ASSESSING FOREST VALUE WITH THE EIGENVECTOR METHOD

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Abstract

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The objective of this paper is to test the possibility of applying multi-criteria programming as a decision-making tool for assessing the value of a management unit. A combined calculation method was used to determine the total value of the growing stock, forestland, non-wood forest functions, game management, forest roads and secondary forest products for the Management Unit "Gaj", Forest Office Našice. The proposed mathematical model can also be used to support an optimal decision-making process in forest management. Saaty's eigenvector method (AHP) was used. This method allows for the inclusion of a large set of complex factors influencing the basic evaluation purpose. The development of computer technology has played an important role in solving mathematical modelling problems by making it possible to develop and apply operational research. Expert Choice and Statistica 6.0 programmes were used. This paper is a contribution to the already broadly used modern methods of evaluating renewable natural resources and establishing scientific foundations for a suitable method of determining forest value.

Key words: dynamic model, total value, eigenvector method, forestry, economics

Introduction

Models are abstract images of the real world that help contemplate, predict and make decisions. Models may be intuitive, or they may be substantiated by experience and information. Forestry often makes use of mathematical models. It is important to take account of the prerequisites required by a model. They are never completely fulfilled. Experience helps us to evaluate the extent of digression from requirements. Models are not permanently valid. Experience with models and new theoretical concepts force us to change and improve models in the course of their usage. The problems of forest management involve a variety of different variables (Kangas, 1993, Mendoza et al., 1999). They may be biological, such as growth and increment, type of soil; economic, such as the price of timber and labour costs; and social, such as ecological laws. All these variables and their interrelations make up a system. The complexity of forestry systems makes predicting the consequences of the taken decisions a difficult task. This is where models come in use. A forest management programme follows the principle of forest production sustainability (Brang et al., 2002). With regard to quantitative goals, a management model may be established using mathematical programming methods. Nevertheless, it is often impossible to measure and express all forest functions in monetary terms (Šegotić, 1998).

Traditional techniques of evaluating market goods cannot be applied to evaluate environmental goods. Traditional methods rely on observing marketing households behaviour in the goods market and on the assessment of their demand function. Such evaluation cannot be made for environmental goods because they are not exchanged on the market. Environmental goods are called collective consumer goods or public goods. These goods are characterised by two distinct properties: non-rivalry of consumption and impossibility of exclusion. Non-rivalry means that several people can use the same unit of a public good at the same time without interfering with one another. The impossibility of excluding somebody means that a person cannot be excluded from consuming a public good – at least not at acceptable costs (Ahlheim, 2002).

Traditional methods generally deal with the value of a stand and the value of the first age class, whereas modern methods focus on ecological, tourist and social forest values. The total economic value method embraces the highest number of parameters, but it is precisely this method that has more theoretical than practical application.

So far, several methods have been described in literature that attempt to assess forest value in different ways (Russel, 2001).

Material and methods

The basic objectives of this paper are to set up a scientific approach to evaluating a forest resource and establish a model applicable in practice. Research was conducted in the Management Unit Gaj. This management unit is located in the Forest Office Našice. The forests in this management unit were managed with the high forest method using the shelterwood and clearcutting system. In the clearcutting systems, the clearcut areas were reforested and restocked with oak acorns or seedlings. The area covering the analysed polygon is dominated by beech forests and sessile oak forests. Alder forests have initially developed in the valleys and abandoned meadows. Beech grows mostly on northern slopes and prevails in higher regions, but in valleys and ditches it descends much lower into the belt of sessile-hornbeam forests. According to the present age class distribution, it can be concluded that large-scale felling operations were performed in the period from 1900 to 1920.

The parameters needed for forest value assessment were evaluated on the example of MU Gaj. Not all parameters have equal weight. For the growing stock above the first age class, a method of current cutting value was used. According to the Regulations of the company "Hrvatske Šume" Zagreb, the value of the growing stock is assessed with this method on the basis of the growing stock value, under the assumption that all growing stock is cut, turned into assortments and sold at average prices realised in the fiscal year, depreciated by exploitation costs.

The value of forestland is determined on the basis of revenue that may be expected from the soil, as well as the selling value in concrete sales. The coefficients for calculating the cadastre revenue were determined according to the data of Orahovica Land Registry District. Depending on the cadastre revenue in Eur/m^2, individual cultures were classified into 8 classes – categories. This management unit was placed into the sixth, seventh and eight categories per cadastre municipalities. According to the data of Našice Forest Office, the average value of a kilometre of forest road is 47.950 Euro (1 Euro = 7.3 hrk). This value includes project costs, construction and maintenance of forest roads. There are a total of 32.05 km of forest roads in this management unit.

According to the data of the analysed management unit, investments (apart from the roads) were made in furnishing a mountaineer chalet situated in this management unit. The management unit is dominated by the management class of sessile oak seed forests and beech seed forests. Accordingly, sessile oak and beech are dominant management species in this polygon.

Revenue from game management also participates in the overall stand value. One-year harvest was assessed on the basis of hunting-productive areas in the management unit. Calculation includes the value of hunting amenities, as well as the costs of game nutrition and supplementary food. All the prices were taken from the currently valid pricelist of the company "Hrvatske Šume" Zagreb.

Mushrooms, blackberries, raspberries, rose hips and elderberries can be gathered for personal use by permission of the Forestry Office. Grazing and allowing cattle to feed with acorns are banned.

The law on water management financing regulates that all forest and forestland users pay water protection fee. Pursuant to this regulation, the Government of the Republic of Croatia prescribes the minimal fee rate or the amount for different categories. A certain forest creates favourable conditions for this function, although its utilisation largely depends on the accessibility of a forest, or its proximity to larger settlements. According to the method by Prpić (1992), the value of non-wood forest functions has been determined as set down in the Regulation (NN/121/97).

Our earlier papers contain the following formula (Posavec, 2001):

$$Vf = Vgs + Vl + Vsbr + Vebr + Vsfp + Vh + Vg + Va + Vi + Vnwff + species \quad (1)$$

where:
Vf = total forest value
Vgs = value of growing stock
Vl = land value
Vsbr = value of simple biological reproduction
Vebr = value of extended biological reproduction
Vsfp = value of secondary forest products
Vh = hydrological value
Vg = value of game management
Va = value of amenities (depreciated)
Vi = investment value
Vnwff = value of non-wood forest functions
Species = dominant management species

Considering that all the mentioned parameters in the formula (1) do not have equal weight, the following formula will be used:

$$V_f = (w_1\, v_{gs}) + (w_2\, v_l) + (w_3\, v_{sbr}) + (w_4\, v_{ebr}) + (w_5\, v_{sfp}) + (w_6\, v_h) + (w_7\, v_g) + (w_8 v_a) + (w_9 v_i) + (w_{10}\, v_{nwf}) + (w_{11}\ \text{species}) \quad (2)$$

where w_1, i=1, …11, are weights of individual parameters. These weights were determined with the eigenvector method. The eigenvector method was one of the first methods to have introduced the concept of input data inconsistency. AHP is a mathematical method that analyses complex issues of multiple criteria decision- making (Saaty, 1980; Čaklović et al, 2001). In essence, AHP is a general theory of real (ratio) scale measurement based on mathematical and psychological foundations. Preference function parameters are estimated on the basis of joint comparisons made by decision makers, according to the importance and desirability of decision-making elements included in the function. In using AHP, differences in the measuring scales and units do not matter since the method is based on pure comparisons of meaning and preference of each pair of decision elements without using physical units. AHP addresses both qualitative and quantitative features. The AHP method is supported by the Expert Choice programme developed by Ernest H. Forman and Thomas L. Saaty. Expert Choice represents an important contribution to the decision theory. It helps a decision maker examine and resolve problems involving multiple evaluation criteria. It was designed to model our way of thought. We create a model, we make a judgement, we make a decision – Expert Choice only facilitates the decision-making process. An important feature of this programme is that it performs sensitivity analyses; in other words, it provides an answer to the issue of how sensitive the priorities of an alternative are in relation to the changes made in the criterion weight.

The eigenvector method has an intuitive explanation in the sense that it averages all possible ways of thought on a given set of criteria and alternatives. This makes the eigenvector method a natural method of calculating weights.

If we have a preference matrix *A* and we want to obtain the weight vector *w*, we must solve the system:

$$(A - nI)\ w = 0,\ n = \text{number of criteria.}$$

This is a linear system of equations that has a nontrivial solution if det (A – nI) = 0, which means that: if, and only if n is an eigenvalue of matrix A, w is then an eigenvector of matrix A. The rank of matrix A is 1; consequently, all eigenvalues, except one, equal to zero. Weights w1, i = 1, 2, …, n are calculated by solving the system

$$(A - nI)\ w = 0 \quad \sum_{i=1}^{n} w_i = 1.$$

Inconsistencies in judgements must almost always be taken into consideration. It may turn out that for a positive reciprocal matrix, small coefficient perturbations cause small perturbations of eigenvalues, as shown by the Perron-Frobenius theorem. For this reason the eigenvector is insensitive to small changes in assessments and is stable. It is also known that a matrix with positive elements has a real positive eigenvalue, whose module transgresses the module of all other eigenvalues. The relevant eigenvector has *nonnegative* elements; when normalised, it is a unit vector. The eigenvector method uses a preference matrix as input data and bases the rank procedure on the Perron theorem (Saaty, 1980).

Research results

The AHP model for this case has a very simple structure (according to Fig. 1). The alternatives are all the parameters used to calculate the total forest value. The eigenvector method is used to arrive at their weights.

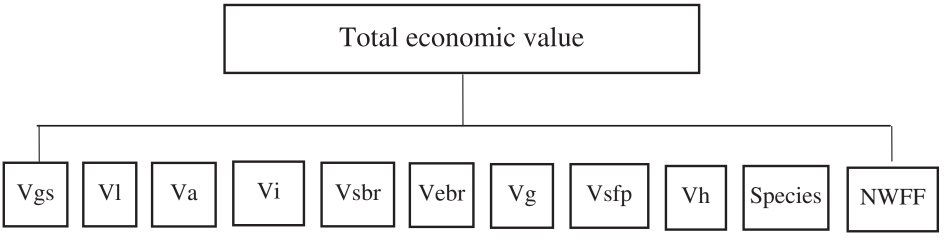
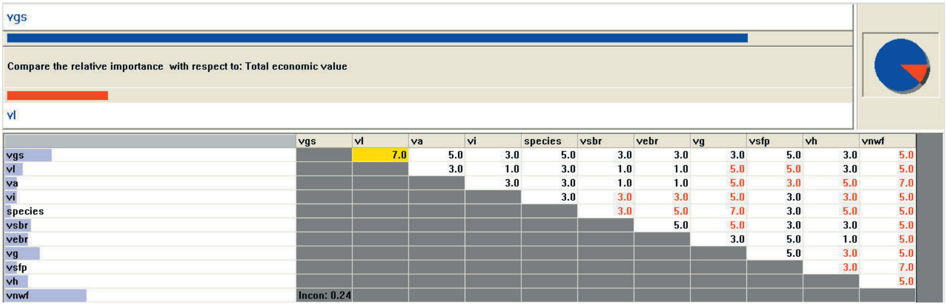


Fig. 1. The AHP model of total economic value calculation.

Weights were calculated on the basis of expert estimates. The experts made pairwise comparisons of all the given parameters. Six experts were questioned and their estimates are presented in Fig. 2.



	vgs	vl	va	vi	species	vsbr	vebr	vg	vsfp	vh	vnwf
vgs		7.0	5.0	3.0	5.0	3.0	3.0	3.0	5.0	3.0	5.0
vl			3.0	1.0	3.0	1.0	1.0	5.0	5.0	3.0	5.0
va				3.0	3.0	1.0	1.0	5.0	3.0	5.0	7.0
vi					3.0	3.0	3.0	5.0	3.0	3.0	5.0
species						3.0	5.0	7.0	3.0	5.0	5.0
vsbr							5.0	5.0	3.0	3.0	5.0
vebr								3.0	5.0	1.0	5.0
vg									5.0	3.0	5.0
vsfp										3.0	7.0
vh											5.0
vnwf	Incon: 0.24										

Fig. 2. Preference matrix (expert: Posavec).

Accordingly, the value of the number 7 in the matrix, in relation to the value of the growing stock (gsv) and the value of land (lv), indicates that the value of the growing stock is strictly preferred to the value of land in the calculation of the total forest value. The numbers shown in the red value in Figure 16 denote parameter preferences from the upper matrix order.

Six experts were surveyed. One of them was more inconsistent, so his estimates were rejected. Saaty recommends that the consistency coefficient be $CR \leq 0.1$. The consistency coefficient $CR < 0.25$ was taken for the needs of this analysis. Five rank lists with parameter weights for forest value calculation were made with the Expert Choice programme.

The following table shows all five expert rank lists, as well as the calculated geometrical and arithmetic mean of parameter weights.

Taking into consideration the arithmetic mean of the parameters for forest value calculation, the result shown in Fig. 3 was obtained.

According to the Figure, the highest value was achieved by the parameter of growing stock (vgs), followed by non-wood forest functions (vnwff) and then simple biological reproduction (sbr).

By inserting the values of arithmetic means in the previously established formula, the total value of this management unit would be:

$$Vf = (w_1\ v_{gs})+(w_2\ v_l)+(\ w_3 v_{sbr})+ (w_4\ v_{ebr})+ (w_5 v_{sfp})+ (w_6 v_h)+ (w_7\ v_g)+ (w_8 v_a)+ (w_9 v_i)+ (w_{10}\ v_{nwf})+ (w_{11}\ species) =$$

= (0.204x3.364.657,53)+(0.099x30.399,22) + (0.115x31.918,84) + (0.063x0.00) + (0.043x8.178,08) + (0.044x4.515,38) + (0.081x13.232,59) + (0.035x1.528.416,85) + (0.035x294.931,23) + (0.183x48.908.904,11) +0.098x12.328,77) = 686.390,14 + 3.009,52 + 3.670,67 + 0,00 + 351,66 + 198,68 + 1.071,84 + 53.494,59 + 10.322,59 + 8.950.329,45 + 1.208,22 = 9.710.047,36 Euro.

The obtained sum is multiplied with the number of parameters (n), resulting in the final value

Vf = 9.710.047, 36 x 11 = 106.810.520, 92 Euro**.**

The values vf, vgs, vl, vsbr, vsfp, vh, Vg, vnwf and va were inserted from the calculations for the analysed management unit made earlier. Identical to the previous model, the value Vebr was not included since no activities of extended biological reproduction were planned or performed in this polygon (Posavec, 2001).

T a b l e 1. Expert rank list.

Parameters	Person1	Person2	Person3	Person4	Person5	Geom. mean gm	Arithm. mean AM
vgs	0.232	0.107	0.160	0.314	0.208	**0.192**	**0.204**
vl	0.080	0.107	0.055	0.150	0.103	**0.094**	**0.099**
va	0.039	0.033	0.036	0.046	0.021	**0.034**	**0.035**
vi	0.036	0.025	0.036	0.058	0.018	**0.032**	**0.035**
species	0.089	0.089	0.025	0.157	0.131	**0.084**	**0.098**
vsbr	0.134	0.240	0.087	0.052	0.062	**0.098**	**0.115**
vebr	0.040	0.022	0.081	0.095	0.076	**0.055**	**0.063**
vgame	0.027	0.189	0.119	0.045	0.025	**0.058**	**0.081**
vsfp	0.067	0.065	0.042	0.014	0.028	**0.037**	**0.043**
vh	0.041	0.040	0.083	0.023	0.034	**0.040**	**0.044**
nwff	0.216	0.083	0.277	0.047	0.293	**0.147**	**0.183**
Total						0.871	1.000

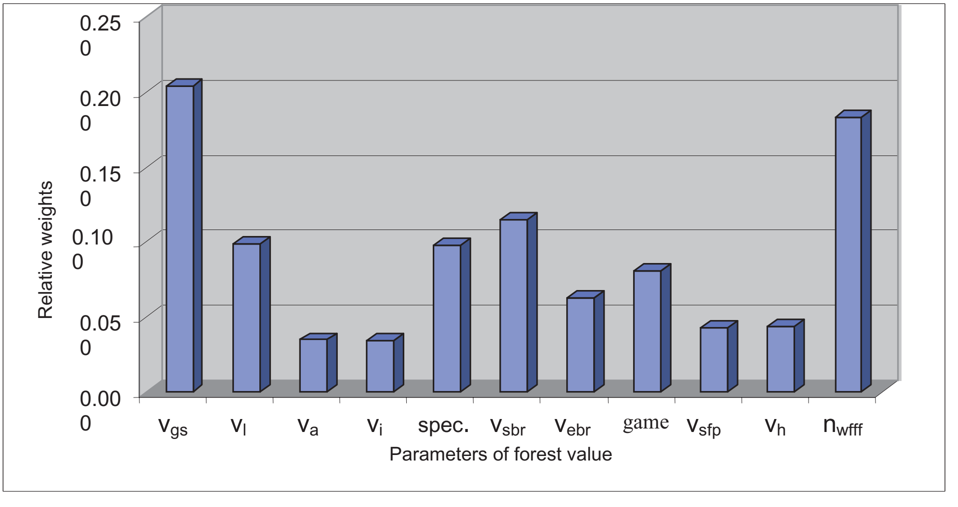


Fig. 3. Parameter weights obtained with the eigenvector method.

The value of investments Vi was included in the analysis according to the management plan form ŠGO-14, item Investment in Equipment. The investment value relates to furnishing the chalet situated in this management unit.

The value of the dominant management species was taken according to the point values of destroyed or decreased non-wood forest functions, Table NWFF-1 (Regulation NN121/97).

Expert estimates based on the impact of the dominant managed species on the stand condition, composition mix, silvicultural form, age, developmental stage, origin, and canopy in the observed polygon were completed with grade 15, which is worth 90.000 points (pursuant to the Regulation NN 121/97).

The figure below shows the sum of ranks of the analysed respondent group.

Forest value

members				
Bozic	**Krapinec**	**Barcic**	**Sporcic**	**Posavec**
0.200	0.200	0.200	0.200	0.200

showWeights: **groupAim** base = 2 Options = weight + weight

Level **2: alternatives**

Comp_1 Weight = 1.000 InvInc = 0.582 (Angle = 30.19 deg)

Nodes:

nwff	0.160	(X=0.945)
vgs	0.156	(X=0.909)
vsbr	0.118	(X=0.509)
vl	0.108	(X=0.382)
species	0.095	(X=0.200)
game	0.084	(X=0.018)
vebr	0.074	(X=-0.164)
hv	0.056	(X=-0.564)
vsfp	0.054	(X=-0.618)
va	0.049	(X=-0.764)
vi	0.046	(X=-0.855)

Total weight=1.00

Fig. 4. Group parameter ranking using the eigenvector method.

The most important factor in the group decision relates to measuring mutual distances among group members in the sense of differences in individual preferences. The obtained distances make up a distance matrix that was used as a basis for group clustering. Distance matrix and cluster results are given in the dendogram below (Fig. 5).

According to the above dendogram, Božić and Posavec, and Krapinec and Barčić made similar estimates. The answers by Šporčić excluded him from these groups, although he approached the Krapinec-Barčić group.

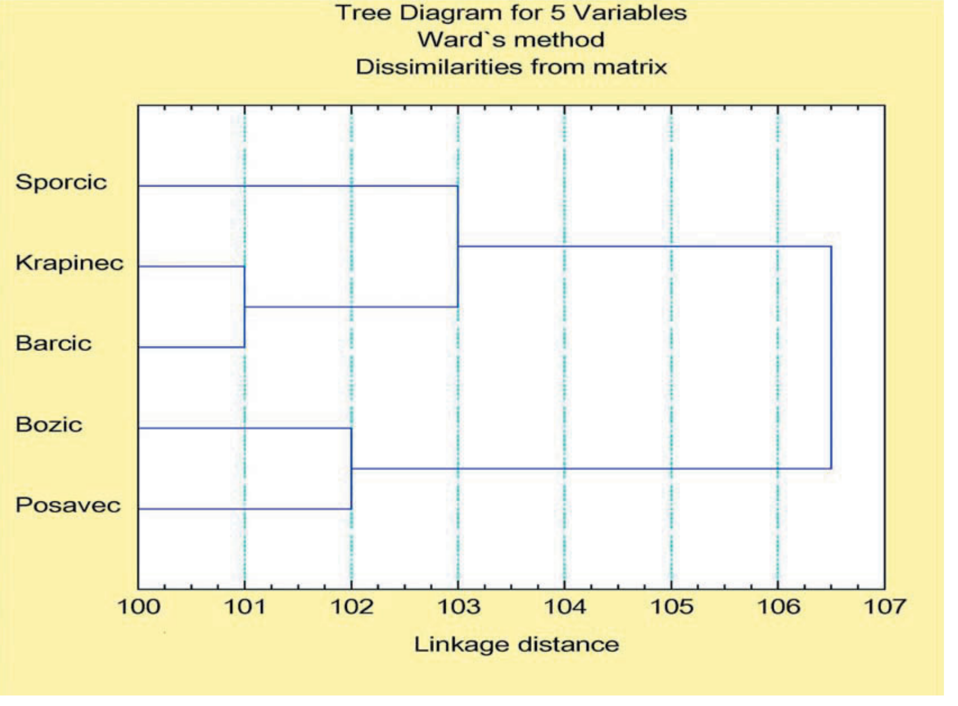


Fig. 5. Cluster analysis of expert evaluation using the eigenvector method (of the AHP model).

Discussion and conclusion

According to the cluster analysis graph, there are no distinct dissimilarities in the estimates of pairwise priorities among group members. In fact, individual estimates of group members do not conflict profoundly. Clustering was performed with the software Statistica 6.0. If there are additional demands for the given ranks (or a feeling for forest value), a given rank may be adjusted to the outlined reasons. Also, a special programme may calculate the total forest value independently.

Characteristically, according to the eigenvector method, the surveyed experts rank the parameters of non-wood forest value, the growing stock value and the simple biological reproduction value among the three first in terms of importance. This indicates awareness by the forestry profession of these functions although no exact evaluating method has been established yet. Expert opinions are also dependent on both knowledge and experience of those surveyed, as well as on the current understanding of the problems and preferences towards a field. Naturally, thorough knowledge of techniques of selecting relevant parameters included in decision-making is necessary. A model may reveal certain illogic features, which may have been hidden through time. The quality of the results obtained with model processing cannot be better than the quality of input information. Model dynamics is expressed in the possibility of its application in different polygons and in a change of parameters in dependence of a stand. The solution achieved with methods and computers is primarily a formal answer to the question asked through a model. In mathematical models, answers are obtained with well-defined optimization methods.

Proper forest management belongs to a sphere of global problem solution related to energy, resources and quality of life. Analyses of past methods and models that deal with forest value assessment have shown that the proposed method of forest value assessment is better than the applied conventional methods. In Croatian forestry, the value of a given management unit has not yet been determined with the proposed method. The proposed method unifies positive efforts of past methods and establishes a new model of calculating the total forest value. The application of new mathematical multiple criteria analysis models requires the knowledge and use of new technologies that help assess natural resources in a better and more qualitative way. The proposed model should be further tested and valued in different polygons, while its gradual improvement should result in an acceptable method of forest value assessment in Croatia. This is a guideline for further research in this field in time to come, in which the value of a forest will increasingly be under public scrutiny.

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