Combining AHP and Smarter in Forestry Decision Making

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Abstract

This paper describes the process of identifying the most multi-functional forest stand using the multi-criteria methods of analytic hierarchy process (AHP) and simple multi-attribute rating technique exploiting ranks (SMARTER) with the loss function approach (LFA) as the aggregation method. The procedure was demonstrated on four stands in Rila Monastery forest (Bulgaria) and involved forestry experts, who had not previously been acquainted with multi-criteria (MC) methodologies. The selection of an appropriate decision support method was therefore crucial. AHP and SMARTER are shown to be convenient methods for this analysis, and a ranking of forest stands is provided at the end of the decision-making process. However, this paper also discusses other possibilities of combining MC methods in making forestry decisions. A combination of different methods establishes a more flexible environment to work in, especially when decision makers come from differing backgrounds or have more or less advanced experience with MC methods.

Keywords: Forestry decision-making; AHP; SMARTER; Rila Monastery forest.

Introduction

Making environmental decisions is "one of the most imposing challenges to policy makers, scientists and stakeholders", closely associated with economic, social, cultural and other concerns (Kellon and Arvai 2011). Environmental decisions should encompass different management goals (Álvarez-Miranda et al. 2017) and consider values and preferences of various stakeholder groups (Martinez-Harms et al. 2015). These are one of the reasons why using the multi-criteria (MC) methodologies has therefore become almost inevitable and constant. For example, Diaz-Balteiro and Romero (2008) have reported more than 200 publications using MC methods to solve diverse forestry issues. MC methods involve high-quality decision support tools, the most important of which are: (1) based on multi-attribute utility functions, such as SMART, its extended version SMARTER, AHP, ANP, TOPSIS etc.; and (2) outranking methods such as PROMETHEE and ELECTRE.

Those models are particularly suited to discrete problems, i.e. problems where the number of alternatives is limited. For continuous problems with an infinite number of possible alternatives, other methods have been developed, such as linear programming and its versions integer programming and goal programming.

In addition, there are some "hybrid" models that merge several existing models, for example SWOT (A'WOT, which integrates the AHP method with SWOT analysis (Kurttila et al. 2000), and methods developed to deal with so-called probabilistic uncertainty, such as stochastic multi-criteria acceptability analysis (SMAA) and its upgraded version SMAA-O (Lahdelma and Salminen 2001).

Those models can be difficult to understand for ordinary decision makers, and a moderator of the decision-making process therefore needs to be careful when selecting an MC method to be applied. In this research, the AHP and SMARTER methods were selected as the most convenient, based on decision makers' preferences after other MC methods were offered and briefly explained. AHP is one of the most commonly applied decision support tools while SMARTER has been neglected in comparison to other techniques. It should be noted that both AHP and SMART form an integral part of the Ecosystem Management Decision-Support (EMDS) System, the most comprehensive and productive model for diverse types of ecological analysis developed by the US Department of Agriculture (Reynolds 2014). This is a further proof that both of these methods deserve more intensive application in forestry planning and management.

This research shows a possible procedure of combining AHP and SMARTER in forestry decision making and is supported with a case study example from Rila Monastery forest in Bulgaria. Rila Monastery forest is a Nature Park and belongs to Natura 2000 network, and for that reason, biodiversity protection is set up as one of the crucial management goals. Simultaneously, one part of the forest is expected to provide incomes by timber production for its owner, Rila monastery under patrimony of Bulgarian Orthodox Church. Part of the forest (especially the one bordering asphalt or stabilized forest roads) is subjected to intense human pressure by tourists coming for picnics in the forests, religious visitors and local people. In addition to that, there is an intense pressure on the area caused by livestock, vehicles and similar disturbances. Thus, achievement of forest multi-functionality is crucial for this area. Many conflicting requirements have to be fulfilled at the same time and that makes a common frame for applying MC methodologies.

The aim of the current research was to identify the most multi-functional forest stand among four stands in Rila Monastery forest by involvement of forestry experts who had not previously been acquainted with MC methodologies.

It should be noted that there are other methods for assessing characteristics and services of a forest ecosystem, for instance timber production, recreation potential etc. (e.g. Grilli et al. 2015). This paper offers an assessment of forest stands from a different perspective, by taking into account decision makers' knowledge and expertise. The proposed procedure is used for general assessment of forest stands in a group decision-making context. Future research might be additionally supported by data derived from empirical forest models, for example Samsara2 (Courbaud et al. 2015).

Methods

This research involved three decision makers, each holding a PhD in forestry sciences but without previous experience with MC methodologies. One of the decision makers is a chief manager of Rila monastery forest (third author of the paper) and he did the assessments for the entire hierarchy of the decision-making problem. The other two decision makers are forest managers working in Serbia, and their task in here was to evaluate the criteria set. These decision makers evaluated criteria set applying the AHP method, and their evaluations were merged into a group decision, in accordance with a loss function approach. Following this, the chief manager of Rila Monastery forest, evaluated forest stands by applying the SMARTER technique with the rank exponent rule. The outputs of the evaluation of these criteria and alternative (forest stand) sets were put together, providing the final results. Each of the methods used in this research are described in the following sections.

The Analytic Hierarchy Process (AHP)

AHP (Saaty 1980) is a multi-criteria decision support method which aids a decision maker *"in facing a complex problem with multiple conflicting and subjective criteria"* (Ishizaka and Labib 2011). At the beginning of the AHP process, it is necessary to develop a hierarchy of the problem with the following structure: the goal, which is placed at the top; the criteria, which are situated at the next level down; and alternatives, which are placed at the bottom. Decision elements at the same level are mutually compared (head to head) with respect to the corresponding superior elements. There are several scales that enable comparisons in AHP, but Saaty's scale of relative importance is the most commonly applied of these (Table 1).

Table 1. Saaty's relative importance scale

Definition	Assigned value
Equally important	1
Weak importance	3
Strong importance	5
Demonstrated importance	7
Absolute importance	9
Intermediate values	2,4,6,8

AHP requires the creation of so-called comparison matrices. A comparison matrix is formed as follows: numerical expressions of pair-wise comparisons (Table 1) are placed in the upper triangle of the matrix; values of 1 are placed on the main diagonal, while the lower triangle contains reciprocals of the values in the upper triangle and these numbers are placed symmetrically to the main diagonal.

From these matrices of comparison, the local weights of elements (represented as cardinal values) can be computed, and there are several methods for making this possible: the additive normalization method, the eigenvector method, the weighted least-squares method, the logarithmic least-squares method, logarithmic goal programming and fuzzy preference programming (Srdjevic 2005). In addition, there are several heuristic techniques which can be applied for the same purpose, e.g. genetic algorithms, particle swarm optimization and an evolution strategy (Srdjevic and Srdjevic 2011). Analysis of the strengths and weaknesses of the each of these listed methods is ongoing. In this research, the eigenvector (EV) method (Saaty's original method) is used to calculate the weights, following the formula:

$$A\omega = \lambda\omega,\ e^T\omega = 1 \quad (1)$$

where ω is the priority vector and λ is the principal eigenvalue of matrix A.

In the AHP framework, it is possible to check the consistency of decision makers' evaluations, and for the EV method, the corresponding consistency parameter is the consistency ratio *(CR).* Saaty (1987) defined the consistency index *(CI)* as:

$$CI = (\lambda_{max} - n)/(n - 1) \quad (2)$$

where n is the number of elements in the comparison matrix, and λ_{max} is the maximum eigenvalue of the matrix.

Accordingly, the consistency ratio *(CR)* is defined as:

$$CR = CI/RI \quad (3)$$

where the random index *(RI)* is the mean of the *CI*s computed over hundreds of randomly generated matrices of the same size. According to Saaty (1980), if $CR<0.1$ the evaluation is considered acceptable. The later research has discussed the acceptable threshold value, and, according to Wedley (1993), if $0.1<CR<0.2$ the evaluation is considered as moderately consistent and still acceptable. Some real case study examples also confirmed $CR<0.2$ as a threshold value (e.g. Lakićević and Srđević 2012).

The Loss Function Approach (LFA)

This approach was proposed by Cho and Cho (2008) for making the AHP decision in a group context. LFA estimates the quality of an evaluation based on the consistency of performance, measured by the *CR* parameter. If the consistency of performance is high, the *CR* value is low and the evaluation quality is also expected to be high; conversely, high *CR* values correspond to a low-quality evaluation.

The process of estimating the evaluation quality consists of four steps. Initially, the mean consistency ratio $\overline{CR}$ and the deviation of the mean consistency ratio are computed for each decision maker involved:

$$\overline{CR} = \sum_{i=1}^{m} \frac{CR_i}{m}, \quad V_{CR} = \sum_{i=1}^{m} \frac{(CR_i - \overline{CR})^2}{(m-1)} \quad (4)$$

where CR_i is the consistency ratio for evaluator i ($i = 1,2,\ldots,m$).

In the next step, an expected loss estimate is calculated as:

$$X = E(L) = V_{CR} + (\overline{CR})^2 \quad (5)$$

The third step calculates the weights of the evaluation quality, using the functions presented in Figure 1 and Table 2.

For six elements (criteria) we have the research evaluation reliability function shown in Table 2.

Table 2. Evaluation reliability function

n	Evaluation reliability function		
6	$F(X) = 1$	$X=0$	(6)
	$F(X) = \exp(-10X)$	$0 < X < 0.3136$	
	$F(X) = 0$	$X \geq 0.3136$	

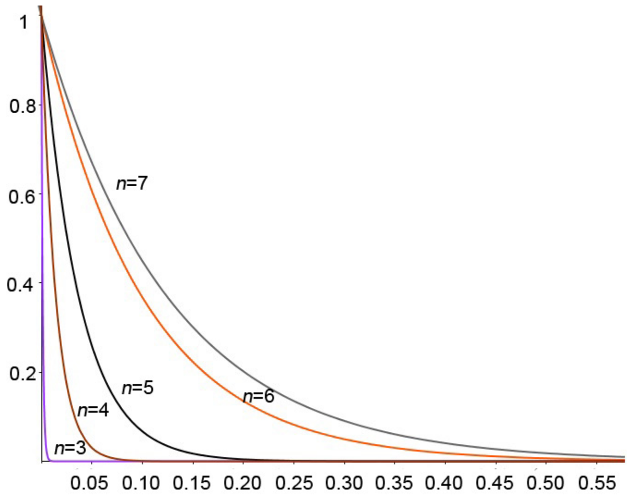

Figure 1. Evaluation reliability function (Cho and Cho 2008)

Finally, the weights of the criteria $C_i(LFA)$ are calculated as:

$$C_i(LFA) = \alpha \sum_{j=1}^{m} F(x_j)\, C_j \quad (7)$$

where C_j is the weight of a criterion calculated by applying the EV method for the m^{th} decision maker, $F(x_j)$ is a reliability function for the m^{th} decision maker's evaluations and α is a normalizing constant.

Simple Multi-Attribute Rating Technique Exploiting Ranks (SMARTER)

SMARTER (Edwards and Barron 1994) is an upgraded version of the SMART method. It requires a ranking of the elements according to their importance, and there are several techniques for calculating the weights of the elements based on this ranking. In this research, we used the rank exponent rule (RER), a technique which along with the ranking of elements includes a definition of the preference ratio between the first and bottom ranked element. The weights of elements are computed as follows:

$$\omega_j(RER) = (n+1-r_j)^z / \sum_{i=1}^{n} r_i^{\,z} \quad (8)$$

where n is the number of elements, r_j is the rank of the j^{th} element and z is a preference ratio between the top and bottom elements.

The value of z is calculated by following the rule:

$$\frac{a_j}{a_i} = \frac{(n+1-r_j)^z}{(n+1-r_i)^z} \quad (9)$$

where a_j/a_i is a ratio between the top and bottom elements, estimated by the decision maker.

If z is assigned the value 0, it means that all elements have equal weights. Figure 2 presents the weights of elements for various *z* values, for the example of the six elements considered.

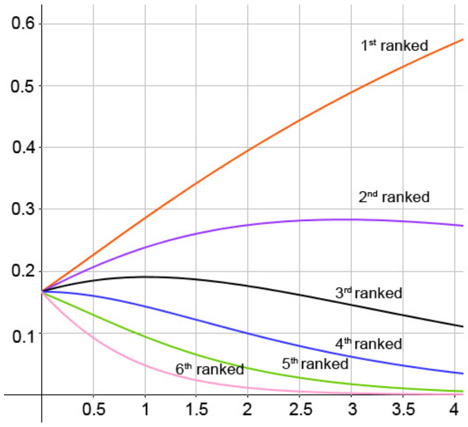

Figure 2. SMARTER with the rank exponent rule

In this research, the SMARTER method with the RER technique were used to calculate the weights of the alternatives. This procedure was selected by the decision maker as being most convenient (in comparison with AHP and other, more advanced MC methods) in this step of the evaluation process.

The weights of the alternatives obtained by applying the RER technique, $\omega_j(RER)$, were combined with the weights of the criteria calculated in a group context using AHP and LFA aggregation, $C_i(LFA)$. The final priorities of the alternatives, p_j, were calculated as follows:

$$p_j = \sum_j C_i(LFA)\omega_j(RER) \quad (10)$$

Case study description

Rila Monastery forest (Figure 3) belong to Rila Monastery ("Rilski manastir" in Bulgarian) and are managed by the monastery forest service. The forested area is approximately 13,400 ha. The forest service is a self-supporting subdivision of the monastery, and is responsible for the protection, management and maintenance of the forest. Rila monastery owns the neighboring forests since the 10th century and relies on regular income from its property. In 1986, 3700 ha of the forests area were declared a strict reserve and in the last two decades 97% of the forests were included within the boundaries of a nature park established in 2000 and into a Natura 2000 network zone established in 2007.

The nature park has its own administration, financed from the state budget, and this is responsible for the maintenance of the park infrastructure, monitoring of biodiversity etc. Due to its cultural heritage (being also a UNESCO site since 1983) the monastery and its forested surroundings are one of the most popular tourists' destinations in Bulgaria. Human impact over the area is significant and stakeholders differ in their expectations.

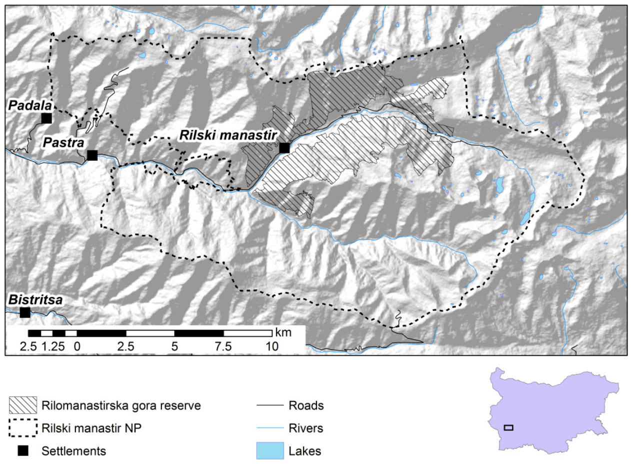

Figure 3. Rila Monastery Nature Park

In the current research, the objective was to identify the most multi-functional forest stand of the four stands analyzed. The decision-making problem was defined as a hierarchy with a goal, criteria and alternatives (forest stands), and is illustrated in Figure 4.

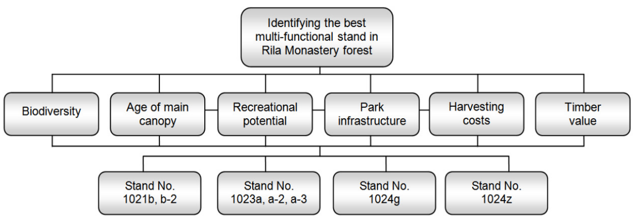

Figure 4. Hierarchy of the decision-making problem

The decision maker decided to apply the SMARTER technique for the evaluation of alternatives with respect to the criteria set, while AHP was applied by all three decision makers for the evaluation of the criteria set with respect to the goal. The selection of the MC method has been done by the decision makers, based on their personal opinion and preferences. This way it was ensured that a decision maker applied technique which fitted the best their preferred evaluation concept.

The following text will provide an insight into the hierarchy levels and elements presented in Figure 4.

Goal: Identify the best multi-functional stand in Rila Monastery forest (G).

Criteria set: biodiversity (C_1); age of main canopy (C_2); recreation potential (C_3); park infrastructure (C_4); harvesting costs (C_5); and timber value (C_6).

Alternatives set: forest stands were labeled as 1021b, b-2 (A_1), 1023a, a-2, a-3 (A_2), 1024g (A_3) and 1024z (A_4), presented in Figure 5. The labels were given according to the forest management plan enforced by the Bulgarian Executive Forest Agency in 2015.

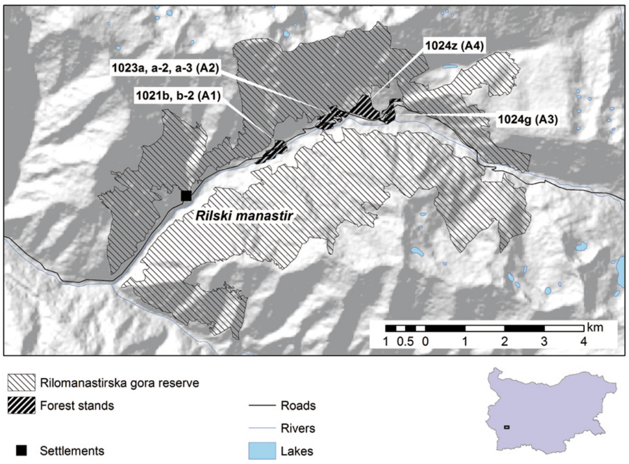

Figure 5. Forest stands, Rila Monastery, Bulgaria

The stands are situated next to asphalt roads, providing approachable access for tourists and harvesting teams. All stands are in a transitional phase between an even and uneven aged structure, and all have the potential to be successfully transformed into beech-coniferous forests managed using the single tree selection system.

A brief description of the basic characteristics of the stands is presented in Table 3.

Table 3. Brief description of the selected forest stands in Rila Monastery forest

Stand No.	Area [ha]	Altitude [m] a.s.l.	Species composition	Share of species [%]	Age of main canopy [years]	Growing stock [m^3/ha]
1021b, b-2	16.3	1250	European beech	100	160	224
1023a, a-2, a-3	23.4	1400	Silver fir	50	110	255
			Norway spruce	10	110	46
			Scots pine	10	110	34
			European beech	30	120	89
1024g	10.1	1450	Silver fir	70	170	336
			Norway spruce	20	170	100
			European beech	10	150	30
1024z	24.8	1500	European beech	70	80	165
			Silver fir	20	110	94
			Norway spruce	10	110	40

In order to provide a reference to similar research, one can analyze the examples provided by Kangas et al. (2015) and Kangas et al (2005). In the first listed research, forest management plans for the selected case study area in Finland were compared with respect to three criteria: net income, stumpage value and scenic beauty index. In the second paper, forest management plans were evaluated by taking into account: timber production, recreation and ecology as selection criteria. Therefore, the criteria used in this research are, to a certain extent, a merge of these two sets already presented in previously published papers.

Results

In the first step, the three decision makers evaluated the six criteria using AHP. That implied performing comparisons of criteria in pair-wise manner using Saaty's scale of importance (presented by Table 1). These evaluations are presented in Figure 6. Consistency ratios for each AHP matrix were calculated, as these represent one of the input data for a loss function approach.

DM_1	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	5	5	9	9	9
C_2		1	3	3	5	5
C_3			1	1	3	5
C_4				1	3	1/3
C_5					1	1/5
C_6						1
CR=0.144						

DM_2	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	2	8	8	1	1
C_2		1	4	4	1/4	1/4
C_3			1	1	1/5	1/5
C_4				1	1/7	1/7
C_5					1	1
C_6						1
CR=0.026						

DM_3	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	4	7	7	2	2
C_2		1	3	3	1/3	1/3
C_3			1	1	1/6	1/6
C_4				1	1	1/7
C_5					1	1
C_6						1
CR=0.078						

Figure 6. AHP evaluations of criteria and consistency ratios *(CR)*

A loss function approach was used to aggregate the individual AHP evaluations into a group evaluation. Based on the value of the *CR*, the quality of the decision makers' evaluations *F(x)* was estimated (Table 4).

Table 4. Evaluation quality using the loss function approach

DM	Mean	Deviation	Expected loss	*F(x)*
DM_1	0.083	0.001861	0.022597	79.8
DM_2	0.083	0.001625	0.002301	97.7
DM_3	0.083	0.000013	0.006097	94.1

Based on the evaluations presented in Figure 6, it was possible to calculate the individual weights of the criteria and the group weight (Table 5). This was carried out in accordance with the loss function approach (LFA), using the evaluation quality *F(x)*.

Table 5. Individual and group (LFA) weights of criteria

Criteria	DM_1	DM_2	DM_3	LFA
C_1	0.520	0.265	0.363	0.388
C_2	0.197	0.110	0.099	0.137
C_3	0.118	0.004	0.004	0.039
C_4	0.060	0.004	0.063	0.042
C_5	0.029	0.275	0.188	0.179
C_6	0.076	0.275	0.246	0.214

In the next step, one of the decision makers from the group, the manager-in-chief of Rila Monastery forest (DM_1), evaluated four stands (alternatives) with respect to the six criteria defined. This evaluation was performed using the SMARTER framework and included the ranking of alternatives and the definition of preference ratios *z* (Table 6).

Table 6. SMARTER evaluation of alternatives, RER technique

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6
A_1	3	1	2	2	2	1
A_2	4	4	3	1	4	4
A_3	1	2	4	4	1	2
A_4	2	3	1	3	3	3
z	0.8	0.7	1.2	1.5	0.5	0.6

Figure 7 presents the weights of the alternatives depending on the ranking of alternatives and the value of the preference ratio (Table 6).

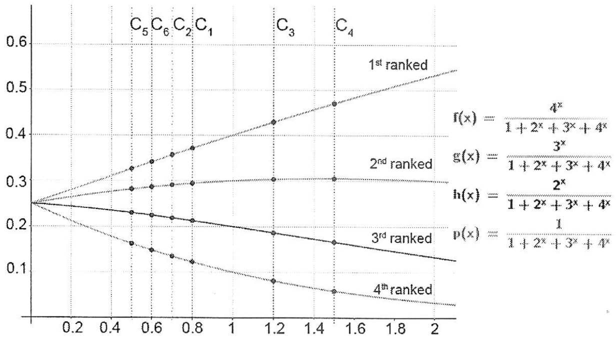

Figure 7. RER technique, weights of alternatives

The values presented in Table 6 and Figure 7 were then transformed into weights of alternatives with respect to the six criteria analyzed (Table 7). The calculation of these values enabled the computation of the final priorities and the corresponding ranking of alternatives (Table 7). The final priorities represent a merging of the SMARTER weights of the alternatives with respect to the criteria and the group LFA weights of the criteria.

Table 7. SMARTER weights of alternatives with respect to criteria, final priorities and rank

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	Priorities	Rank
A_1	0.213	0.356	0.304	0.305	0.282	0.341	0.280	2
A_2	0.122	0.135	0.187	0.470	0.163	0.148	0.154	4
A_3	0.371	0.291	0.081	0.059	0.325	0.287	0.309	1
A_4	0.294	0.219	0.429	0.166	0.230	0.225	0.257	3

As the results in Table 7 show, the highest ranked alternative is A_3, corresponding to forest stand 1024g. This ranking of alternatives represents the end of the decision-making process and gives an overview of general assessment of forest stands in multi-criteria context.

Discussion

This chapter is divided into two sub-chapters providing the discussion on: (a) methodology used in the research, justification for its application and proposals for using other MC methods in the future research and (b) results obtained for a case study area, Rila Monastery forest.

Discussion on the MC methods used

This research presents one possible way of combining multi-criteria methodologies in forestry decision making. The methods used here are AHP and SMARTER, which were convenient for simultaneous use since they provide results presented as cardinal values. If we consider Stevens' scale of measure (Stevens 1951), the results obtained at the end of the AHP and SMARTER process belong to the ratio scale, and this gives rise to diverse possibilities for the aggregation of output data.

In the first phase of this research, AHP method was used for determining the importance of each criterion (biodiversity, age of main canopy, recreation potential, park infrastructure, harvesting costs and timber value) with respect to the goal, identifying the best multi-functional stand in Rila Monastery forest. The AHP method was an appropriate one for this type of assessment as it enables the comparison of both quantitative and qualitative criteria as well as of objective and subjective criteria. The assessment was performed in a group context, and a loss function approach was used for the aggregation of the AHP evaluations. Even though there are several alternative options for aggregating individual assessments into a group one (e.g. Regan et al. 2006, Dong et al. 2010), LFA was selected here as it determines the quality of the evaluation based on decision makers' evaluation consistency. This feature was assessed as being important, since the aim was to assign different weights to the decision makers based on their evaluation success.

In the second phase, it was necessary to estimate the weights of alternatives, and the SMARTER method was selected for this purpose. The decision maker evaluated alternatives set (forest stands) with respect to each criterion. The evaluation consisted of ranking the alternatives and defining the preference ratio between top and bottom ranked alternative for each criterion being considered. SMARTER method has been assessed as an appropriate for this general assessment and ranking of forest stands.

Results obtained at the first and second level were aggregated in order to obtain the final priorities of the forest stands and their corresponding rankings. The final ranking, along with the performance of each forest stand to each criterion, represent an initial step in developing next management plan of Rila Monastery forest. For the more detailed management actions, the MC methods used in the research could be linked with the results from empirical studies, assessments and models, and that can also be a direction for a future research agenda.

It should be noted that AHP and SMARTER proved to be convenient methods for this analysis, but also some other methods could have been used instead of SMARTER. In that case, one of the options could be PROMETHEE, an MC method which requires the weights of the criteria to be defined prior to the evaluation process. It can therefore be successfully combined with the AHP results from the first step of the analysis.

In the current study, the evaluation of the alternatives with respect to the criteria set was performed by a single decision maker, since he was the leading expert for the forest stands analyzed. If the evaluation of alternatives was performed in a group context, then it would be necessary to find an appropriate aggregation procedure. Our proposal in this case would be to apply the aggregation of individual priorities (Forman and Peniwati 1998) or to consider other techniques presented in recently published papers (e.g. Grošelj et al. 2015).

Discussion on the results obtained

Analysis of criteria set has been performed in a group context and confirmed biodiversity as the most important criterion (relative importance: weight of 38.8%). According to the results obtained, the second ranked criterion is timber value (weight of 21.4%), followed by harvesting costs (weight of 17.9%), while the forth ranked criterion is age of main canopy (weight of 13.7%). Two remaining criteria are related to tourism aspect and are being assessed as less important; these are: park infrastructure (weight of 4.2%) and recreation potential (weight of 3.9%). The obtained results are in accordance with the current objectives of forest management, emphasizing nature protection and timber production as primary goals, with nature protection slightly prevailing among them.

Comparison of alternatives with respect the criteria set enabled final ranking of Rila monastery forest stands. According to the obtained results/ranking, the best multifunctional forest stand among the evaluated four stands in Rila monastery forest is the one labeled as 1024g. It is the oldest one (170 years old), mixed fir-spruce-beech forest with the highest growing stock per 1 ha (466 m^3/ha). This stand most effectively combines all the functions sought by the different stakeholders including the owner and the society. In the analysis, this stand was the assessed as the highest ranked one for the two important criteria – biodiversity and harvesting costs. According to the analysis performed, the bottom positioned stand is forest stand 1023a, a-2, a-3 and the reason for that is the poor performance of the stand for all criteria except of park infrastructure criterion, which is (in the previous step) proved to be a criterion with the low influence on the overall assessment.

This research could serve as a suitable practical example for the next management planning (scheduled for 2020) of the park territory and of Rila monastery forest.

Conclusions

Multi-criteria methods have an important role in forest management and planning. Many recently published papers confirm the importance of applying the multi-criteria methods in solving forestry issues, especially when it comes to participatory decision-making scheme (Dragoi 2016, Brescancin et al 2017, Huber et al. 2017). In addition, new approaches to combining different methods are constantly being developed (e.g. Srdjevic et al. 2013, Lakicevic et al. 2014) and this paper aims to address this question further.

The general recommendation would certainly be to combine various MC methods for forestry-related issues in order to come to a reliable final decision. Nowadays, decisions concerning the environment are made by taking into account the opinions and expertise of decision makers from diverse backgrounds, and the selection of a single MC method for all decision makers can therefore be misleading and inefficient. In this regard, the moderator of the decision-making process has a difficult task, starting with explaining the different MC techniques to the evaluators, respecting the decision makers' preferences regarding the methods they will apply, providing help during the evaluation process and finding an appropriate method to aggregate their individual decisions into a group one.

In this paper, one possible way of combining MC methods is shown, which takes into account the preferences of decision makers regarding the decision support method to be applied. This approach prevents a situation in which an expert applies a MC method s/he does not feel comfortable with, which may then lead to inconsistent or hesitant decision making. There are many more possibilities for combining MC methods in forestry, and future research may investigate these issues further. Additional options are open if the problem is seen from a broader perspective by relying on the results from contemporary empirical forest models.

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References

Álvarez-Miranda, E., Garcia-Gonzalo, J., Ulloa-Fierro, F., Weintraub, A. and Barreiro, S. 2017. A multicriteria optimization model for sustainable forest management under climate change uncertainty: An application in Portugal. *European Journal of Operational Research*, ISSN 0377-2217 (in press).

Brescancin, F., Dobšinská, Z., De Meo, I., Šálka, J. and Paletto, A. 2017. Analysis of stakeholders' involvement in the implementation of the Natura 2000 network in Slovakia. *Forest Policy and Economics*, 2017, ISSN 1389-9341 (in press).

Cho, Y.G. and Cho, K.T. 2008. A loss function approach to group preference aggregation in the AHP. *Computers & Operations Research* 35(3): 884–892.

Courbaud, B., Lafond, V., Lagarrigues, G., Vieilledent, G., Cordonnier, T., Jabot, F. and de Coligny, F. 2015. Applying ecological model evaludation: Lessons learned with the forest dynamics model Samsara2. *Ecological Modelling* 314: 1–14.

Diaz-Balteiro, L. and Romero, C. 2008. Making forestry decisions with multiple criteria: a review and an assessment. *Forest Ecology and Management* 255(8–9): 3222–3241.

Dong, Y., Zhang, G., Hong, W.C. and Xu, Y. 2010. Consensus models for AHP group decision making under row geometric mean prioritization method. *Decision Support Systems* 49(3): 281–289.

Dragoi, M. 2016. Joining or not joining non-industrial private forests into a single management unit: A case-study shaped as an Analytic Network Process. *Forest Policy and Economics*, ISSN 1389-9341 (in press).

Edwards, W. and Barron, F.H. 1994. SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. *Organizational Behavior and Human Decision Processes* 60(3): 306–325.

Forman, E. and Peniwati, K. 1998. Aggregating individual judgments and priorities with the analytic hierarchy process. *European Journal of Operational Research* 108: 165–169.

Grilli, G., Nikodinoska, N., Paletto, A., and De Meo, I. 2015. Stakeholders' preferences and economic value of forest ecosystem services: an example in the Italian Alps. *Baltic Forestry* 21(2): 298-307.

Grošelj, P., Zadnik Stirn, L., Ayrilmis, N. and Kitek Kuzman, M. 2015. Comparison of some aggregation techniques using group analytic hierarchy process. *Expert Systems with Applications* 42(4): 2198–2204.

Huber, P., Hujala, T., Kurttila, M., Wolfslehner, B. and Vacik, H. 2017. Application of multi criteria analysis methods for a participatory assessment of non-wood forest products in two European case studies. *Forest Policy and Economics*, Available online at: https://doi.org/10.1016/j.forpol.2017.07.003 (in press).

Ishizaka, A. and Labib, A. 2011. Review of the main developments in the analytic hierarchy process. *Expert Systems with Applications* 38(11): 14336-14345.

Kangas, A., Kurttila, M., Hujala, T., Eyvindson, K. and Kangas, J. 2015. Decision Support for Forest Management, Managing Forest Ecosystems. Springer International Publishing, Cham, p. 52-53.

Kangas, J., Store, R. and Kangas, A. 2005. Socioecological landscape planning approach and multicriteria acceptability analysis in multiple-purpose forest management. *Forest Policy and Economics* 7(4): 603-614.

Kellon, D. and Arvai, J. 2011. Five propositions for improving decision making about the environment in developing communities: Insights from the decision sciences. *Journal of Environmental Management* 92: 363–371.

Kurttila, M., Pesonen, M., Kangas, J. and Kajanus, M. 2000. Utilizing the analytic hierarchy process (AHP) in SWOT analysis – a hybrid method and its application to a forest-certification case. *Forest Policy and Economics* 1(1): 41–52.

Lahdelma, R. and Salminen, P. 2001. SMAA-2: Stochastic multicriteria acceptability analysis for group decision making. *Operations Research* 49(3): 444–454.

Lakićević, M. and Srđević, B. 2012. AHP–group decision-making in selecting tree species for urban wet sites. *Contemporary Agriculture* 61(1-2): 8-14.

Lakicevic, M., Srdjevic, Z., Srdjevic, B. and Zlatic, M. 2014. Decision making in urban forestry by using approval voting and multicriteria approval method (case study: Zvezdarska forest, Belgrade, Serbia). *Urban Forestry & Urban Greening* 13(1): 114–120.

Martinez-Harms, M.J., Bryan, B.A., Balvanera, P., Law E.A., Rhodes J.R., Possingham, H.P. and Wilson K.A. 2015. Making decisions for managing ecosystem services. *Biological Conservation* 184: 229-238.

Regan, H.M., Colyvan, M. and Markovchick-Nicholls, L. 2006. A formal model for consensus and negotiation in environmental management. *Journal of Environmental Management* 80(2): 167–176.

Reynolds, K.M. and Hessburg, P.F. 2014. An overview of the ecosystem management decision-support system. In: K.M. Reynolds, P.F. Hessburg and P.S. Bourgeron (Eds.): Making transparent environmental management decisions: Applications of the ecosystem management decision support system. Springer, Berlin, P. 3-20.

Saaty, R.W. 1987. The analytic hierarchy process – what it is and how it is used. *Mathematical Modelling* 9(3): 161-176.

Saaty, T.L. 1980. The Analytical Hierarchy Process. McGraw-Hill, New York, 350 pp.

Srdjevic, B. 2005. Combining different prioritization methods in the analytic hierarchy process synthesis. *Computers & Operations Research* 32: 1897–1919.

Srdjevic, B. and Srdjevic, Z. 2011. Bi-criteria evolution strategy in estimating weights from the AHP ratio-scale matrices. *Applied Mathematics and Computation* 218: 1254–1266.

Srdjevic, Z., Lakicevic, M. and Srdjevic, B. 2013. Approach of decision making based on the analytic hierarchy process for urban landscape management. *Environmental Management* 51(3): 777–785.

Stevens, S.S. 1951. Mathematics, measurement, and psychophysics. In: S.S. Stevens (Ed.), Handbook of Experimental Psychology. Willey, Oxford, p. 1-49.

Wedley, W.C. 1993. Consistency prediction for incomplete AHP matrices. *Mathematical and Computer Modelling* 17(4-5): 151-161.