Evaluation of qualitative attributes of forest ecosystems by means of numerical quantifiers

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ABSTRACT: This paper presents a proposal of four variants of quantifiers for the numerical expression of qualitative attributes of forest ecosystems, for example site, naturalness, biodiversity, ecological stability, threat of injurious agents, status of forest biotopes of European significance in the NATURA 2000 network and so on. Quantifiers enable to completely characterise the whole set of these qualitative attributes of the ecosystem by one number which directly indicates the relative approximation of the ecosystem (in %) to the required most favourable status. They have more advantages: different numerical operations can be done with them, it is possible to aggregate evaluated units of the ecosystem to larger entities, to determine average value, variability and confidence limits of the final evaluation and to compare resulting statuses mutually or very objectively on the principle of biometric monitoring in a longer time. The construction of quantifiers is opened and it arbitrarily enables to choose input parameters at need (numerical quantifications of ecosystem quality statuses and weights of their criteria and indicators) and to search for optimal solutions. The reaction of quantifiers to different input situations is analysed on model examples and suggestions for their introduction into practice are presented. Special PC software was elaborated for the automated calculation of quantifiers.

Keywords: forest ecosystems; forest biotopes; quantification of qualitative attributes

In forestry, ecology and nature protection there often exists a task when it is necessary to completely evaluate the qualitative attributes of the forest ecosystem or its smaller parts – forest stands, biotopes and the like. It can be related to site quality, biological diversity, ecological stability, threat of injurious agents, management condition and so on. Currently, it is an especially crucial topic in the NATURA 2000 Project, where so-called *Favourable Conservation Status* (FCS) of forest biotopes of European and national significance is evaluated. In general, the unit of evaluation (of forest stand, biotope) is assigned to the corresponding qualitative category in accordance with in-advance defined criteria and indicators, for example in forest biotopes into 4 classes: A – excellent status, B – good status, C – disturbed status, D – inconvenient status. This evaluation is simple and clear. It becomes problematic when it is necessary to express the status of evaluated unit in a complex way with regard to all evaluated criteria and indicators or when it is necessary to assess the global status of a larger number of units and to aggregate the evaluation to higher hierarchical levels – localities, regions and to the national level and/or to the European Community. The situation is becoming much more complicated when the evaluated units are of different size (area) and when the used evaluation criteria and indicators have different weights (significance, importance). Categories A, B, C, D are typical qualitative variables to which common numerical operations are not applicable (from biometric characteristics only the mode can be used – the category of the highest abundance).

Quantification can be the initial solution – so the numerical formulation of this qualitative evaluation. Four solution methods are introduced in the present paper. More options are taken into consideration to judge these methods and to select the most suitable – without weights and with weights and with the assigning of different numerical values to qualitative categories A, B, C, D. All of them are verified on model examples with the application to the system of evaluation of forest biotopes within the NATURA 2000 Project. Computer software for the automated processing of evaluation results is a part of the solution. The programme is designed in the DELPHI environment and the authors will provide it to interested persons free of charge by request.

METHODS

Model example of the initial solution for the evaluation of forest biotope

The problem will be explained and gradually solved on a common model example. This is a concern of the forest biotope within which three criteria were evaluated – tree species composition (*a*), inside structure (*b*) and negative influences which affect it (*c*) and within them other specific indicators (a_i, b_i, c_i). The biotope was assigned to the corresponding categories of favourable status A, B, C, D in accordance with that. Results are shown in Table 1. As you can see, for a given forest biotope, 9 different evaluations of its FCS arose: (A, B), (A, D, B, A, C), (A, B). Excellent status A was assigned to its tree species composition, age structure, occurrence of rough and extra valuable trees and health condition. On the contrary, from the aspect of the occurrence of rough deadwood its status is bad C and from the aspect of natural regeneration it is almost inconvenient D. Now the task is to integrate this relatively heterogeneous evaluation of individual FCS into the final assessment which would allow to completely judge the total status of the biotope and consequently to compare it either to statuses of the same biotope in a long-term period or to other biotopes.

Different methods of quantification of forest biotope qualitative status

The task formulated in the previous section can be solved by several methods. We are considering two basic approaches and more variants within them. Each of the variants has different attributes, advantages and disadvantages. It can differently sensitively react to the characteristics of evaluated biotope in different situations and thus provide different results. That is why we will apply the considered variants, except for the example in Table 1, to other model biotopes; obtained results will be mutually compared and conclusions for their practical usability will be derived.

Average point value (mark) of biotope status

By this variant the point value (mark) $Z = 1 – 2 – 3 – 4$ will be assigned to qualitative categories A, B, C, D and relative weights w_i will be given to criteria *a*, *b*, *c* and another proportions of these weights w_{ij}, e.g. according to Table 2a, will be given to indicators a_i, b_i, c_i within the criteria. Not only marks Z_i and weights w_i, w_{ij} but also their multiples $Z_i \times w_i$ and $Z_{ij} \times w_{ij}$ for all the possible combinations are introduced in this table because of the clearness and easiness of calculations. Of course the choice of marks and weights can be different, but it depends on mutual proportions between them and on the simplicity of their use. The resulting average mark will be calculated from the concrete evaluation of criteria *a, b, c* of the A, C, B biotope, for example as an arithmetic mean of assigned points

– either *simple* (without weights)

$$\overline{Z}_S = \sum_{i=1}^{n} Z_i/n, \text{ for A = 4, C = 2, B = 3} \rightarrow$$

$$\overline{Z}_S = (4 + 2 + 3)/3 = 3.0 \qquad (1)$$

Table 1. A scheme of criteria and indicators for assigning the biotope to the category A, B, C, D in accordance with its status, taken over from the NATURA 2000 SK Project (Schwarz et al. 2005) (**x** – example of a concrete evaluation)

Criteria	Indicators	Biotope status			
		A (excellent)	B (good)	C (disturbed)	D (inconvenient)
a	*a*1	**x**			
	*a*2		**x**		
b	*b*1	**x**			
	*b*2				**x**
	*b*3		**x**		
	*b*4	**x**			
	*b*5			**x**	
c	*c*1	**x**			
	*c*2		**x**		

For Table 1 to 3:
a – typical species: *a*1 – tree species, *a*2 – plants and shrubs; *b* – biotope structure: *b*1 – age structure, *b*2 – natural species regeneration, *b*3 – spatial structure, *b*4 – rough and extra valuable trees, *b*5 – rough deadwood; *c* – negative influences: *c*1 – health condition status, *c*2 – wider spatial coherences

Table 2. Evaluation of the biotope status by the method of average point value (mark)

a) Assigned point values (Z_{ij}) for the categories of biotope status A, B, C, D and weights (w_{ij}) for criteria *a, b, c* and indicators a_i, b_i, c_i (**x** – concrete evaluation of model example 1)

Criteria (weights)	A	B	C	D	Indicator (weights)	A	B	C	D
	Z = 4	Z = 3	Z = 2	Z = 1		Z = 4	Z = 3	Z = 2	Z = 1
a = 0.45	**1.8**	1.35	0.9	0.45	*a*1 = 0.30	**1.2**	0.90	0.6	0.30
					*a*2 = 0.15	0.6	**0.45**	0.3	0.15
b = 0.35	1.4	1.05	**0.7**	0.35	*b*1 = 0.10	**0.4**	0.30	0.2	0.10
					*b*2 = 0.05	0.2	0.15	0.1	**0.05**
					*b*3 = 0.10	0.4	**0.30**	0.2	0.10
					*b*4 = 0.05	**0.2**	0.15	0.1	0.05
					*b*5 = 0.05	0.2	0.15	**0.1**	0.05
c = 0.20	0.8	**0.60**	0.4	0.20	*c*1 = 0.10	**0.4**	0.30	0.2	0.10
					*c*2 = 0.10	0.4	**0.30**	0.2	0.10

b) Examples of evaluation 1–5: $\overline{Z}_s$ – simple mean (without weights), $\overline{Z}_w$ – weighted mean (with weights)

Criteria	**1**	2	3	4	5	Indicator	**1**	2	3	4	5
a	A	A	B	A	B	*a*1	**A**	A	B	A	B
b	**C**	A	B	D	D	*a*2	**B**	A	B	B	C
c	**B**	B	A	A	D	*b*1	**A**	B	A	C	D
						*b*2	**D**	A	C	D	D
						*b*3	**B**	A	B	D	D
						*b*4	**A**	B	B	C	B
						*b*5	**C**	A	B	D	C
						*c*1	**A**	A	A	B	C
						*c*2	**B**	C	A	A	D
Z_s	**3.0**	3.7	3.3	3.0	1.7	Z_s	**3.1**	3.6	3.2	2.3	1.8
Z_w	**3.1**	3.8	3.2	2.4	1.9	Z_w	**3.4**	3.7	3.3	2.8	2.0
T.a.	**B**	A	B	B/C	D/C	T.a.	**B**	A	B	C/B	C

– or *weighted* (with regard to chosen weights)

$$\overline{Z}_W = \sum_{i=1}^{n} w_i Z_i, \text{ for A = 4, C = 2, B = 3}$$

and weights 0.45– 0.35 – 0.20 →

$$\overline{Z}_v = (0.45 \times 4 + 0.35 \times 2 + 0.2 \times 3) = 3.1 \qquad (2)$$

Average marks Z for the evaluation of indicators a_i, b_i, c_i would be calculated in a similar way, the result would be $\overline{Z}_s$ = 3.1 and $\overline{Z}_w$ = 3.4.

In accordance with the calculated mean $\overline{Z}$ from single marks of individual criteria and indicators it is backwardly possible to assign the total qualitative category (FCS) to the whole biotope, e.g. by linear interpolation of the possible scale of the best (4) and the worst (1) evaluation in this way: A (4.0 – 3.25), B (3.25 – 2.5), C (2.5 – 1.75), D (1.75 – 1.0).

In Table 2b, this quantification is also carried out for another 4 model examples which have very different input characteristics. An approach to the solution is double – rougher and more detailed: in the left half of the table the person charged with evaluation evaluates criteria *a, b, c* as a part together, in the right half of the table the person charged with evaluation also records separately his/her evaluation for the individual indicators a_i, b_i, c_i. The following generalisations can be derived from presented demonstrations:

- Point evaluation of the biotope status is very simple, logically easy to understand;
- Average mark $\overline{Z}$ schematically embodies the biotope quality, the nearer to 4.0, the more favourable the status of the biotope is;
- In general, the weighted mean provides better characterisation of the real biotope status;
- Individual point values 4, 3, 2, 1 are graded in the same intervals, they suppose that the biotope status B, C, D is 2-times, 3-times, 4-times worse than the status A, which does not corresponds fairly well to the biological matter of these categories;

Table 3. Resultant (aggregated) evaluation of the biotope status by the method of numerical quantifiers Q

a) Assigned quantifiers Q_{ij} for A, B, C, D biotope qualitative statuses and w_{ij} weights for evaluation criteria *a, b, c* and for indicators $a_i.b_i, c_i$ (**x** – evaluation of example 1)

Criterion and its weights (w_i)	Indicator and its weights (w_{ij})	Biotope status and its quantifiers Q_j			
		A	B	C	D
		Q = 1.0	Q = 0.8	Q = 0.5	Q = –1.0
a = 0.45	*a*1 = 0.30	**0.30**	0.24	0.150	–0.30
	*a*2 = 0.15	0.15	**0.12**	0.075	–0.15
b = 0.35	*b*1 = 0.10	**0.10**	0.08	0.050	–0.10
	*b*2 = 0.05	0.05	0.04	0.025	**–0.05**
	*b*3 = 0.10	0.10	**0.08**	0.050	–0.10
	*b*4 = 0.05	**0.05**	0.04	0.025	–0.05
	*b*5 = 0.05	0.05	0.04	**0.025**	–0.05
c = 0.20	*c*1 = 0.10	**0.10**	0.08	0.050	–0.10
	*c*2 = 0.10	0.10	**0.08**	0.050	–0.10

b) Examples of evaluation 1–10: quantifiers Q_1, Q_2 and Q_3

Indicator	Examples of biotopes evaluation									
	1	2	3	4	5	6	7	8	9	10
*a*1	**A**	A	B	C	A	B	A	A	D	A
*a*2	**B**	A	B	C	B	B	D	A	D	B
*b*1	**A**	A	B	C	A	B	A	B	B	D
*b*2	**D**	A	B	C	B	C	C	D	B	D
*b*3	**B**	A	B	C	A	C	A	B	B	D
*b*4	**A**	A	B	C	B	B	A	B	B	C
*b*5	**C**	A	B	C	B	C	B	C	B	D
*c*1	**A**	A	B	C	A	B	C	D	A	A
*c*2	**B**	A	B	C	B	C	C	D	A	A
Q_1	**80.5**	100.0	80.0	50.0	92.0	71.0	56.5	42.2	3.0	34.5
Q_2	**19.8**	100.0	79.7	49.5	88.1	64.1	–72.6	–41.1	–236	–46.0
Q_3	**82.9**	100.0	79.2	48.8	91.0	68.0	53.1	–22.6	–115	–47.7

Q_1 – determined by simple sum of Q_{ij} (the operator OR)
Q_2 – determined by EMDS method from Q_{ij} of all 9 indicators (the operator AND)
Q_3 – determined by EMDS method from sum of the Q_{ij} indicators within *a, b, c* criteria (by combination of OR and AND operators)

- Worse evaluation C, D will not be expressed strongly enough in the resulting mark, not even by the occurrence of two criteria and/or five indicators with the evaluation of D, an average mark is ca 2.0, so the total status of the biotope is evaluated as "disturbed", not as "inconvenient";
- Thus the method is applicable only for approximate, orientation quantification of the biotope total status.

Quantifier expressing the relative approximation of the biotope status to the required optimum

By this variant, appropriate quantifiers Q_{ij}, e.g. according to Table 3a, will be assigned to all the possible combinations of criteria and indicators a_i, b_i, c_i with grades of biotope quality A, B, C, D. Applied quantifiers originated from the assigned values 1.0 – 0.8 – 0.5 and minus 1.0 (they express the relative approximation of the biotope to the favourable status relatively well at 100 – 80 – 50% and very badly – at minus 100%) to qualitative categories A – B – C – D, relative weights 0.45 – 0.35 – 0.20 were assigned to criteria *a – b – c* and to indicators within the criteria further proportions of these weights, similarly like in Table 2a with regard to different significance of these attributes. Of course, other different combinations are also possible. They are purposely chosen to have a sufficient "distance" from each other in a model case when their influence on the final evaluation result will be better shown. Three different methods of the final quantifier derivation were tested for own quantification of the biotope status using the principle of the knowledge system NetWeaver (Reynolds 1999), which is a part of the *EMDS* system (*EMDS* – Ecomanagement Decision Support System) for the support of the decision-making process in ecological management. Results for a model biotope and another 9 various examples are summarised in Table 3b.

Quantifier Q_1

It is defined as *a simple sum of Q_{ij} quantifiers* assigned to individual indicators in categories A, B, C, D. The operator OR, the logical sum is applied, thus an assumption about mutual independence of indicators. The result is expressed in %:

$$Q_1 = 100 \times \sum_{i=1}^{n} Q_{ij}, \text{ for example } 1 \rightarrow Q_1 =$$
$$= 100 \times (0.30 + 0.12 + ... + 0.08) = 80.5\% \quad (3)$$

Quantifier Q_2

It is derived from *all Q_{ij} quantifiers for criteria and indicators together* on the principle of the *EMDS* (Reynolds 1999) system. The operator AND is used, thus an assumption about mutual dependence of indicators and the result is expressed in % of the maximal possible value of the best biotope status Q_2(max), i.e. of the status where all criteria and indicators are evaluated by A:

$$Q_2 = \frac{\min(Q_{ij}) + [AVG(Q_{ij}) - \min(Q_{ij})] \times [\min(Q_{ij}) + 1]/2}{Q_2\ (\max)} \times 100 \quad (4)$$

$$Q_2(\max) = 0.05 + \left[\frac{0.3 + 0.15 + ... + 0.1}{9} - 0.05\right] \times$$
$$\times\ [0.05 + 1]/2 = 0.0821 \quad (5)$$

We will obtain this equation for example 1

$$Q_2 = (-0.05 + \left[\frac{0.3 + 0.12 + ... + 0.08}{9} - (-0.05)\right] \times$$
$$\times [-0.05 + 1]/2)/Q_2(\max) \times 100 \rightarrow$$
$$\rightarrow Q_2 = \frac{0.0162}{0.0821} \times 100 = 19.8\% \quad (6)$$

Quantifier Q_3

It is also determined on the principle of *EMDS* (Reynolds 1999), but *combined – from the sum of Q_{ij} quantifiers within criteria a, b, c*. The same formula as for Q_2 will be used, but only with a difference that the values of quantifiers assigned to indicators (*a*1, *a*2), (*b*1, *b*2, *b*3, *b*4, *b*5) and (*c*1, *c*2) will be summed within the criteria at first and the resultant sums will be considered as the formula. These facts are the reason: mutual dependence of attributes is not assumed within the individual criteria – e.g. the structure of the biotope can be relatively good if one of the conditions *a*1, *a*2 is satisfied at least, e.g. all required tree species occur, but the herb cover is not sufficient, partial quantifiers can be summed (the operator OR is applied). On the other hand, much higher conditionality exists between criteria *a, b, c* – the biotope cannot maintain the favourable status if it does not meet for example the criterion of tree species composition (*a*) although it excellently meets the other criteria (*b, c*), that is why the operator AND has to be applied for the aggregation of the evaluation. The boundary value Q_3 will also be naturally changed after this modification as follows: for the best case (all evaluations of A) will be Q_3 (max) = +0.280.

We will obtain this equation for our model example 1:

$$\text{sums } Q_a = 0.2 + 0.04 + 0.04 = 0.28$$
$$Q_b = 0.4 + 0.05 = 0.45$$
$$Q_c = 0.04 + 0.05 + 0.05 = 0.14 \quad (7)$$

$$Q_3 = 0.14 + \left[\frac{0.28 + 0.45 + 0.14}{3} - 0.14\right] \times [0.14 + 1]/2 =$$
$$= (0.255/0.280) \times 100 = 80.5\% \quad (8)$$

If we compare the results in Table 3b, we can state that:

– Of all three quantifiers the quantifier Q_3 seems to be the most suitable from the material and logical aspect, it best represents the real biotope status, sufficiently sensitively reacts to worse evaluation (C, D) and combination of the operators OR and AND, well considers the mutual relation (conditionality) of evaluation criteria and indicators; quantifier Q_1 can serve as the orientation one, Q_2 is not applicable;
– By its value Q_3 expresses the direct rate of approximation of the evaluated biotope status to the most favourable status = 100%;
– Q values are quantitative variables and therefore it is possible to execute all numerical operations, e.g. to determine the average value as a characteristic of the total biotope quality level, variability of individual Q_i values from forest spatial units on a local level, on the level of the biotope and the whole country, and also the rate of accuracy of the obtained result;
– It is also possible to easily do a qualitative expression from the numerical expression of the biotope status using the FCS, if an agreed key is used for return transformation, e.g.

$Q_3 > 90\% \rightarrow$ A, $Q_3 = 90–70\% \rightarrow$ B, $Q_3 = 70–49\% \rightarrow$ C, $Q_3 < 49\% \rightarrow$ D

Q_3 calculation can also be well handled on a hand-held calculator and automated on a PC.

Software for automated calculation of numerical quantifiers

The main motivation for software elaboration was a difficult calculation chiefly by using the Q_2 and Q_3 quantifiers. Quantifiers utilise the operator AND calculated by so-called *minimum-biased weighted average*, which is complicated for the use of a hand-held calculator. The automation of calculation is primarily required:

– when searching for an optimal number of criteria and their indicators for the evaluation of forest biotope status, determination of their weights and marks for individual qualitative statuses,
– by the single routine calculation of quantifiers within the process of the evaluation of forest biotopes.

The software was designed in the DELPHI programming environment. The program is intended for operation systems of the type Windows 95, 98, 2000, NT, Millennium and XP. Its architecture is built on a single library of algorithms for the calculation of Q_1, Q_2 and Q_3 quantifiers. The encapsulation of algorithms to a single object secures its simple incorporation into the wider host information system, eventually its implementation to hand-held field computers (so-called *Handheld PC*). The user operating environment was designed in the form of extension over objects except for the single library of objects. The user operating environment enables comfortable work by determination of criteria, indicators and their weights, by determination of evaluation marks for qualitative statuses and also by single calculation of forest biotope status on the basis

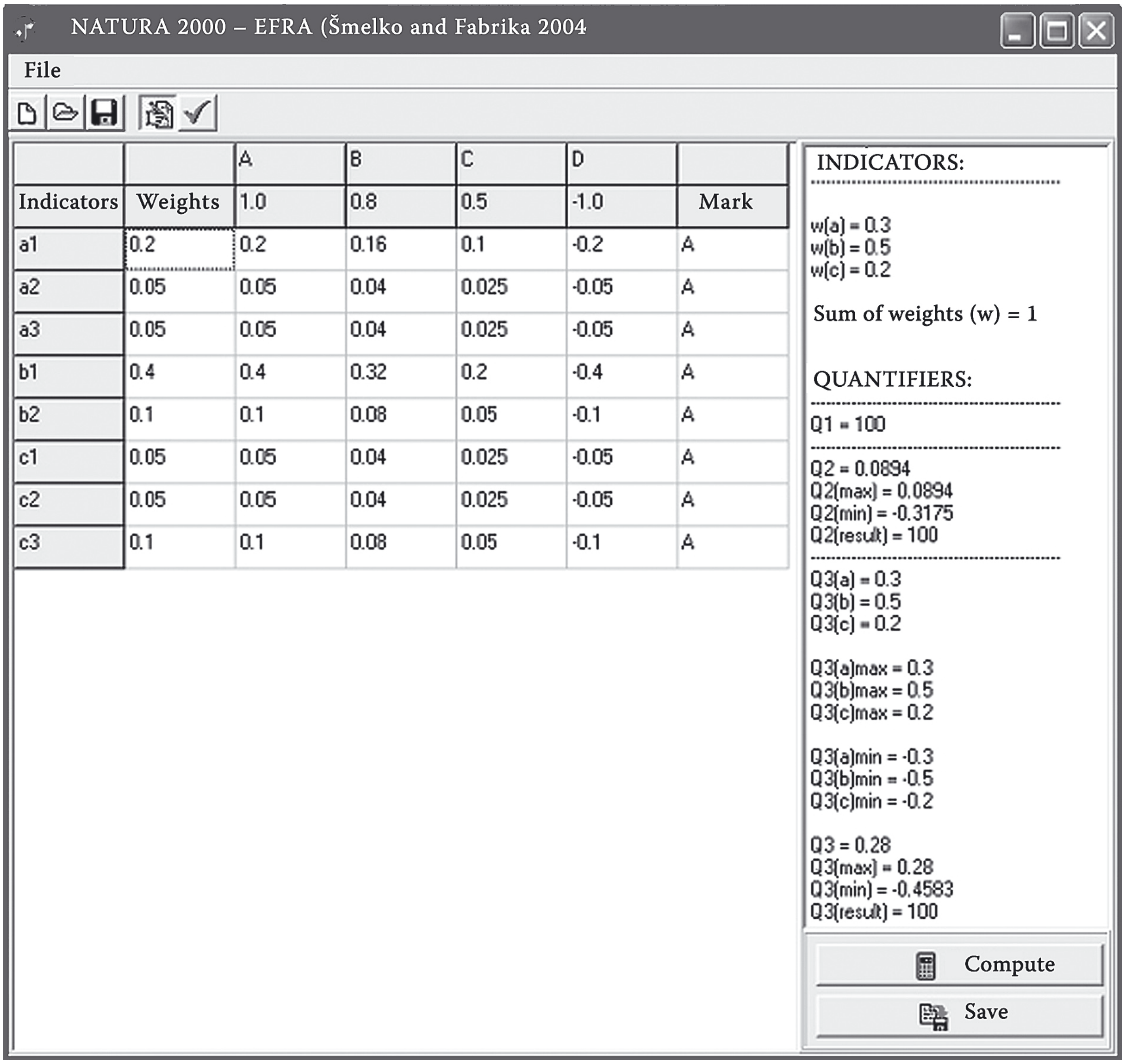

Fig. 1. Main menu of the software for the calculation of qualitative attributes of forest ecosystems

of marks for individual indicators. The menu of the software is presented in Fig. 1. The software consists of file menu, toolbar, table part and calculation part.

The table part contains a table in the form known from MS Excel program. The first column contains individual indicators. The second column contains their weights. Another column contains weights for qualitative statuses (A, B, ...) and the last one contains assigned mark to specified indicator. The table can be switched to two modes. Modes are switchable by buttons placed on the toolbar:

Edit mode: it enables to change the values of weights (w) for individual indicators. Weights are changed by clicking on a corresponding weight box and by editing from the computer keyboard. It is not possible to change converted weights for individual qualitative statuses, because they are automatically changing within the process of calculation in accordance with determined algorithms.

Selection mode: it enables to assign statuses (marks) for individual indicators. The cursor is changed into a "hand with finger". Its mark will be given by clicking the cursor on the indicator row and on the column of corresponding mark and it will be displayed in the last column.

The calculation part contains a review window with results. The help of *Calculate* button on its bottom part updates the window. It is possible to save the window content into the text file on disc by help of *Save* button on its bottom part. At first, it is necessary to define a name and a path for the text file by Windows system dialog. The window contains the following information from the calculation of quantifiers:

– Weights w for individual criteria and total control sum of weights (it should contain the value of 1),
– Total quantifier $Q_{1,}$
– Quantifier Q_2, its maximal value as well as the resulting value expressed relatively in terms of percentage from the maximum,
– Quantifier Q_3 and the resulting values for individual criteria, maximal values for individual criteria, total quantifier for the whole biotope, maximal value for the total quantifier and total value of the total quantifier expressed relatively in terms of percentage from the maximum.

The content of the table part for the entry of indicator weights and marks is flexible and changeable by help of submenu of the main menu *File* or by help of equivalent buttons on the toolbar:

New: the button (submenu of the *File* menu) enables to enter a new evaluation. The following window menu will be displayed after its start (Fig. 2). It is possible to specify the number of indicators for individual criteria in the window in Fig. 2. It is possible to enter 24 criteria. Small letters of the alphabet (*a* to *z*) designate criteria. Criteria which have defined the number of indicators are accepted. In the window it is also possible to specify the number of qualitative grades for the evaluation of biotope status indicator as well as their relative marks (e.g. from –1.0 to +1.0). It is possible to enter 10 qualitative grades. Capital letters of the alphabet (*A* to *J*) designate grades. The scale of entered mark is arbitrary, but with regard to the character of algorithms for quantifier calculation the scale from –1.0 to +1.0 is recommended.

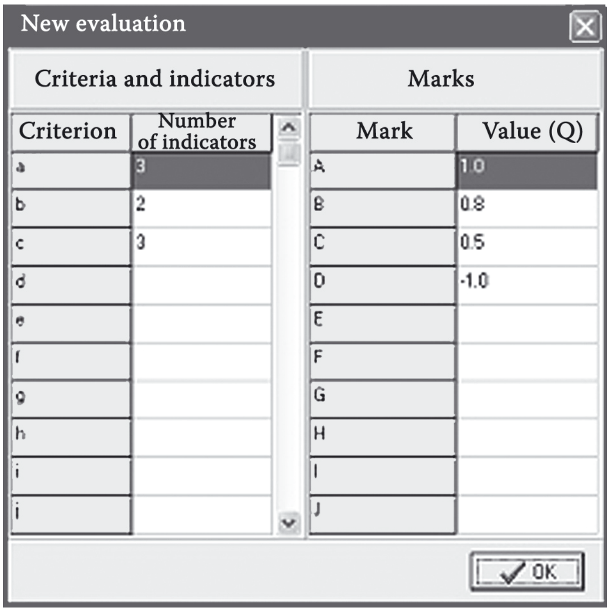

Fig. 2. Menu for the specification of new evaluation

Open: the button (submenu of the *File* menu) enables to open the existing evaluation table from an external file. It is necessary to specify the name and the path to the file on disc by the dialog of Windows operating system.

Save: the button (submenu of the *File* menu) enables to save the current evaluation table on disc. It is necessary to specify the name and the path to the file on disc by the dialog of Windows operating system after its use.

DISCUSSION

The presented attempt to quantify qualitative attributes of forest ecosystems by numerical quantifiers is relatively new. It has not been elaborated in a more detailed form yet. The use of this solution is known only in two cases in forestry. The first one relates to the qualitative inventory of forest stands by which Priesol (1961) replaced qualitative classes of four-part classification scale A, B, C, R with numerical values 4, 3, 2, 1, and based on them and on the relative composition of trees in these classes he expressed the average quality and its variability in the stand (e.g. 2.26 ± 0.65). A similar procedure was used in the second case – by the monitoring of the forest health condition when more authors (Heško et al. 1989; Palát et al. 1994) tried to express the tree composition in the known defoliation classes of tree crowns 0, 1, 2, 3, 4 (to 10%, 11–25%, 26–60%, 61–99%, 100%) by one common number, they used the average as an indicator, from these numerically marked classes, which was weighted with their relative frequencies. Both solutions are very similar to our variant of determination of so-called average mark, and that is why they have basically the same characteristics and also shortcomings as we mentioned in the text above. This practice is especially disadvantageous in the classification of tree health condition because individual classes have a very different range, which distorts the final evaluation and mainly its accuracy; it disables the objective return transformation into the average value of defoliation and it also has other negative impacts as Šmelko (1997) warned. The number of similar quantification attempts is much lower in the field of ecology and nature protection. Greater attention has been paid to this theme in the last period because of the NATURA 2000 Project implementation. In general, it also remains here on the principle of average mark; only the question of suitable weights for individual criteria and indicators of biotope statuses is more elaborated and discussed. Interesting examples can be found in the publications from Bavaria (Fischer et al. 2002) for forest biotopes in the area of "Hienheimer Wald" and from Slovakia (Polák, Saxa 2005) for bird and non-forest biotopes.

Our proposals are more oriented to a new generation of numerical quantifiers designated as Q, where the theory of *EMDS* (Reynolds 1999) is used and the current need for creating preconditions for introducing optimal biometric methods by the process of monitoring of forest ecosystems and for establishing the corresponding information system is taken into regard. All three variants of quantifiers Q_1, Q_2, Q_3 were tested against an extensive survey. Different combinations were tested, namely on 22 concrete forest biotopes integrated into the network of NATURA 2000 in Slovakia. Different relative values in the scale from +1 to –1, e.g. 1.0 – 0.4 – (–0.4) – (–1.0), 1.0 – 0.5 – 0 – (–0.5), 1.0 – 0.5 – 0 – (–1) were assigned to qualitative statuses A, B, C, D and such weights were attributed to the criteria and indicators which corresponded best to a given biotope according to the experts' opinion. It showed that the different relative quantification of A, B, C, D statuses did not cause any serious differences in the total evaluation of the biotope on condition that the limit values of quantifiers Q are reasonably adjusted for their return transformation (in 10 tested model cases none of the biotopes was assigned for this reason to another category than it was originally appertained). A different situation is in weights w; these have to be chosen for each biotope or a group of related biotopes individually. The weights of criteria a, b, c and indicators a_i, b_i, c_i varied in rather a wide range in the 22 tested biotopes (Table 4). Average values of weights common for all biotopes were also quite well applicable. Obtained results were fully used for a preliminary evaluation of the favourable status of forest biotopes of the European significance in the territory of the Slovak Republic (Schwarz et al. 2005) and were taken to a manual for programmes of NATURA 2000 solicitude (Polák, Saxa 2005).

CONCLUSION

In general, it can be stated that the proposed quantifiers, mainly variant Q_3, are suitable and well applicable to the evaluation of qualitative attributes of forest ecosystems including forest biotopes in the NATURA 2000 network. They directly express the rate at which the given ecosystem approximates to the required optimal status (100%) by its numerical value (e.g. 95%, 60%, 20%) and they have a number of other advantages. They completely characterise several qualitative aspects of the ecosystem by one number, different numerical operations can be done with them, it is possible to aggregate evaluated units of the ecosystem to larger entities, to determine average value, variability and confidence of the precision of final evaluation and to compare resulting statuses mutually or very objectively on the principle of biometric monitoring in a longer time. The construction of quantifiers is opened and it arbitrarily enables to choose input parameters at need (numerical quantifications of A, B, C, D statuses and weights of their

Table 4. Variability of criteria weights a, b, c and indicators a_i, b_i, c_i in 22 tested biotopes

w	a	b	c	$a1$	$a2$	$b1$	$b2$	$b3$	$b4$	$b5$	$c1$	$c2$
Min.	0.20	0.30	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Max.	0.55	0.55	0.50	0.40	0.20	0.15	0.10	0.20	0.10	0.10	0.40	0.15
Average	0.40	0.40	0.20	0.29	0.11	0.13	0.06	0.09	0.06	0.06	0.12	0.08

criteria and indicators) and to search for optimal solutions. Special software for personal computers was elaborated for this purpose and for routine use of quantifiers.

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Hodnotenie kvalitatívnych vlastností lesných ekosystémov pomocou číselných kvantifikátorov

ABSTRAKT: V príspevku sa podáva návrh na štyri varianty kvantifikátorov pre číselné vyjadrenie kvalitatívnych vlastností lesných ekosystémov, ako je napr. stanovište, prirodzenosť, biodiverzita, ekologická stabilita, ohrozenosť škodlivými činiteľmi, stav lesných biotopov európskeho významu v sústave NATURA 2000 ap. Kvantifikátory umožňujú charakterizovať celý súbor takýchto kvalitových znakov ekosystému komplexne jedným číslom, ktoré svojou hodnotou priamo udáva relatívne priblíženie sa ekosystému (v percentách) k želanému najpriaznivejšiemu stavu. Majú viaceré prednosti – dajú sa s nimi robiť rôzne počtárske operácie, agregovať hodnotené jednotky ekosystému do vyšších celkov, stanoviť priemernú hodnotu, variabilitu i rámec presnosti výsledného hodnotenia a porovnávať zistené stavy navzájom alebo v dlhšom časovom slede s uplatnením princípov biometrického monitorovania. Konštrukcia kvantifikátorov je otvorená, dovoľuje ľubovoľne podľa potreby voliť vstupné parametre (číselné kvantifikácie kvalitových stavov ekosystému a váhy ich kritérií a indikátorov) a hľadať optimálne riešenia. Reakcia kvantifikátorov na rôzne vstupné situácie sa rozoberá na modelových príkladoch a predkladajú sa námety na ich praktické použitie. Pre automatizovaný výpočet kvantifikátorov je vypracovaný špeciálny program na PC.

Kľúčové slová: lesné ekosystémy; lesné biotopy; kvantifikácia ich kvalitatívnych znakov

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