obtained for each social group, as shown in Table 4.

It should be noted that the rankings of timber producers are very different from those of the three other groups. In contrast, the rankings of the environmentalists, recreationists, and reindeer herders are very similar. For $\pi = 1$, recreationists and reindeer herders have exactly the same ranking. The ranking for the environmentalists differs slightly from that of the recreationists and reindeer herders for some of the lower-ranking alternatives. However, there is no real difference in actual preference, and the ranking for the three social groups can be considered the same. For $\pi = \infty$, environmentalists and recreationists rank the alternatives exactly the same. The ranking for reindeer herders is the same for the lower-ranked alternatives but differs from that of the environmentalists and recreationists for the alternatives higher up in the ranking. Thus, the preferences of the reindeer herders are not considered to be exactly the same as those of the environmentalists and recreationists.

4.4. Phase 4: Elicitation of the final consensus rankings

The purpose of the final phase of the proposed procedure is to aggregate the rankings of the different social groups to determine the social rankings of the forest plan alternatives. To do this, model 3 is applied to the group rankings for the metrics $\pi = 1$ and $\pi = \infty$, respectively. Two values of the control parameter μ, $\mu = 1$ and $\mu = 0$, is used to find solutions that consider the interests of the majority and the minority. Different weights are also attached to the social groups to produce solutions with varying balances between the social groups. For a consensus for rankings produced with $\pi = \infty$, there are three rankings to aggregate:

Table 2. Solutions for a consensus matrix with different values of the control parameter λ for (A) timber producers, (B) environmentalists, and (C) recreationists.

(A) Timber producers.

λ	$m_{1,2}^{c,1}$	$m_{1,3}^{c,1}$	$m_{2,3}^{c,1}$	Aggregated disagreement	Maximum disagreement
0	0.20	1	1.20	32.87	7.80
(0, 0.20]	0.20	1.20	1	19.94	7.80
(0.20, 0.50]	0.20	1	1	19.34	8.00
(0.50, 1]	1	1	1	18.54	8.80

(B) Environmentalists.

λ	$m_{1,2}^{c,2}$	$m_{1,3}^{c,2}$	$m_{1,4}^{c,2}$	$m_{2,3}^{c,2}$	$m_{2,4}^{c,2}$	$m_{3,4}^{c,2}$	Aggregated disagreement	Maximum disagreement
0	5	6	1.60	0.14	3	0.20	45.04	11.26
(0, 0.30]	5	5	1	2.54	3	1	39.04	11.26
(0.30, 1]	5	5	1	5	3	0.20	32.52	14.52

(C) Recreationists.

λ	$m_{1,2}^{c,3}$	$m_{1,3}^{c,3}$	$m_{1,4}^{c,3}$	$m_{1,5}^{c,3}$	$m_{2,3}^{c,3}$	$m_{2,4}^{c,3}$	$m_{2,5}^{c,3}$	$m_{3,4}^{c,3}$	$m_{3,5}^{c,3}$	$m_{4,5}^{c,3}$	Aggregated disagreement	Maximum disagreement
0	5.40	1	3	1	5	5	1	1	7	3	157.74	23.60
(0, 0.45]	5	1	3.40	5	5	5	1	1	3	3	132.55	23.60
(0.45, 0. 50]	5	1	3	5	5	5	3	1	3.40	3	130.55	25.60
(0.50, 1]	5	1	3	5	5	5	3	1	3	3	130.15	26.00

Table 3. Criteria weights obtained for timber producers, environmentalists, recreationists, and reindeer herders.

Social group (i)	λ	W_1^i	W_2^i	W_3^i	W_4^i	W_5^i	W_6^i
Timber producers (i = 1)	(0, 0.20]	0.38	0.31	0.31	—	—	—
	(0.20, 1]	0.33	0.33	0.33	—	—	—
Environmentalists (i = 2)	(0, 1]	0.68	0.14	0.14	0.04	—	—
Recreationists (i = 3)	(0, 0.45]	0.58	0.12	0.02	0.17	0.12	—
	(0.45, 1]	0.60	0.12	0.12	0.12	0.04	—
Reindeer herders (i = 4)	—	0.06	0.52	0.18	0.10	0.10	0.04

Note: The criteria weights for timber producers, environmentalist, and recreationists are derived from the consensus matrices, and the criteria weights for reindeer herders are calculated directly from the judgment matrix.

Table 4. The ranking of alternatives for the different social groups for the metrics $\pi = 1$ and $\pi = \infty$.

Social group	π	Ranking
Timber producers	1	A9 ≻ A12 ≻ A10 ≻ A11 ≻ A5 ≻ A8 ≻ A6 ≻ A7 ≻ A4 ≻ A2 ≻ A1 ≻ A3
	∞	A9 ≻ A5 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A2 ~ A3 ~ A4
Environmentalists	1	A4 ≻ A1 ≻ A3 ≻ A2 ≻ A8 ≻ A6 ≻ A7 ≻ A5 ≻ A12 ≻ A10 ≻ A9 ≻ A11
	∞	A4 ≻ A2 ≻ A1 ≻ A3 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
Recreationists	1	A4 ≻ A1 ≻ A3 ≻ A2 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
	∞	A4 ≻ A2 ≻ A1 ≻ A3 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
Reindeer herders	1	A4 ≻ A1 ≻ A3 ≻ A2 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
	∞	A1 ~ A3 ≻ A2 ≻ A4 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11

Note: The symbol ≻ means “preferred”, and the symbol ~ means “indifferent to”.

timber producers, reindeer herders, and environmentalists–recreationists. To avoid a very large number of possible combinations of weights, the reindeer herders have always been given the same weight as the environmentalists and recreationists together. Solutions with different balances between social groups are obtained by distributing the weights between timber producers on the one hand and the other groups on the other hand. The rankings obtained are shown in Tables 5 and 6.

In the aggregated rankings for the metric $\pi = 1$, the highest-ranked alternative is always the most preferred alternative of either the timber producers (forest plan A9) or the three other social groups (forest plan 4). However, when the group rankings obtained for the metric $\pi = \infty$ are aggregated, the consensus rankings show more variation at the top. This is especially true for the solutions corresponding to $\mu = 0$. The weights attached to the social groups have a great impact on the consensus rankings obtained when the

Table 5. Solutions for an aggregated ranking of alternatives for the four social groups with (A) metric π = 1 and μ = 1 and (B) metric π = 1 and μ = 0.

(A) Metric π = 1 and μ = 1.		
Weight[a]		Ranking
$w_1 > w_2$		A9 ≻ A12 ≻ A10 ≻ A11 ≻ A5 ≻ A8 ≻ A6 ≻ A7 ≻ A4 ≻ A2 ≻ A1 ≻ A3
$w_1 = w_2$		A4 ≻ A1 ≻ A2 ~ A9 ≻ A5 ~ A8 ≻ A6 ≻ A7 ≻ A10 ≻ A12 ≻ A3 ~ A11
$w_1 < w_2$		A4 ≻ A1 ≻ A3 ≻ A2 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
(B) Metric π = 1 and μ = 0.		
w_2	w_2	Ranking
1	0	A9 ≻ A12 ≻ A10 ≻ A11 ≻ A5 ≻ A8 ≻ A6 ≻ A7 ≻ A4 ≻ A2 ≻ A1 ≻ A3
0.9	0.1	A9 ≻ A12 ≻ A11 ≻ A5 ≻ A8 ≻ A10 ≻ A6 ≻ A1 ≻ A7 ≻ A4 ≻ A2 ≻ A3
0.8	0.2	A9 ≻ A12 ≻ A11 ≻ A1 ≻ A5 ≻ A8 ≻ A6 ≻ A7 ≻ A4 ≻ A10 ≻ A2 ≻ A3
0.7	0.3	A9 ≻ A3 ≻ A10 ≻ A11 ≻ A8 ≻ A5 ~ A6 ≻ A4 ≻ A7 ≻ A2 ~ A12 ≻ A1
0.6	0.4	A4 ≻ A12 ≻ A10 ≻ A5 ≻ A6 ~ A8 ≻ A3 ≻ A11 ≻ A7 ≻ A2 ≻ A1 ~ A9
0.5	0.5	A4 ≻ A1 ~ A12 ≻ A10 ≻ A8 ≻ A5 ~ A6 ≻ A7 ~ A9 ≻ A2 ≻ A3 ~ A11
0.4	0.6	A4 ≻ A12 ≻ A3 ≻ A10 ≻ A8 ≻ A5 ~ A6 ≻ A1 ≻ A7 ≻ A2 ≻ A9 ≻ A11
0.3	0.7	A4 ≻ A12 ≻ A3 ≻ A1 ≻ A6 ~ A8 ≻ A5 ≻ A7 ≻ A10 ≻ A11 ≻ A2 ≻ A9
0.2	0.8	A4 ≻ A1 ≻ A3 ≻ A12 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A2 ≻ A9 ≻ A11
0.1	0.9	A4 ≻ A3 ≻ A2 ≻ A1 ≻ A6 ~ A8 ≻ A12 ≻ A5 ≻ A7 ≻ A10 ≻ A9 ≻ A11
0	1	A4 ≻ A1 ≻ A3 ≻ A2 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11

Note: The symbol ≻ means "preferred" and the symbol ~ means "indifferent to".

[a] w_1 is the weight attached to timber producers, and w_2 is the weight attached to the other three social groups together (environmentalists, recreationists, and reindeer herders).

Table 6. Solutions for an aggregated ranking of alternatives for the four social groups with (A) metric $\pi = \infty$ and μ = 1 and (B) metric $\pi = \infty$ and μ = 0.

(A) Metric $\pi = \infty$ and μ = 1.		
w_1	$w_2 = w_3$	Ranking
1	0	A9 ≻ A5 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A2 ~ A3 ~ A4
0.9	0.05	A9 ≻ A5 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A2 ~ A3 ~ A4
0.8	0.1	A9 ≻ A5 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A2 ~ A3 ~ A4
0.7	0.15	A9 ≻ A5 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A2 ~ A3 ~ A4
0.6	0.2	A9 ≻ A5 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A2 ~ A3 ~ A4
0.5	0.25	A9 ≻ A12 ≻ A4 ≻ A8 ≻ A11 ≻ A5 ~ A6 ≻ A1 ~ A3 ≻ A7 ~ A10 ≻ A2
0.4	0.3	A1 ≻ A2 ≻ A3 ~ A4 ≻ A5 ~ A8 ≻ A6 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
0.33	0.33	A1 ≻ A2 ≻ A3 ~ A4 ≻ A5 ~ A8 ≻ A6 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
0.3	0.35	A1 ≻ A3 ≻ A2 ≻ A4 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
0.2	0.4	A4 ≻ A2 ≻ A1 ≻ A3 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
0.1	0.45	A1 ≻ A2 ≻ A4 ≻ A3 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
0	0.5	A1 ≻ A4 ≻ A2 ≻ A3 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11
(B) Metric $\pi = \infty$ and μ = 0.		
w_1	$w_2 = w_3$	Ranking
1	0	A9 ≻ A5 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A2 ~ A3 ~ A4
0.9	0.05	A5 ≻ A9 ≻ A12 ≻ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A4 ≻ A2 ~ A3
0.8	0.1	A5 ≻ A12 ≻ A10 ≻ A9 ≻ A8 ≻ A11 ≻ A6 ≻ A3 ≻ A1 ≻ A7 ≻ A2 ~ A4
0.7	0.15	A5 ≻ A12 ≻ A10 ≻ A8 ≻ A6 ~ A11 ≻ A3 ≻ A9 ≻ A1 ≻ A7 ≻ A2 ~ A4
0.6	0.2	A12 ≻ A3 ~ A10 ≻ A9 ≻ A8 ≻ A6 ~ A11 ≻ A5 ≻ A1 ≻ A7 ≻ A2 ~ A4
0.5	0.25	A5 ≻ A2 ~ A12 ≻ A8 ≻ A11 ≻ A6 ≻ A9 ≻ A1 ≻ A3 ≻ A7 ~ A10 ≻ A4
0.4	0.3	A12 ≻ A2 ≻ A4 ~ A10 ≻ A8 ≻ A11 ≻ A5 ≻ A6 ≻ A1 ≻ A7 ≻ A3 ≻ A9
0.33	0.33	A5 ≻ A2 ≻ A4 ~ A10 ≻ A8 ≻ A11 ≻ A6 ≻ A1 ≻ A7 ≻ A3 ≻ A12 ≻ A9
0.3	0.35	A2 ≻ A1 ≻ A5 ≻ A8 ≻ A6 ~ A11 ≻ A9 ≻ A7 ~ A10 ≻ A3 ≻ A12 ≻ A4
0.2	0.4	A1 ≻ A5 ≻ A2 ≻ A3 ≻ A8 ≻ A6 ≻ A11 ≻ A7 ~ A10 ≻ A12 ≻ A4 ≻ A9
0.1	0.45	A2 ≻ A3 ~ A4 ~ A12 ≻ A1 ~ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A9 ≻ A11
0	0.5	A1 ≻ A4 ≻ A2 ≻ A3 ≻ A8 ≻ A6 ≻ A5 ≻ A7 ≻ A10 ≻ A12 ≻ A9 ≻ A11

Note: w_1 is the weight attached to timber producers, w_2 is the weight attached to the social groups of environmentalists and recreationists together, and w_3 is the weight attached to the reindeer herders. The symbol ≻ means "preferred" and the symbol ~ means "indifferent to".

control parameter μ is set to 1, for both metrics $\pi = 1$ and $\pi = \infty$. Thus, when the weight attached to timber producers is larger than the weight attached to the other social groups together, the consensus ranking obtained is identical to the ranking corresponding to timber producers. These patterns will be discussed further in the next section.

5. Discussion

This paper has demonstrated how a method based upon distance function minimization can be a pragmatic approach for addressing the aggregation of preferences in participatory forest planning. It is particularly designed to meet the requirements of a situation with a diverse set of social groups that are unlikely to fathom each other's interests.

Let us start with a methodological reflection. In a participatory planning situation, it is a great advantage to use a method that offers a clear interpretation of the preferential meaning of the different consensuses obtained during the process. Thus, the planning process is made transparent to the stakeholders or social groups involved, and a clear understanding of the participatory process can facilitate the final social acceptance of a consensus. In several phases of the procedure presented here, control parameters (λ and μ) and a distance metric (π) have been employed to find solutions for consensus from the majority and the minority point of view. The control parameters λ and μ enable trade-off between the majority consensus and the minority consensus. For λ or μ equal to 0, the best solution from the point of view of the minority (the worst off individual or group) is obtained, while for λ or μ equal to 1, the best solution from the majority point of view is obtained. For values of λ and μ belonging to the open interval (0,1), compromise consensuses between the interests of the majority and the minority can be straightforwardly obtained. This is a property of the method that makes it very flexible and suitable to use in participatory situations. Normally, with the standard aggregation method using the arithmetic or geometric mean, a sole solution is produced and presented as the optimal solution. The traditional way to produce several different solutions is to use the weighted mean and apply different relative weights for the stakeholders or social groups. Unfortunately, this is a disadvantage in participatory planning situations when relative power relationships between stakeholders can be a sensitive issue. With the approach applied in this case study, different rankings can be established not only by changing the relative weights of the stakeholders but also by balancing the point of view of the majority against the view of the minority.

Our work has a value-focused thinking orientation, as it is encouraged in the decision-making literature (see the work by Keeney (1992)). This meant that the interaction with the stakeholders was made before they knew the main features of the forest plans under consideration. The simultaneous consideration of values and alternatives (plans) implies a different theoretical orientation that might lead to different results (Hiltunen et al. 2008). With that kind of approach, the number of alternatives must, however, be restricted for practical reasons; in the present case, making pairwise comparisons of 12 alternatives would have required each stakeholder to make 12(12–1)/2 = 66 comparisons, which seems impractical. However, knowledge about the range of alternatives for each criterion might have affected the stakeholders' preferences for the criteria, because the importance assigned to a criterion is very probably dependent on the range considered for that criterion (von Winterfeldt and Edwards 1986).

Another potentially controversial point is that the stakeholders stated their preferences for criteria only relevant to them, following the second group decision-making approach described by Belton and Stewart (2002). This approach was chosen to suit the situation in the present study; the stakeholders had identified criteria relevant to them and were asked to state their preferences for "their" criteria only to facilitate the judgment process and make it meaningful for the stakeholders. The approach was also supposed to reduce the risk that strategic behavior would influence judgments. However, since the stakeholders did not state their preferences for all criteria, individual trade-offs between timber production, recreation, nature conservation, and reindeer herding are not made explicit; thus, the aggregation method and potential weights assigned to stakeholders become very influential for the outcome. Related to this, another consequence to consider is that the formation of the social groups may affect the results. In this case, the social groups were defined by the authors; the groups could have been defined in another way e.g., by the stakeholders or by making the municipality a separate group. If so, the consensus rankings produced would possibly have diverged from the rankings produced in this case.

The rankings of alternatives for each social group display a distinctive pattern (see Table 4); for both the $\pi = 1$ and $\pi = \infty$ metrics, the rankings of timber producers were markedly different from the rankings of the other social groups. In contrast, the rankings for environmentalists, recreationists and reindeer herders were very similar or even identical in some cases. The conclusion is that the case is characterized by two sides with opposing preferences: timber producers on one hand and environmentalists, recreationists and reindeer herders on the other. We believe that this is a pattern that may be quite common in forest management planning situations and that the approach proposed in this paper is very well suited to meet the requirements of situations like this.

When the control parameter μ is set to 1, the weights of the different stakeholders will strongly affect the solutions for a consensus ranking. Hence, if a compromise solution is desired, only the solutions where the two opposing sides have equal weights are of interest. There are two such solutions, one for metric $\pi = 1$ and one for metric $\pi = \infty$. In a forest planning situation involving stakeholders with conflicting interests, presenting solutions that are identical to the preferences of one of the parties would not likely be accepted by the stakeholders whose preferences are neglected and, thus, can create distrust in the whole participatory process.

When the control parameter μ is set to 0 and the stakeholder weights are varied, there are a number of different consensus rankings. From a practical point of view, it is the top parts of the different rankings that are of most interest; these are the most likely candidates for an accepted consensus solution. In this context, the set of three to four alternatives that occur in the top of a ranking can be defined as a "kernel" of alternatives. As Table 4 shows, the rankings of the two sides in this case, timber producers and the other groups together, have different kernels with no alternatives in common. Thus, for consensus rankings with very different weights for the two sides, the kernel coincides with the kernel of the dominant side (see Tables 5 and 6). When the weights of the two sides are more balanced, the kernels of the consensus solutions contain alternatives from both sides.

For the consensus rankings for metric $\pi = 1$ and $\pi = \infty$ with control parameter $\mu = 1$, the only two solutions of interest are the ones where the two sides have equal weight. However, even for these solutions the highest ranked alternative is always the most preferred alternative for one of the social groups. Presenting such solutions could be a problem in a participatory process because a solution that obviously favors one group in this way is less likely to be accepted by the other stakeholders. However, these solutions could be interesting in situations where stakeholders have less polarized interests, are equal in terms of their influence, or are willing to accept a majority decision. For the kind of participatory planning situation presented in this study, we believe that the consensus rankings for metric $\pi = \infty$ with control parameter $\mu = 0$ offer the most promising compromise solutions. In these consensus rankings the kernels are a mix of alternatives from both timber producers and the other social groups. It is compromise solutions of this kind that are interesting in a participatory process with more or less polarized interests and where the stakeholders do not have the same decision-making power.

One way to increase the participatory element of the method would be to let the stakeholders make pairwise comparisons on the importance of the different social groups. The weights obtained for the social groups could be used to determine only one consensus ranking for each combination of the values of the control parameters (λ and μ) and the distance metric (π). Another realistic and effective approach could be to present the kernels of the consensus rankings as results rather than the strict rankings. Furthermore, rather than letting the analyst or the decision maker choose one among the solutions produced, the kernels or consensus rankings could be used as a starting point for a negotiation process among stakeholders concerning the choice of forest management plan. From a bargaining perspective, this would constitute a more balanced initial point of negotiation with respect to the recreationists, environmentalists, and reindeer herders than the situation prior to the participatory process, where timber production was the predominant goal. Alternatively, the participatory process could also be extended into a collaborative learning process, where stakeholders would learn about the situation and the values of other stakeholders. The goal would be to enable the stakeholders to assess all criteria and, thereby, also increase the social learning effect.

6. Conclusions and further research

Nowadays, many forestry decisional contexts require the consideration of several criteria of different nature as well as the consideration of different viewpoints by several stakeholders. Moreover, it is not uncommon in forest planning situations for the stakeholders to not have the same set of criteria. Within this scope, we have proposed a method to address this type of problem, and the theory has been applied to a participatory decision-making problem in an urban forest in Sweden. The proposed aggregation method has some advantages:

1. It is a method based upon distance functions, so it provides compromise with good theoretical properties, e.g., Pareto optimality, anonymity, neutrality (see González-Pachón and Romero 1999).
2. All the compromise solutions obtained can be interpreted in preferential terms.
3. It is a noninteractive method. The only interaction required from the stakeholders is for identifying criteria and obtaining the pairwise preferential information and limits the burden on stakeholders as well as analysts.
4. The method combines the principle of the majority (“group utility”), with the principle of the minority in Rawl’s sense (“utility of the stakeholder most displaced with respect to the consensus obtained”).
5. The computational burden required to implement the method is very low. It only requires solving a reduced number of moderate-sized linear programming problems.

Item number three in the list above is an advantage but also a disadvantage in that it limits the opportunities for interaction and, thereby, social learning. A further application of this methodology would be to extend the process with a phase where results are presented to the stakeholders. The opinions on the rankings of alternatives for each social group by its members could be recorded and measured; this could also be done with the consensus rankings (see e.g., Linares 2009). Such a procedure would serve two different purposes. From a practical point of view, this feedback phase would make the participatory process iterative and could increase the possibility of attaining social learning and transfer of knowledge. From a methodological point of view, the outcome would be an assessment of how well the method captured the preferences of the different stakeholders involved in the decision-making process.

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Appendix A

Table A1. A summary of Saaty's fundamental scale (Saaty 1977).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed

Appendix B

The criteria to be compared through a pairwise comparison format are as follows:

- Maximize net present value (NPV) (C_1)
- Even harvest flow (C_2)
- Increased production capacity (C_3)
- Maximize thinning area (C_4)
- Maximize old forest area (C_5)
- Minimize clearcut size (C_6)
- Maximize proportion of birch (C_7)
- Maximize proportion of spruce and birch (C_8)
- Minimize total clearcut area (C_9)
- Minimize area planted with lodgepole pine (C_{10})
- Minimize fertilized area (C_{11})

Fig. B1. Pairwise comparison matrices.

Pairwise comparison matrices from timber producers:

$$\begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \end{array} \quad \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 1 & 0.2 & 0.2 \\ 5 & 1 & 0.33 \\ 5 & 3 & 1 \end{bmatrix} \end{array} \quad \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 1 & 7 & 1 \\ 0.14 & 1 & 0.2 \\ 1 & 5 & 1 \end{bmatrix} \end{array} \quad \begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 1 & 1 & 0.33 \\ 1 & 1 & 1 \\ 3 & 1 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array}\begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{bmatrix} 1 & 0.2 & 5 \\ 5 & 1 & 5 \\ 0.2 & 0.2 & 1 \end{bmatrix} \end{array}$$

Pairwise comparison matrices from environmentalists:

$$\begin{array}{c} \\ C_5 \\ C_6 \\ C_7 \\ C_9 \end{array}\begin{array}{c} \begin{array}{cccc} C_5 & C_6 & C_7 & C_9 \end{array} \\ \begin{bmatrix} 1 & 1 & 7 & 3 \\ 1 & 1 & 5 & 3 \\ 0.14 & 0.2 & 1 & 0.2 \\ 0.33 & 0.33 & 5 & 1 \end{bmatrix} \end{array} \quad \begin{array}{c} \\ C_5 \\ C_6 \\ C_7 \\ C_9 \end{array}\begin{array}{c} \begin{array}{cccc} C_5 & C_6 & C_7 & C_9 \end{array} \\ \begin{bmatrix} 1 & 9 & 3 & 1 \\ 0.11 & 1 & 0.14 & 0.14 \\ 0.33 & 7 & 1 & 1 \\ 1 & 7 & 1 & 1 \end{bmatrix} \end{array} \quad \begin{array}{c} \\ C_5 \\ C_6 \\ C_7 \\ C_9 \end{array}\begin{array}{c} \begin{array}{cccc} C_5 & C_6 & C_7 & C_9 \end{array} \\ \begin{bmatrix} 1 & 5 & 5 & 5 \\ 0.2 & 1 & 5 & 5 \\ 0.2 & 0.2 & 1 & 0.2 \\ 0.2 & 0.2 & 5 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ C_5 \\ C_6 \\ C_7 \\ C_9 \end{array}\begin{array}{c} \begin{array}{cccc} C_5 & C_6 & C_7 & C_9 \end{array} \\ \begin{bmatrix} 1 & 1 & 5 & 1 \\ 1 & 1 & 5 & 3 \\ 0.2 & 0.2 & 1 & 0.2 \\ 1 & 0.33 & 5 & 1 \end{bmatrix} \end{array}$$

Pairwise comparison matrix from reindeer herders:

$$\begin{array}{c} \\ C_4 \\ C_5 \\ C_6 \\ C_9 \\ C_{10} \\ C_{11} \end{array}\begin{array}{c} \begin{array}{cccccc} C_4 & C_5 & C_6 & C_9 & C_{10} & C_{11} \end{array} \\ \begin{bmatrix} 1 & 1 & 0.33 & 0.33 & 0.33 & 0.33 \\ 1 & 1 & 5 & 5 & 5 & 5 \\ 3 & 0.2 & 1 & 5 & 3 & 5 \\ 3 & 0.2 & 0.2 & 1 & 3 & 3 \\ 3 & 0.2 & 0.33 & 0.33 & 1 & 5 \\ 3 & 0.2 & 0.2 & 0.33 & 0.2 & 1 \end{bmatrix} \end{array}$$

Fig. B1 (*concluded*).

Pairwise comparison matrices from recreationists:

$$\begin{array}{c} \\ C_5 \\ C_6 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccc} C_5 & C_6 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 1 & 7 & 7 & 7 & 5 \\ 0.14 & 1 & 5 & 1 & 1 \\ 0.14 & 0.2 & 1 & 1 & 7 \\ 0.14 & 1 & 1 & 1 & 7 \\ 0.2 & 1 & 0.14 & 0.14 & 1 \end{bmatrix} \end{array} \qquad \begin{array}{c} \\ C_5 \\ C_6 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccc} C_5 & C_6 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 1 & 1 & 1 & 3 & 1 \\ 1 & 1 & 3 & 3 & 3 \\ 1 & 0.33 & 1 & 3 & 3 \\ 0.33 & 0.33 & 0.33 & 1 & 3 \\ 1 & 0.33 & 0.33 & 0.33 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ C_5 \\ C_6 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccc} C_5 & C_6 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 1 & 5 & 1 & 7 & 0.33 \\ 0.2 & 1 & 5 & 7 & 0.2 \\ 1 & 0.2 & 1 & 0.2 & 0.33 \\ 0.14 & 0.14 & 5 & 1 & 1 \\ 3 & 5 & 3 & 1 & 1 \end{bmatrix} \end{array} \qquad \begin{array}{c} \\ C_5 \\ C_6 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccc} C_5 & C_6 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 1 & 9 & 1 & 1 & 5 \\ 0.11 & 1 & 5 & 1 & 5 \\ 1 & 0.2 & 1 & 1 & 7 \\ 1 & 1 & 1 & 1 & 1 \\ 0.2 & 0.2 & 0.14 & 1 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ C_5 \\ C_6 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccc} C_5 & C_6 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 1 & 1 & 1 & 1 & 0.2 \\ 1 & 1 & 0.2 & 5 & 0.2 \\ 1 & 5 & 1 & 5 & 0.2 \\ 1 & 0.2 & 0.2 & 1 & 3 \\ 5 & 5 & 5 & 0.33 & 1 \end{bmatrix} \end{array} \qquad \begin{array}{c} \\ C_5 \\ C_6 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccc} C_5 & C_6 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 1 & 5 & 1 & 3 & 5 \\ 0.2 & 1 & 3 & 5 & 3 \\ 1 & 0.33 & 1 & 0.33 & 0.33 \\ 0.33 & 0.2 & 3 & 1 & 0.33 \\ 0.2 & 0.33 & 3 & 3 & 1 \end{bmatrix} \end{array}$$

$$\begin{array}{c} \\ C_5 \\ C_6 \\ C_8 \\ C_9 \\ C_{10} \end{array} \begin{array}{c} \begin{array}{ccccc} C_5 & C_6 & C_8 & C_9 & C_{10} \end{array} \\ \begin{bmatrix} 1 & 5 & 5 & 5 & 7 \\ 0.2 & 1 & 5 & 5 & 5 \\ 0.2 & 0.2 & 1 & 5 & 7 \\ 0.2 & 0.2 & 0.2 & 1 & 5 \\ 0.14 & 0.2 & 0.14 & 0.2 & 1 \end{bmatrix} \end{array}$$