Evaluation of the Multicriteria Approval Method for Timber-Harvesting Group Decision Support

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The decision support methods most often used in timber-harvesting planning are based on a single criterion. In this study, a voting-theory-based method called multicriteria approval (MA) is introduced to the group decision support of timber-harvesting. The use of voting methods alleviates the problems caused by the multitude of decision objectives involved in forestry decision-making and by the poor quality of information concerning both the preferences of decision-makers and the evaluation of decision alternatives with respect to the objectives often faced in practical timber-harvesting planning. In the case study, the tactical forest management plan of a forest holding jointly owned by three people was specified at the operative timber-harvesting level. The task was to find the best actual operative alternatives for the harvesting that had been proposed in the tactical plan. These timber-harvesting alternatives were combinations of treatment, timber-harvesting system and the timing of logging. Forest owners established multiple criteria under which the alternatives were evaluated. Two versions of MA were tested, one of them based on individual decision analyses and other one based on a composite analysis. The first was markedly modified from the original MA, combining properties of MA and Borda count voting. The other was an original MA with the order of importance for criteria estimated either using Borda count or cumulative voting. The results of the tested MA versions produced were very similar to each other. MA was found to be a useful tool for the group decision support of timber-harvesting.

Keywords group decision support, multicriteria approval, timber-harvesting planning, voting methods
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1 Introduction

Contemporary natural resources management is meeting increasing demands for sustainability. This also holds for timber-harvesting planning. The meaning of sustainability is always context-specific, but in this case, sustainable timber-harvesting means that timber-harvesting is managed the way that economic, social and ecological needs are simultaneously satisfied. Forest owners have many objectives concerning the utilisation of forests as well as forest trading; in addition to economic values, forest owners often consider values like nature conservation, outdoor recreation and minor logging damage. Those goals should be considered at both the tactical and the operative levels of forest planning. This makes timber-harvesting decision support situations more complex, creating a need for effective decision analysis methods which are able to take into account criteria that have been ignored in conventional timber-harvesting planning methods (Palander 1998). In the context of timber-harvesting planning, multi-criteria decision support approaches have not been used so far. However, they provide a potential approach to managing these kinds of complex decision problems.

The choice of harvesting technology and timing in conventional timber-harvesting planning methods are often based on linear programming or methods related to it (Mikkonen 1983), the only objective generally being either to minimise cost or maximise profit. Using goal programming or parametric optimisation, multiple objectives may exist along with a demand for linearity and the necessity of cardinal and numerical evaluation models. In practice, such data is not always available for some criteria, such as biodiversity and the scenic beauty of forest landscape. Increasingly, there are decision-making situations in which preference and evaluation information is imperfect and of poor quality as to the scale. Procedures that are able to deal with non-cardinal information are needed. In addition, linear programming and methods related to it are difficult to understand, and decision-makers may need simpler methods.

Group decision-making is becoming an important part of wood supply chain management and timber-harvesting planning. A group decision-making problem is faced, for instance, when dealing with timber-harvesting planning of a forest holding owned by several people. In Finland, this kind of ownership is increasing since forest holdings are more and more often owned by heirs and other consortia. Laukkanen et al. (2002) suggested that new methods are needed for this kind of group decision support. These methods should be easy to understand and simple to implement. Further, the inquiries required of decision-makers should not be complicated.

In general, the central problem of group decision-making is to define fair methods for aggregating individual choices to yield a social choice between many alternatives (Arrow 1951). Reaching a consensus or compromise is a key objective in most decision-making groups (Palander 1998, 2002). Many multi-criteria decision support methods might be applicable to group decision support in forestry, as for example methods based on multi-attribute utility theory or outranking approaches (e.g. Keeney 1992, Beroggi 1999, Belton and Stewart 2002), which have been applied in cases of forest planning (e.g. Kangas 1992, Kangas et al. 2001). The voting theory which originates in social choice theory can also be applied in natural resource management (e.g. Foran and Warde 1995, Martin et al. 1996, d'Angelo et al. 1998, Shields et al. 1999, Laukkanen et al. 2002, Reilly 2002, Kangas et al. 2005). Social choice theory considers decision problems in which a society or a collective group has to take a decision in a democratic way (see Arrow 1951, Kelly 1988). A previous study in which multi-attribute utility theory, outranking methods and voting-based methods were compared (Laukkanen et al. 2002) suggest that voting methods have some features that make them worth testing in the group decision support of forestry.

Most voting systems are considered as single criterion analyses since the individuals compare alternatives directly, but Fraser and Hauge (1998) have introduced an application of the approval voting method called multicriteria approval (MA), which has been specially developed for multiple-criteria situations. Recently, Laukkanen et al. (2002) promoted MA for tactical forest management planning. The approval voting procedure was proposed independently by several analysts in the l970s, such as Brams and Fishburn (l978).

It is a voting system which is based on dichotomous preferences (Kelly 1988). Voters divide candidates into two groups, those approved and those not approved, meaning that they can vote for as many candidates as they wish. Each approved candidate receives one vote and the candidate with the most votes wins (Brams and Fishburn 1983). Approval voting is used in many universities and in several professional organisations (Brams l988, Brams and Fishburn l988). The Secretary-General of the United Nations is also elected by approval voting (Brams and Fishburn 1983). This voting system is more likely to select condorcet candidates than other systems, including plurality voting, which is the best-known voting system (Brams and Fishburn 1991). It tends to promote the election of moderate candidates and to prevent situations in which the candidate elected is ranked last by those who did not vote for him or her. At the same time, minority candidates would receive votes commensurate with their actual support (Brams and Fishburn 1991). Approval voting usually encourages sincere voting and is not likely to be manipulated, because there is no motivation to vote for candidates who are below average with respect to the other candidates (e.g. Straffin 1980, Saari and van Newenhizen 1987).

The aim of this study is to develop the original MA method in order to better suit the group decision support needs of the timber harvesting planning. The reason why MA is presented as a new method in timber-harvesting decision-making situation is to overcome the problems caused by the multitude of decision objectives and by the low quality of information concerning both the preferences of decision-makers and the evaluation of decision alternatives with respect to the objectives. Two versions of MA will be tested. One of the versions is an original MA, which is fine-tuned by making use of the Borda count and cumulative voting methods in forming the composite order of importance for the criteria. The other one is markedly modified from the original MA, being based on individual decision analyses and combining the properties of MA and Borda count voting. In a case study, MA method is applied to, and tested in, a real decision-making situation of timber-harvesting planning in a consortium-owned forest holding. The tactical forest management plan chosen in previous study is specified at the operative timber-harvesting level, because the tactical and operative planning levels should ideally be linked. Results of the two MA versions are compared. New versions of the method are evaluated and discussed in group decision support and timber-harvesting planning aspects.

2 Methodology

2.1 Description of the Decision Problem

The background for this study is a situation in which a tactical forest plan was chosen for a forest holding owned by a consortium (see Laukkanen et al. 2002). Three owners were involved, each having an equal share of the holding, and the plan was chosen by group decision support. The forest holding, comprising about 30 hectares, is situated in Kuusamo in north-eastern Finland. It is divided into 13 compartments, each being relatively homogenous in its soil and stand characteristics. The tactical planning period consisted of two 10-year periods, and the plan was a combination of compartment-wise treatment schedules over the 20-year planning horizon. Choosing the tactical plan applying MA was the first stage in the decision-making process (Fig. 1). The plan proposed that one compartment, of 3.8 hectares, would be harvested during the first 10 years. This compartment is pine-dominated, but contains some spruce and birch. Its stand structure is not typical of Finland, consisting of two age classes, with hold-over trees of 17 metres average height and another tree storey of 10 metres average height.

A stand like this might be harvested in many ways. Because the tactical planning period is usually about 10 years, only the operating principles can be given in the tactical plan. These principles provide information about the stands on which timber-harvesting can be recommended for during the planning period in order to meet the objectives of the decision-makers. Tactical plans also suggest specific treatments but, in a tactical planning situation, it is impossible to predict timber prices for longer than five years or so. One may not even know what timber-harvesting systems will actu-

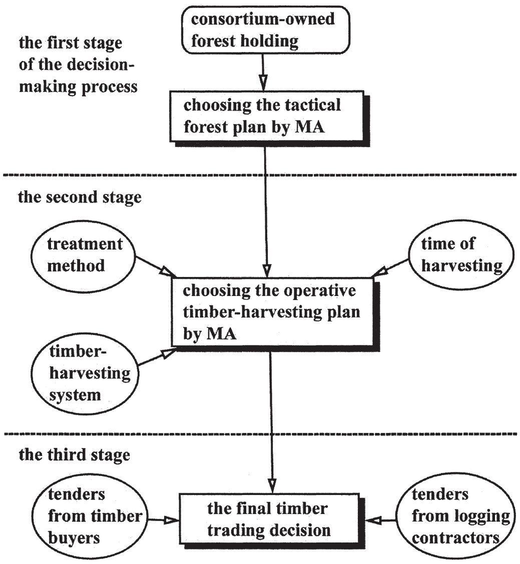

Fig. 1. Three stages of the decision-making process and the link between tactical forest planning and operative timber-harvesting planning.

ally be available in the area to be logged.

In this case study, the tactical plan was specified at the operative level, at which the timber-harvesting alternative was decided for the stand. An operative timber-harvesting plan details how those previously recommended treatments will actually be carried out, including the timing and the harvesting systems to be used. The operative planning period was chosen as the next harvesting year. The MA method was used again in this operative level choice problem, which could be considered as the second stage of the decision-making process (Fig. 1).

The idea is to do a timber trade at the delivered price on the roadside and a separate logging contract for the timber-harvesting. Before this trade, tenders from logging contractors and timber buyers will be requested for the timber-harvesting alternatives that are chosen in operative timber-harvesting planning. The third stage of the decision-making process is that the final timber trade decision will be made based on those tenders (Fig. 1). Information for timber-harvesting planning, such as timber prices, will be updated when tenders are invited.

2.2 Decision Alternatives

We began the MA process by defining the timber-harvesting alternatives. Five different treatment methods, appropriate for the stand, were suggested: 1) clear-felling, with scalping and planting 2) seed-tree cut, with scalping 3) thinning from below 4) thinning uniformly, or 5) thinning from above. Inquiries showed that three timber-harvesting systems were available in that area: 1) chain-saw felling, with forest hauling by a forwarder 2) harvester felling, with forest hauling by a forwarder 3) felling and hauling by a harvester/forwarder combi machine. In addition, two possible timber-harvest timings were considered: 1) summer, when the ground is free of frost 2) winter, when the ground is frozen. Combining all the treatment methods, harvesting systems and timings resulted in 30 possible alternatives for use in the decision-making process (Table 1).

2.3 Decision Criteria

Next phase of the MA process was determination of the criteria by which to compare these alternatives. After negotiations, the forest-owners selected five criteria: net harvesting income, effects on nature conservation values, effects on recreational values, expectation of logging damage and favouring local contractors. As can be seen, the forest owners had economic, ecological and social aims. The main economic criterion is net income. Expectation of logging damage is basically both an economic and an ecological criterion. Nature conservation is an ecological criterion. Favouring of local entrepreneurs is a purely social criterion, and social sustainability aspects can also be seen in the recreation criterion.

2.4 Evaluation of the Timber-Harvesting Alternatives

Table 2 shows all the criterion values for each timber-harvesting alternative. The net income was valued by means of the Monsu forest planning software (Pukkala 2001), designed for multiple-use forestry and particularly for the management planning of forest holdings. Different treatments

Table 1. Timber-harvesting alternatives.

Alternative	Treatment method	Timber harvesting system	Time of harvesting
A1	Clear-felling–scalping–planting	Chain-saw–forwarder	Summer
A2	Clear-felling–scalping–planting	Chain-saw–forwarder	Winter
A3	Clear-felling–scalping–planting	Harvester–forwarder	Summer
A4	Clear-felling–scalping–planting	Harvester–forwarder	Winter
A5	Clear-felling–scalping–planting	Combi machine	Summer
A6	Clear-felling–scalping–planting	Combi machine	Winter
A7	Seed-tree cut–scalping	Chain-saw–forwarder	Summer
A8	Seed-tree cut–scalping	Chain-saw–forwarder	Winter
A9	Seed-tree cut–scalping	Harvester–forwarder	Summer
A10	Seed-tree cut–scalping	Harvester–forwarder	Winter
A11	Seed-tree cut–scalping	Combi machine	Summer
A12	Seed-tree cut–scalping	Combi machine	Winter
A13	Thinning from below	Chain-saw–forwarder	Summer
A14	Thinning from below	chainsaw–forwarder	Winter
A15	Thinning from below	Harvester–forwarder	Summer
A16	Thinning from below	Harvester–forwarder	Winter
A17	Thinning from below	Combi machine	Summer
A18	Thinning from below	Combi machine	Winter
A19	Thinning uniformly	Chain-saw–forwarder	Summer
A20	Thinning uniformly	Chain-saw–forwarder	Winter
A21	Thinning uniformly	Harvester–forwarder	Summer
A22	Thinning uniformly	Harvester–forwarder	Winter
A23	Thinning uniformly	Combi machine	Summer
A24	Thinning uniformly	Combi machine	Winter
A25	Thinning from above	Chain-saw–forwarder	Summer
A26	Thinning from above	Chain-saw–forwarder	Winter
A27	Thinning from above	Harvester–forwarder	Summer
A28	Thinning from above	Harvester–forwarder	Winter
A29	Thinning from above	Combi machine	Summer
A30	Thinning from above	Combi machine	Winter

of the compartment were simulated and Monsu calculated the net income for each harvesting schedule, reducing the harvest income by the cost of possible post-logging activities, such as soil preparation and artificial regeneration.

The differences in net incomes produced by the alternatives were attained using timber-harvesting costs, which were calculated for each alternative because they had an effect on the delivered prices on the roadside used in Monsu software and thus on expected net income. Timber-harvesting costs for each alternative were calculated with productivities for each alternative and the working-hour costs for each timber-harvesting system (Valkonen 1986, Metsä- ja uittoalan… 1991, Kuitto et al. 1994, Ryynänen 2001, Sirén and Aaltio 2001). The delivered price for clear-felling by a harvester and forest hauling by a forwarder was obtained from the statistics. The difference between the timber-harvesting cost of clear-felling by a harvester and that of each other alternative was calculated and the difference was subtracted from the delivered price of clear felling by a harvester.

The estimates for expected logging damage of remaining trees were based on results from earlier studies. The damage models used here are preliminary and are based on presumptions. Because this kind of two-aged forest stand structure is not typical in Finland, there are no studies which would have been made for this kind of forest. Damage studies are very stand-dependent and damage percentages are always higher in two-aged stands than in even-aged stands. Mutka (2001) has studied logging damage for two-aged

Table 2. Criterion values for the timber-harvesting alternatives, the limit between approval and disapproval for each criterion, and the direction of preference.

Timber-harvesting alternative	Local contractors, km	Logging damage, damaged stems	Nature conservation, rank	Net income, euros	Recreation, rank
A1	15	0	28	9015	28
A2	15	0	22	8735	25
A3	26	0	30	10524	30
A4	26	0	24	10524	27
A5	39	0	29	9221	29
A6	39	0	23	9221	26
A7	15	9	25	8243	22
A8	15	9	10	7547	11
A9	26	10	27	9310	24
A10	26	9	12	9310	21
A11	39	9	26	8455	23
A12	39	9	11	8455	20
A13	15	59	19	1711	10
A14	15	57	7	1093	1
A15	26	65	21	3436	13
A16	26	63	9	3436	4
A17	39	62	20	2477	12
A18	39	60	8	2477	3
A19	15	64	16	3761	14
A20	15	62	4	3353	2
A21	26	70	17	5088	16
A22	26	68	6	5088	6
A23	39	67	18	4330	15
A24	39	65	5	4330	5
A25	15	78	13	5999	17
A26	15	76	1	5554	7
A27	26	86	15	7016	19
A28	26	84	3	7016	9
A29	39	82	14	6511	18
A30	39	80	2	6511	8
Median value	26	60, 62	15, 16	6511	15, 16
Mean value	26.7	43.1		6258.2	
Min/Max	Min	Min	Min	Max	Min

stands caused by harvester felling and the skidding of a forwarder. The results of Mutka's study, which was done in Russia, were used because the forest stand structures were similar and the case study area in Russia is geographically not very far away from the area of the present study. The damage percentage for the harvester-forwarder was determined from the remaining number of stems per hectare and the season in question (Mutka 2001). If the remaining number of stems was 50 the damage percentage was 19.2. If the remaining number of stems was 600 the damage percentage was 15.0.

Harstela (1996) studied damage in even-aged stands caused by chain-saw felling and forwarder skidding. The damage percentage was 4.4. There are no studies about chain-saw/forwarder damage in two-aged stands. Based on undocumented experience and intuition Harstela's percentage was raised and established at nine percent less than the harvester and forwarder damage in Mutka's study (2001). Damage by the harvester/forwarder combi machine was calculated simply by halving the difference in logging damage between these two harvesting technologies, because a forwarder is not used in this harvesting system. As far as is known there is only one empirical study on damage caused by this new harvesting technology (Sirén and Aaltio 2001), and the results are not applicable to this kind of forest stand structure.

The forest owners appreciated favouring the timber-harvesting systems owned by local contractors, and were interested in providing job opportunities for people living near the holding. The measure of this social criterion was the distance between the forest holding and the home of each contractor.

An ordinal scale was used to make qualitative evaluations of how the timber-harvesting alternatives affect nature conservation and recreation. Alternatives for both criteria were ranked from best to worst. Two experts conducted assessments of nature conservation, while the effects on recreation were determined by the forest owners. After negotiating, the owners determined an order for the alternatives with respect to recreation. The nature conservation assessments of the two experts were consistent as well. The conservation criterion in particular is not of a subjective nature in the owners' point of view. Defining its importance in relation to other criteria is certainly the task of the owners, but estimating the priorities of the alternatives with respect to conservation requires either expert knowledge or evaluation models produced by empirical research. In this study, we relied on the available expertise because no reliable models have been developed, and because evaluation always is a case-wise task.

The limits between approval and disapproval of each timber-harvesting alternative for each criterion were determined for both versions of MA (Table 2). The direction of preference (min/max) was defined as well. The net income criterion was maximised, while the other criteria were minimised.

2.5 Multicriteria Approval Method (MA)

2.5.1 The Original MA

In the method used in this study, multicriteria approval (MA), voters of approval voting are replaced by criteria, and approval voting candidates are replaced by decision alternatives. The original MA described here is a multi-criteria decision support system for one decision-maker (Fraser and Hauge 1998).

The MA process begins by defining the alternatives and the criteria by which these alternatives will be compared. Secondly, decision-makers rank the criteria by their importance, which phase differs from the approval voting situation, in which voters have equal importance (Fraser and Hauge 1998). The limits between approval and disapproval for each criterion are defined next (Fraser and Hauge 1998). It is then possible to determine which of the alternatives are approved and which disapproved with respect to each criterion. If more is preferred to less, an alternative will be approved for the criterion if the criterion value is above the limit and if less is preferred to more, an alternative will be approved for the criterion if the criterion value is below the limit. For numerical criterion values, the limit between approval and disapproval for each criterion is the mean value of the criterion values of all alternatives, as Fraser and Hauge (1998) defined it. The midpoint of the range of variation can also be used as a limit (Laukkanen et al. 2002). The median of the criterion values can be used as well (Laukkanen et al. 2004).

The determination of the voting result begins by deciding how many *ordinally dominant* alternatives exist using a variation of the ordinal deductive selection system's (Meister and Fraser 1995) algorithm. Alternative k is classified as *ordinally dominant* if

$$f\left(n^*\right)_{ki} \geq 0 \;\; \forall n^*, \;\; 1 \leq n^* \leq n, \;\; \forall\, i \neq k \qquad (1)$$

where

$$f\left(n^*\right)_{ki} = \sum_{j=1}^{n^*} g_{ijk} \qquad (2)$$

and

$$g_{ijk} = \begin{cases} 1, \textit{if} \;\; c_j(a_k) \in P \wedge c_j(a_i) \notin P \\ 0, \textit{if} \;\; c_j(a_k) \in P \wedge c_j(a_i) \in P \\ 0, \textit{if} \;\; c_j(a_k) \notin P \wedge c_j(a_i) \notin P \\ -1, \textit{if} \;\; c_j(a_k) \notin P \wedge c_j(a_i) \in P \end{cases}$$

where the value of criterion c_j in alternative a_k is $c_j(a_k)$, the value of criterion c_j in alternative a_i is $c_j(a_i)$, and the approved set of alternatives is P.

According to Fraser and Hauge (1998), there are five possible voting result classes in MA: *unanimous*, *majority*, *ordinally dominant*, *deadlocked* and *indeterminate*. The *unanimous* class is a subclass of *majority* and both of these are subclasses of *ordinally dominant*. Based on the pairwise comparisons, each alternative is defined either as *ordinally dominant* or *indeterminate.*

The *unanimous* voting result means that only one alternative has been approved with respect to all criteria. When the result is *majority*, only one alternative has been approved with respect to the majority of the criteria which have been defined as the most important. The result o*rdinally dominant* occurs if one alternative has been defined as superior on the grounds of the importance order of the criteria and dichotomous preferences. *An ordinally dominant* alternative does not lose to any other alternative. If two or more alternatives are approved and disapproved with respect to the same criteria, the voting result is *deadlocked*. If one superior alternative cannot be defined as superior from the order of importance of the criteria, the voting result is *indeterminate*, in which case more preference information is needed.

2.5.2 MA Version 1 – Individual Forest Owner MA Analyses

The first version of MA is markedly modified from the original MA, combining properties of MA and Borda count voting. In this version, the MA analysis is conducted separately for each forest owner. For this purpose, each owner forms an individual order of importance for the criteria.

The limits between approval and disapproval of each timber-harvesting alternative for each criterion are determined. The direction of preference (min/max) is defined as well. The limit between approval and disapproval for each criterion is defined using the median value of the criterion values of all alternatives. For the sake of sensitivity analysis, the mean value, being the way Fraser and Hauge (1998) defined the limit, is also used as a limit of approval. The approval limit for the qualitative criteria is the median value because it is not reasonable to calculate the mean value for a ranking. After defining the limits between approval and disapproval, it is possible to determine dichotomous preferences; in other words, which of the timber-harvesting alternatives are approved and which disapproved with respect to each criterion.

The total votes for each timber-harvesting alternative are calculated by combining the principles of the Borda count voting and MA. If n is the number of criteria, an alternative gets n Borda count votes for the first-ranked criterion, $n-1$ votes for the second-ranked criterion and so on to the last-ranked criterion, which gets 1 vote. According to the MA principles, an alternative gets 1 vote when it is approved for a criterion and 0 votes when it is disapproved for a criterion. The Borda votes and the approval votes are multiplied by each other and the products for each alternative added up. The individual MA analyses of forest owners are combined by totalling the votes each alternative gets from the owners.

2.5.3 MA Version 2 – Composite Forest Owner MA Analysis

In the second version, a composite MA analysis of the forest owners is used and therefore, a composite order of importance across all the decision-makers is needed. This version is an original MA with a composite order of importance for the criteria estimated using Borda count and cumulative voting.

In the Borda count voting system (Borda l78l), each forest owner is asked to form an order of importance for the criteria. The first-ranked criterion receives n votes, the second-ranked $n-1$ votes and so on to the lowest-ranked, which receives 1 vote (where n is the number of criteria). The votes for each criterion from all owners are totalled and the composite order forms from these scores.

In cumulative voting, each owner is asked to divide 100 votes between the criteria so that the votes describe the importance of the criteria in relation to each other. The votes for each criterion are added up and the composite order forms on this basis. In this case, the owners have equal shares of the forest holding and thus equal importance in relation to each other. In the case of unequal importance, one possibility would be to give a number of votes to an owner to be divided between criteria which describes his/her importance in relation to other owners.

The limits between approval and disapproval of each timber-harvesting alternative for each criterion are the same as in MA version 1, in other words, the median value and the mean value of the criterion values of all alternatives. Based on the approval limits, it is possible to determine which of the timber-harvesting alternatives are approved and which disapproved with respect to each criterion. In this version, the voting result is determined the same way as in the original MA (see section 2.4.1).

3 Results

3.1 MA Version 1 – Individual Forest Owner MA Analyses

In the first version, the MA analysis was conducted separately for each forest owner using separate importance orders for the criteria. First, the results were calculated using the median criterion values as the limits of approval and disapproval. After defining which of the timber-harvesting alternatives were approved and which disapproved with respect to each criterion, the total votes for each timber-harvesting alternative were calculated by combining the principles of the Borda count voting and MA (see section 2.4.2). The Borda votes (see Table 5) and the approval votes were multiplied by each other and the products for each alternative added up. The individual MA analyses of the forest owners were combined by totalling the votes each alternative got from the owners (Fig. 2, Appendix 1).

Timber-harvesting alternative 8 was the winner with 45 votes. It was acceptable with respect to all criteria in all individual forest owner analyses. No other alternative was approved on all criteria. Alternative 8 was the first choice in all individual forest owner analyses despite the fact that the owners appreciate different criteria. According to alternative 8, the stand will be harvested in winter using seed-tree cut by chain-saw. The second best alternatives were also sought because a few timber-harvesting alternatives were wanted for negotiations with logging contractors and timber buyers. The second place went to alternative 28, which received 38 points, and involves thinning the stand from above using a harvester. The time of harvesting is winter. Alternative 28 was also the second best choice of owners 2 and 3 in individual analyses, because it was approved with respect to all the criteria except logging damage. In the individual MA analysis of the forest owner 1,

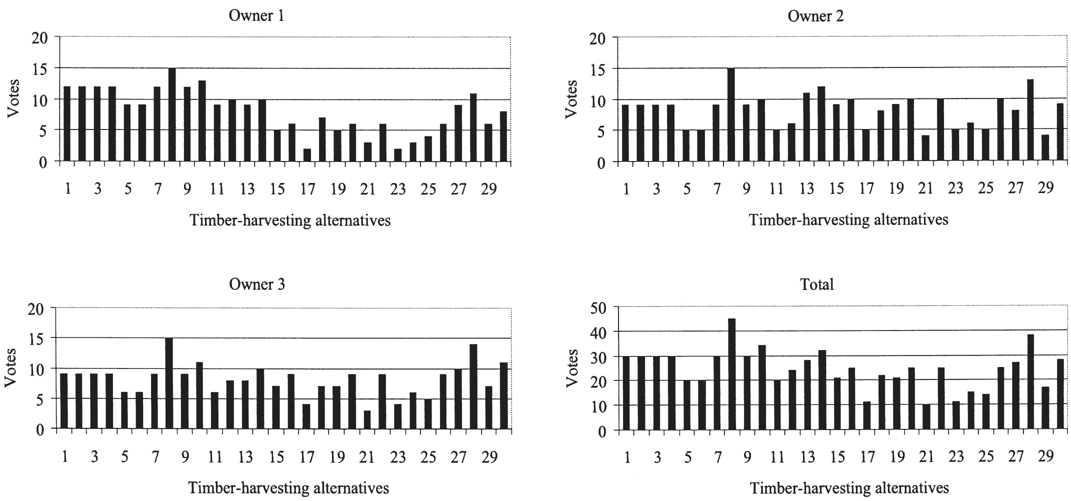

Fig. 2. Votes of each alternative received from individual forest owner's analyses when the median criterion values were used as approval limits, and total of all votes over all owners.

Table 3. Forest owners' individual orders of importance for the criteria and the composite importance order formed using Borda count voting.

	Owner 1		Owner 2		Owner 3		Total votes	Composite order
	Rank	Votes	Rank	Votes	Rank	Votes		
Local contractors	3	3	2	4	3	3	10	3
Logging damage	2	4	4	2	5	1	7	4
Nature conservation	5	1	5	1	4	2	4	5
Net income	1	5	3	3	1	5	13	1
Recreation	4	2	1	5	2	4	11	2

alternative 28 was seventh best. This alternative is a compromise choice which in this case means that one of the owners has to make some concession.

3.2 MA Version 2 – Composite Forest Owner MA Analysis

As the second version, a composite MA analysis was conducted using a composite order for the criteria (see section 2.4.3). The owner's composite order of importance for the criteria was the same formed with both Borda count votes and by dividing 100 votes between the criteria: 1) net income 2) effects on recreational values 3) favouring local entrepreneurs 4) expectation of logging damage 5) effects on nature conservation values (Tables 3 and 4).

First, the results were calculated using the median criterion values as limits of approval and disapproval. Based on the approval limits, it was possible to determine which of the timber-harvesting alternatives were approved and which disapproved with respect to each criterion (Table 5). When each timber-harvesting alternative was compared with other alternatives in accordance with Formula 2, it became obvious that alternative 8 did not lose to any other alternative and $f(n^*)_{ki}$ never took a negative value. It turned out that the

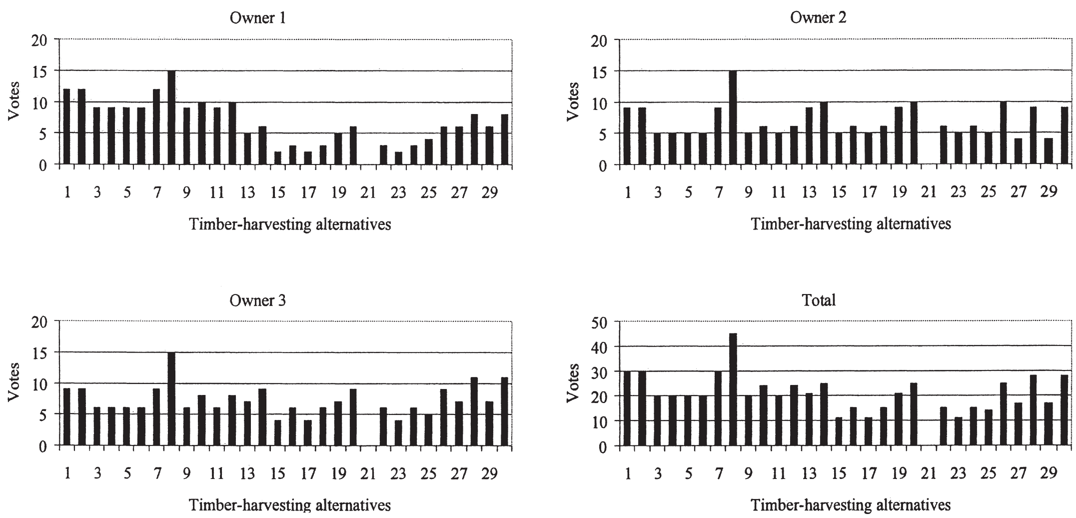

Fig. 3. Votes of each alternative received from individual forest owner's analyses when the mean criterion values were used as approval limits, and total of all votes over all owners.

Table 4. Forest owners' composite order of importance for the criteria formed using cumulative voting.

	Owner 1	Owner 2	Owner 3	Total votes	Composite order
Local contractors	20	25	20	65	3
Logging damage	23	10	5	38	4
Nature conservation	13	5	15	33	5
Net income	29	20	35	84	1
Recreation	15	40	25	80	2

voting result was *unanimous* because alternative 8 was acceptable with respect to all criteria, being superior on this basis because no other alternative was approved on all criteria (Table 5).

The second best choice was alternative 28, which was approved with respect to the three most important criteria. Thus it did not lose to any other alternative except the unanimous winner. In pairwise comparisons, $f(n^*)_{ki}$ took a negative value for all other alternatives at the beginning of the comparison or at least after alternatives had been compared on the third-ranked criterion.

3.3 Sensitivity Analyses

3.3.1 MA Version 1

For the sake of sensitivity analysis, the results of the first MA version were also calculated using the mean criterion values as approval limits. In this analysis, timber-harvesting alternative 8 was still the winner with 45 points (Fig. 3, Appendix 2). The second best alternatives were 1, 2 and 7 which received 30 points.

3.3.2 MA Version 2

The results of the composite MA analysis were also calculated using the mean criterion values as limits of approval and disapproval. This sensitivity analysis showed that alternative 8 was acceptable with respect to all criteria, again being defined as *ordinally dominant*, in particular as the *unanimous winner* (Table 6). The second best choices were alternatives 28 and 30, which were approved with respect to the two most important criteria and the least important criterion. No other

Table 5. Composite analysis. Approvals (+) and disapprovals (–) of the alternatives for each criterion using the median criterion values as approval limits.

Alternative	Net income	Recreation	Local contractors	Logging damage	Nature conservation
A1	+	–	+	+	–
A2	+	–	+	+	–
A3	+	–	+	+	–
A4	+	–	+	+	–
A5	+	–	–	+	–
A6	+	–	–	+	–
A7	+	–	+	+	–
A8	+	+	+	+	+
A9	+	–	+	+	–
A10	+	–	+	+	+
A11	+	–	–	+	–
A12	+	–	–	+	+
A13	–	+	+	+	–
A14	–	+	+	+	+
A15	–	+	+	–	–
A16	–	+	+	–	+
A17	–	+	–	–	–
A18	–	+	–	+	+
A19	–	+	+	–	–
A20	–	+	+	–	+
A21	–	–	+	–	–
A22	–	+	+	–	+
A23	–	+	–	–	–
A24	–	+	–	–	+
A25	–	–	+	–	+
A26	–	+	+	–	+
A27	+	–	+	–	+
A28	+	+	+	–	+
A29	+	–	–	–	+
A30	+	+	–	–	+

Table 6. Composite analysis. Approvals (+) and disapprovals (–) of the alternatives for each criterion using the mean criterion values as approval limits.

Alternative	Net income	Recreation	Local contractors	Logging damage	Nature conservation
A1	+	–	+	+	–
A2	+	–	+	+	–
A3	+	–	–	+	–
A4	+	–	–	+	–
A5	+	–	–	+	–
A6	+	–	–	+	–
A7	+	–	+	+	–
A8	+	+	+	+	+
A9	+	–	–	+	–
A10	+	–	–	+	+
A11	+	–	–	+	–
A12	+	–	–	+	+
A13	–	+	+	–	–
A14	–	+	+	–	+
A15	–	+	–	–	–
A16	–	+	–	–	+
A17	–	+	–	–	–
A18	–	+	–	–	+
A19	–	+	+	–	–
A20	–	+	+	–	+
A21	–	–	–	–	–
A22	–	+	–	–	+
A23	–	+	–	–	–
A24	–	+	–	–	+
A25	–	–	+	–	+
A26	–	+	+	–	+
A27	+	–	–	–	+
A28	+	+	–	–	+
A29	+	–	–	–	+
A30	+	+	–	–	

alternative except alternative 8 was approved with respect to the two most important criteria.

3.4 Comparison of the Two MA Versions

The results attained using MA version 1 and MA version 2 were very similar to each other. Based on the sensitivity analyses, it could be said that those versions are not sensitive to the changes in the approval limits. Both versions of MA chose timber-harvesting alternative 8 when the approval limits were defined by the median criterion values. The second best alternative was alternative 28. Alternative 8 was also chosen in the sensitivity analyses in which the approval limits were defined by the mean criterion values. The second best choices in the sensitivity analysis of the first version were alternatives 1, 2 and 7, and in the sensitivity analysis of the second version alternatives 28 and 30.

Because the study material was fairly small, the results can not be generalized. However, in this study, the main point was to compare the applicability of the developed MA versions in the practical timber-harvesting group decision support situation. In general, both versions of the MA method proved to be comprehensible and easy to implement and interpret, and could thus easily be applied in the group decision support situations.

In the second version, which was fine-tuned from the original MA, the forest owners' composite order of importance for the criteria was formed for use in a composite MA analysis. Two different ways of forming the composite order were tested. The Borda count voting seemed to be a simpler way for the decision-makers than cumulative voting, because the only thing they needed to do was to rank the criteria. More consideration was demanded when 100 votes were divided between the criteria. In any case, these two voting methods led to the same order of importance.

From the group decision support aspect, the first version with individual decision analyses seemed to have some advantages over the second, with composite analysis. In the second version, decision-makers needed to find composite criteria by means of negotiation. In the first version, it would have been possible to use the individual criteria of each forest owner because of individual analyses. In this study, all the owners ended up having the same five criteria in the second version as well, but they still were able to construct individual orders of importance for those criteria. Because the owners had the same number of criteria, the votes of each owner for each alternative were simply totalled. If the owners had had a different number of criteria, the votes of the owners should have been scaled, for example, to 100 or 1.

4 Discussion

In this study, a voting-theory-based method called multicriteria approval (MA) was applied to group decision support situation of timber-harvesting planning. MA and its calculations were developed to be suitable for group decision support. Two different versions of the method were tested and compared, the main interest being directed to the practical suitability of the method for the group decision support of timber-harvesting planning. A tactical forest plan of a consortium-owned forest holding chosen in a previous study was specified at the operative timber-harvesting level at which the best timber harvesting alternatives were chosen by MA. This kind of approach allows the fields of forest planning and practical timber-harvesting planning to move closer to each other.

MA was found to be suitable for timber-harvesting decision support, because it can take into consideration criteria which have not been considered in conventional timber-harvesting planning methods, but which should be considered today in nearly any forestry decision-making process. Compared to other multi-criteria decision support methods, MA demands much less preference information from decision-makers, ordinal preference information for the criteria being sufficient. Evaluation of harvesting alternatives with respect to some qualitative criteria can also be done using the ordinal scale. Ecological and recreational information is often of poor quality, only ordinal values being available. On the other hand, these subjective evaluations might be laborious for decision-makers, at least if the number of alternatives is large. To avoid this, experts or assistants can do these evaluations in advance, after which the decision-makers approve the rankings or suggest new ones. Because in MA analysis information might be lost when the cardinal information potentially available is not fully exploited, the method is at its best in situations where information that other decision support methods demand is difficult or expensive to obtain or quality of the information available is poor.

Jointly owned forests are problematic from the forest management point of view (Laukkanen et al. 2002). All the owners need to approve management actions. The MA method favours moderate decisions which are better than average with respect to all criteria, which makes it suitable for the control of group decision support conflict situations. Another fact that makes MA appropriate for group decision support is the ease of the inquiries required from decision-makers, which makes the process quick and convenient to carry out. For this reason, it seems that the inquiries for MA could be carried out via the Internet. MA is also hard to manipulate and is fair for both those with expertise on decision support methods or forestry as well as for laymen. This kind of voting approach could also be worth consideration, for instance, in the group decision-making situations of wood procurement organisations or in the participatory planning processes of the state-owned forests.

MA version 1 which was based on individual decision analyses proved to produce same kind of results than the original MA although this version was markedly modified. All of the tests indicated timber-harvesting alternative 8 to be the first choice. Because alternative 28 took most second places among all the tests, it was decided to take it into account in the final stage of the decision-making process. Timber-harvesting alternatives 8 and 28 were left as alternative solutions and the forest owners will use them in forest trading when negotiating with timber buyers and logging contractors. The final choice between these alternatives will be made on the basis of tenders from logging contractors and timber buyers.

It is worth noting that when a specified timber harvesting plan was made at the operative level, and will further be specified on grounds of final price offers, it is possible that the alternative finally chosen will differ from the treatment proposal of the tactical forest plan regarding net income, the key figures of remaining trees, and so on. In consequence of this, the tactical plan proposals concerning some other stands might need to be changed; in other words, the tactical forest management plan needs to be updated or reformulated for the time after harvesting.

From the point of view for practical suitability, both versions of the MA proved to be comprehensible and easy to implement. The results were interpretable as well. Thus, the MA versions could easily be applied in the group decision support situations. The first version with individual decision analyses seemed to have some advantages over the second, with composite analysis. The first one was slightly easier, because the forest owners' composite order of importance for the criteria was not needed. The first version with individual MA analyses also had more characteristics of a group decision support method. The problem to be solved in the future is the combining of the individual analyses when the individual criteria for each forest owner or other decision-maker are used. The possibility of manipulation in voting could be assumed to be bigger in MA version 2 in which the composite MA analysis is used. If the composite order of importance for the criteria is formed by dividing 100 votes between the criteria, someone could, for example, give all the votes for one criterion in order to get this criterion to the first place.

The main point in this study was to compare the applicability of the developed MA versions in the practical timber-harvesting group decision support situation. Methodologically, the applicability of the method could be confirmed. However, in a small case study like this, it is not possible to analyse the users' perception of the usefulness, comprehensibility and so on. This would require a large sample of forest owners with different decision problems.

As a whole, this kind of multi-criteria decision support approach creates a good basis for sustainable timber-harvesting planning where the various dimensions of sustainability are integrated. As can be seen in this study, economic targets are important for forest owners, but they also want to take responsibility for the ecological and social issues related to forestry. The social sustainability of timber-harvesting, which has previously received less attention than economic and ecological sustainability, has recently become prominent as well. In this study, the forest owners appreciated favouring the timber-harvesting systems owned by local contractors, and were interested in providing job opportunities for people living near the holding. They wanted to take some responsibility for aspects of social sustainability within their rural region, even though it might mean slight financial loss.

This was the first time a voting-theory-based method was used in group decision support of timber-harvesting planning. However, at the same time, the MA method has been applied to participatory decision support of timber-harvesting planning (Laukkanen et al. 2004). New versions of the MA method have been developed and tested in that study, too. Laukkanen et al. (2004) noted that the approval limit defining issue of MA is worth further studies. It is questionable if the use of median or mean values as approval limits fully answer the purpose of practical decision making. For this reason, it could be studied in the future, if a forest owner or decision-maker could define a true approval limit by himself/herself as a threshold value separately for each criterion, in which case the limit would better fit to the utility value of a criterion, and the definition would not be sensitive to the set of alternatives considered. Another possibility would be the use of fuzzy logic approach in defining approval limits.

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References

d'Angelo, A., Eskandari, A. & Szidarovsky, F. 1998. Social choice procedures in water-resource management. Journal of Environmental Management 52: 203–210.

Arrow, K.J. 1951. Social choice and individual values. John Wiley and Sons, Inc., New York. 124 p.

Belton, V. & Stewart, T. 2002. Muliple criteria decision analysis: an integrated approach. Kluwer Academic, Dordrecht. 372 p.

Beroggi, G. 1999. Decision modeling in policy management: an introduction to the analytic concepts. Kluwer Academic Publishers, Boston.

de Borda, J-C. l78l. Mémoire sur les élections au scrutin. Histoire de l'Académie Royale des Sciences, Paris.

Brams, S.J. 1988. MAA elections produce decisive winners. Focus: The Newsletter of the Mathematical Association of America 8: 1–2.

— & Fishburn, P.C. 1978. Approval voting. American

Political Science Review 72: 831–847.
— & Fishburn, P.C. 1983. Approval voting. Birkhäuser, Boston. 198 p.
— & Fishburn, P.C. l988. Does approval voting elect the lowest common denominator? PS: Political Science & Politics 2l: 277–284.
— & Fishburn, P.C. 1991. Alternative voting systems. In: Maisel, L.S. (ed.). Political parties and elections in the United States: an encyclopedia. Vol. 1. Garland, New York. p. 23–31.
Foran, B. & Wardle, K. 1995. Transitions in land-use and the problems of planning – a case-study from the mountainlands of New Zealand. Journal of Environmental Management 43: 97–127.
Fraser, N.M. & Hauge, J.W. 1998. Multicriteria approval: application of approval voting concepts to MCDM problems. Journal of Multi-Criteria Decision Analysis 7: 263–272.
Harstela, P. 1996. Forest work science and technology. Part II. Silva Carelica 31. 175 p.
Kangas, A., Kangas, J. & Pykäläinen, J. 2001. Outranking methods as tools in strategic natural resources planning. Silva Fennica 35(2): 215–227.
— , Laukkanen, S. & Kangas, J. 2005. Social choice theory and its applications in sustainable forest management – a review. Forest Policy and Economics. Accepted.
Kangas, J. 1992. Metsikön uudistamisketjun valinta – monitavoitteisen hyötyteoriaan perustuva päätösanalyysimalli. Summary: Choosing the regeneration chain in a forest stand: a decision analysis model based on multiattribute utility theory. University of Joensuu, Publications in Sciences 24. 230 p.
— & Kangas, A. 2002. Multiple criteria decision support methods in forest management. An overview and comparative analyses. In: Pukkala, T. (ed.). Multi-objective forest planning. Kluwer Academic Publishers. Managing Forest Ecosystems 6. p. 37–70.
Keeney, R.L. 1992. Value-focused thinking. A path to creative decision making. Harvard University Press, Cambridge. 416 p.
Kelly, J.S. 1988. Social choice theory. Springer-Verlag, New York. 163 p.
Kuitto, P-J., Keskinen, S., Lindroos, J., Oijala, T., Rajamäki, J., Räsänen, T. & Terävä, J. 1994. Puutavaran koneellinen hakkuu ja metsäkuljetus. Summary: Mechanized cutting and forest haulage. Metsätehon tiedotus 410. (Metsäteho Report 410). 38 p.
Laukkanen, S., Kangas, A. & Kangas, J. 2002. Applying voting theory in natural resource management: a case of multiple-criteria group decision support. Journal of Environmental Management 64: 127–137.
— , Palander, T. & Kangas, J. 2004. Applying voting theory in participatory decision support for sustainable timber-harvesting. Canadian Journal of Forest Research 34(7): 1511–1524.
Martin, W.E., Shields, D.J., Tolwinski, B. & Kent, B. 1996. An application of social choice theory to U.S.D.A. Forest Service decision making. Journal of Policy Modeling 18(6): 603–621.
Meister, D. & Fraser, N.M. 1995. The ordinal deductive selection system for multicriteria decision-making. Unpublished paper. University of Waterloo, Waterloo, Ontario, Canada.
Metsäalan työehtosopimus. 2001. Maaseudun työnantajaliitto, Metsähallitus, Metsäteollisuus ry, Yksityismetsätalouden Työnantajat, Puu- ja erityisalojen liitto.
Mikkonen, E. 1983. The usefulness of some techniques of the mathematical programming as a tool for the choice of timber harvesting system. Acta Forestalia Fennica. 183. 110 p.
Mutka, M. 2001. Harvennushakkuiden korjuujälki Karjalan tasavallassa Sortavalan ja Pitkärannan metsäpiireissä vuosina 1989–1994. Master's thesis. University of Joensuu, Faculty of Forestry.
Palander, T. 1998. Tactical models of wood-procurement teams for geographically decentralized group decision-making. D.Sc. (Agr. and For.) thesis. University of Joensuu, Faculty of Forestry, Academic Dissertation. 75 p.
— , Toivonen, M. & Laukkanen, S. 2002. Groupware and group decision support systems for wood procurement organisation. A review. Silva Fennica 36(2): 585–600.
Pukkala, T. 2001. Monikäytön suunnitteluohjelmisto MONSU. Ohjelmiston toiminta ja käyttö. (MONSU forest-planning software. Operation and use of the software.) Hand-out. University of Joensuu. 75 p.
Reilly, B. 2002. Social choice in the south seas: electoral innovations and the Borda count in the Pacific Island countries. International Political Science Review 23: 355–372.
Ryynänen, S. 2001. Harvennusharvestereiden tuottavuus ja kustannukset. Työtehoseuran julkaisu 381. (TTS-institute's publication 381). 67 p.
Saari, D.G. & van Newenhizen, J. 1987. The problem of

indeterminancy in approval, multiple, and truncated voting systems. Public choice 59: 101–120.

Shields, D., Tolwinski, B. & Kent, B.M. 1999. Models for conflict resolution in ecosystem management. Socio-Economic Planning Sciences 33(l): 61–84.

Sirén, M. & Aaltio, H. 2001. Seurantatutkimus. In: Kärhä, K. (ed.). Harvennuspuun koneelliset korjuuvaihtoehdot. Harko-projektin (1999–2001) loppuraportti. Summary: Alternative harvesting systems in mechanized thinning. Final report of Harko project (1999–2001). Työtehoseuran julkaisuja 382: 49–52. (TTS-institute's publications 382: 49–52).

Straffin, P.D. 1980. Topics in the theory of voting. Birkhäuser, Boston.

Valkonen, J. 1986. Tuottavuus ja työpanos maatilan metsätöissä. Työtehoseuran metsätiedote 407. (TTS-institute's forestry bulletin 407).

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Appendix 1. MA version 1 with median criterion values as approval limits. Individual forest owner MA analyses were combined by totalling the votes of individual analyses for each alternative.

	Votes of forest owner 1	Votes of forest owner 2	Votes of forest owner 3	Total of all votes
A1	12	9	9	30
A2	12	9	9	30
A3	12	9	9	30
A4	12	9	9	30
A5	9	5	6	20
A6	9	5	6	20
A7	12	9	9	30
A8	15	15	15	45
A9	12	9	9	30
A10	13	10	11	34
A11	9	5	6	20
A12	10	6	8	24
A13	9	11	8	28
A14	10	12	10	32
A15	5	9	7	21
A16	6	10	9	25
A17	2	5	4	11
A18	7	8	7	22
A19	5	9	7	21
A20	6	10	9	25
A21	3	4	3	10
A22	6	10	9	25
A23	2	5	4	11
A24	3	6	6	15
A25	4	5	5	14
A26	6	10	9	25
A27	9	8	10	27
A28	11	13	14	38
A29	6	4	7	17
A30	8	9	11	28

Appendix 2. MA version 1 with mean criterion values as approval limits. Individual forest owner MA analyses were combined by totalling the votes of individual analyses for each alternative.

	Votes of forest owner 1	Votes of forest owner 2	Votes of forest owner 3	Total of all votes
A1	12	9	9	30
A2	12	9	9	30
A3	9	5	6	20
A4	9	5	6	20
A5	9	5	6	20
A6	9	5	6	20
A7	12	9	9	30
A8	15	15	15	45
A9	9	5	6	20
A10	10	6	8	24
A11	9	5	6	20
A12	10	6	8	24
A13	5	9	7	21
A14	6	10	9	25
A15	2	5	4	11
A16	3	6	6	15
A17	2	5	4	11
A18	3	6	6	15
A19	5	9	7	21
A20	6	10	9	25
A21	0	0	0	0
A22	3	6	6	15
A23	2	5	4	11
A24	3	6	6	15
A25	4	5	5	14
A26	6	10	9	25
A27	6	4	7	17
A28	8	9	11	28
A29	6	4	7	17
A30	8	9	11	28