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A method for estimating the suitability function of wildlife habitat for forest planning on the basis of expertise

Jyrki Kangas, Jari Karsikko, Laura Laasonen & Timo Pukkala

TIIVISTELMÄ: ASIANTUNTEMUKSEEN PERUSTUVAN RIISTAN ELINYMPÄRISTÖN ARVOTTAMISMALLIN LAADINTAMENETELMÄ

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In the method presented in this study, a group of experts evaluate, in a pairwise manner, a set of forest areas with respect to the game species considered. On the basis of these comparisons, relative priorities of forest areas are estimated using the eigenvalue technique. Using regression analysis, a habitat suitability function is estimated in which the priority is predicted by measures already familiar in forest planning. As a case study, a habitat suitability function was estimated for black grouse. The function is applicable in forest planning carried out using modern planning techniques.

Tutkimuksessa esitettävässä menetelmässä joukko asiantuntijoita arvottaa pareittaisin vertailuin joukon metsäalueita tarkasteltavan riistalajin elinympäristövaatimusten kannalta. Vertailujen perusteella estimoidaan metsäalueiden suhteellisia hyvyyksiä kuvaavat tunnusluvut käyttäen ominaisarvolaskentaa. Regressioanalyysillä laaditaan malli, jossa metsäalueen hyvyyttä tarkasteltavan riistalajin kannalta selitetään metsäsuunnittelussa tiedossa olevien metsäalueen tunnusten arvoilla. Näin laadittua riistan elinympäristön arvottamismallia voidaan käyttää modernein menetelmin tehtävässä metsäsuunnittelussa.

Keywords: wildlife management, production functions, multiple use, forest management, black grouse, models.
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Authors' addresses: *Kangas:* The Finnish Forest Research Institute, P.O. Box 68, FIN-80101 Joensuu, Finland; *Karsikko, Laasonen and Pukkala:* University of Joensuu, Faculty of Forestry, P.O. Box 111, FIN-80101 Joensuu, Finland.

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1 Introduction

Objectives other than those based solely on timber production are carrying more and more weight nowadays in forestry decision-making. This is true not only of the public, but also is often the case with private forest landowners (e.g. Hyberg and Holthausen 1989, Kreutzwiser and Wright 1990). Satisfying the basic needs of wildlife populations is an example of such objectives. Incorporating wildlife management into forest planning is a task for multiple-use planning of forest resources.

Problems crucial to any forest planning process include (i) determining the objectives and their importance, (ii) describing the decision alternatives, (iii) evaluating the decision alternatives with respect to each objective, and (iv) making the objectives and evaluations of decision alternatives commensurable. Because of the complexity of forest planning problems, optimization techniques are needed to work out the optimal combination of standwise treatment schedules for a forest area.

Multiple-use planning of forest resources is always multiobjective, and the objectives are seldom measurable using the same units. Different units create problems particularly in steps (i) and (iv). Recently, planning methods have been developed especially for taking the preferences of the decision-maker more accurately into account (e.g. Mendoza and Sprouse 1989, Kangas and Pukkala 1992, Kangas et al. 1993), considering non-linear utility functions (Pukkala and Kangas 1993), quantifying qualitative data (Korhonen 1986, Hyberg 1987, Korhonen and Wallenius 1990, Kangas 1992a, 1992b), and making different kind of objectives commensurable (Mendoza and Sprouse 1989, Kangas 1992b, Pukkala and Kangas 1993). Basic techniques and methods for strategic and tactical forest planning are also available when it is a question of multiobjective optimization with non-linear utility functions, or strategic decision-making with qualitative criteria.

The main problem of incorporating wildlife management into forest planning is the lack of production functions or other evaluation models that could be used to estimate the priorities of decision alternatives with respect to wildlife populations. When models based on objective information are not available, the needs of wildlife populations – shelter, reproduction, food and water, and movement – may be incorporated into planning using expert knowledge (e.g. Kangas 1992b).

Much research has been done in Nordic Countries on the economic evaluation of wildlife (e.g. Mattson 1990, Ovaskainen et al. 1992) and habitats of wildlife species (e.g. Helle and Järvinen 1986, Rolstad and Wegge 1989, Helle and Helle 1991). However, there is a dearth of habitat suitability functions based on objective data, and applicable to modern forest planning methods. For example, monetary evaluations of wildlife populations do not solve the problems of incorporating wildlife management into forest planning. Priorities should be calculated from the information available on the decision alternatives. However, much expertise has been gathered over the years, both in research and in practical wildlife management.

Various habitat evaluation procedures have been developed in the USA as habitat-based approaches for assessing the impacts of proposed plans on wildlife resources (e.g. Urich and Graham 1983, Hunter 1990, Anderson 1991). Most procedures are based on habitat suitability indices, often ranging from 0.1 to 1.0. The habitat suitability index measures how well existing or proposed habitat conditions compare to optimum conditions. The product of the index and the area of available habitat measures, in habitat units, both the quality and quantity of the habitat (Urich and Graham 1983).

Applying habitat suitability indices, as described above, to multiple-use planning is problematic and ambiguous. For example, the relation between habitat preference and carrying capacity at the level of the population is not clear (Hobbs and Hanley 1990). This is why habitat units can not be used as an absolute measure of habitat quality and quantity. Furthermore, interpretation of indices on an interval or ratio scale is questionable.

To be of use in forest planning, habitat suitability function has to, at least, produce priorities of decision alternatives on an interval, and preferably on a ratio, scale. In addition, in practical forest planning, the estimation process should be automatic. A measure should be available for each plan or treatment schedule. With multicriteria decision methods, ratio scale is usually needed.

In this study, a method for estimating a habitat suitability function on the basis of expertise is presented. Using the function, relative priorities of decision alternatives can be calculated with respect to the needs of wildlife species. The method is illustrated by a case study, in which a habitat suitability function is estimated for calculating priorities of forest plans with respect to the needs of black grouse (*Tetrao tetrix, Lyrurus tetrix L.*).

2 Estimation method

2.1 Steps of the method

The main steps of the process of estimating a habitat suitability function are as follows:

(i) a set of experts on habitat evaluation with respect to the needs of the wildlife species in question is chosen,
(ii) a material consisting of a set of different forest areas is produced,
(iii) the forest areas produced in step (ii) are evaluated by the experts chosen in step (i),
(iv) the relative priority of each area is estimated on the basis of step (iii), and
(v) the priority function is estimated which predicts the relative priorities estimated in step (iv), using measurable characteristics of the forest areas produced in step (ii) as predictors.

The resulting priority function is a habitat suitability function of the wildlife species for which the material was evaluated. It gives relative habitat suitability indices for alternative forest areas, or states of a forest area. These indices can be used for integrating the needs of wildlife into multiple-use planning of forest resources.

Before the comparison process, information on the needs of the species in question is gathered: both theoretical and empirical research is examined, and experts are interviewed, if necessary. This prior information is needed to produce a proper material with reasonable variability with respect to priority, and to choose the information to be presented to the experts for evaluation. Prior information also helps to decide the predictors of the habitat suitability function.

Different forest areas are evaluated by comparing them in a pairwise manner. Pairwise comparisons are analysed using the eigenvalue technique developed by Saaty (1977). The technique is the same as applied in the Analytic Hierarchy Process (Saaty 1980), and is based on a general theory of ratio scale estimation (Saaty 1977, Harker and Vargas 1987).

In step (v), the habitat suitability function is estimated using regression analysis.

2.2 Analysis of pairwise comparisons

In making the comparison, it is a question of which of the two forest areas is better with respect to the needs of the species, and how much better it is. The expert has the option of expressing the priority ratio as (i) equal priority of both forest areas, (ii) weak priority of one forest area over another, (iii) strong priority of one forest area over another, (iv) demonstrated priority of one forest area over another, or (v) absolute priority of one forest area over another. The priority ratios are translated into numerical values of 1:1, 3:1, 5:1, 7:1, and 9:1, respectively, or 2:1, 4:1, 6:1, and 8:1, as intermediate values. After carrying out the comparisons, a reciprocal matrix **A** of pairwise comparisons (1) is constructed.

$$\mathbf{A} = (a_{ij}) = \begin{bmatrix} 1 & p_1/p_2 & \cdots & p_1/p_n \\ p_2/p_1 & 1 & \cdots & p_2/p_n \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ p_n/p_1 & p_n/p_2 & \cdots & 1 \end{bmatrix} \qquad (1)$$

where p_i/p_j is the priority ratio between forest areas i and j; n is the number of forest areas compared

Using the matrix as input, the relative priorities of the forest areas under comparison, with respect to the needs of the species, are computed using the eigenvalue technique. The right eigenvector of the largest eigenvalue of matrix **A** constitutes the estimation of relative priorities. The relative priorities are calculated by solving the eigenvector equation

$$(\mathbf{A} - \lambda_{max}\mathbf{I})\mathbf{q} = 0 \quad (2)$$

where λ_{max} is the largest eigenvalue of **A**; **q** is its right eigenvector; **I** is the unity matrix

Saaty (1977) has shown that λ_{max} of a reciprocal matrix **A** is always greater or equal to n. If the pairwise comparisons do not include any inconsistencies, λ_{max} = n. The more consistent the comparisons are, the closer the value of computed λ_{max} is to n. Based on this property, a consistency index, CI, has been constructed.

$$CI = (\lambda_{max} - n) / (n - 1) \quad (3)$$

CI estimates the level of consistency with respect to the entire comparison process. A consistency ratio, CR, also measures the coherence of the pairwise comparisons. To estimate the CR, the average consistency index of randomly generated comparisons, the ACI, has to be calculated. The ACI varies functionally according to the size of the matrix (e.g. Saaty 1980).

$$CR = 100(CI / ACI) \quad (4)$$

In human evaluation processes, some inconsistencies can be expected. As a rule of thumb, a CR value of 10 % or less is considered acceptable.

3 Material

3.1 Alternative plans

The case study area covers about 117 ha in the Koli village (64°N, 31°E), North Karelia, Eastern Finland. The site varies from very fertile (*Oxalis-Myrtillus* type) to poor (*Calluna* type) (Cajander 1949). Most sites belong to medium fertility classes (*Myrtillus* and *Vaccinium* type). About 85 % of the standing volume is Scots pine, the rest being mainly birch. The average stand volume is quite high, 150 m^3/ha, and more than half of the area is old enough to be regenerated.

The forest has been divided into 114 compartments. The stand characteristics of each compartment have been measured using ocular compartment inventory. The field data for a compartment included, among others, stand basal area, tree age, and tree height, which were known for each tree species.

Several different treatment schedules were simulated for each compartment for the coming 20-year period using the program devised by Pukkala (1993). The total number of treatment schedules was 444.

Ten different management plans were compiled from the simulated schedules using the heuristic optimization method of Pukkala and Kangas (1993). The idea was to produce clearly different plans, one plan aiming at high birch volume, another at low remaining birch volume, a third at high removal, etc. This variation was created by changing the criteria used in the optimization, and by varying their relative importance.

The final state of the forest, after implementing the ten 20-year plans, was described by several numerical parameters and by three thematic maps (Fig. 1). The numerical parameters included the proportions of different tree species of standing volume, age class distribution, area of birch stands, total length of boundaries between distinct forest stands (height difference > 5 meters), etc. The first thematic map showed the extent and location of such stands, where the share of birch was at least 50 % of stand volume, or the share of birch was at least 10 %, and birch was the tallest tree species. The second map indicated the proportion of conifers in the stand volume, and the third the mean tree height in different stands.

Both the numerical information and the maps showed properties of the forest that, according to literature on the subject (e.g. Marcström et al. 1981, Angelstam 1983, Kolstad et al. 1984, Marjakangas 1986) and the preliminary interviews of two experts, might be useful in comparing the plans with respect to the habitat suitability for black grouse.

An additional way of presenting alternative plans was a landscape illustration created by computer graphics (see e.g. Kellomäki and Pukkala 1988, Nuutinen and Pukkala 1992). The illustration showed the landscape after a period of 20 years, when viewed from Lake Pielinen. This presentation method was aimed at helping experts who had no forestry education, and who were therefore less familiar with forest maps and numerical forestry parameters.

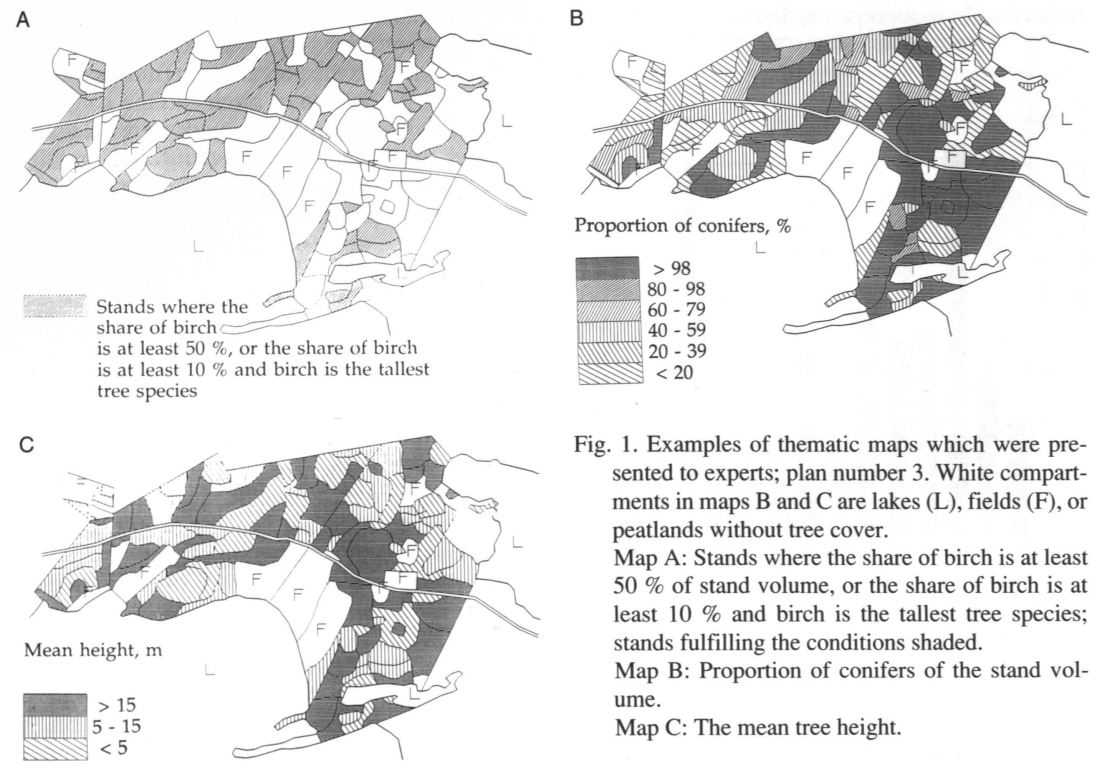

Fig. 1. Examples of thematic maps which were presented to experts; plan number 3. White compartments in maps B and C are lakes (L), fields (F), or peatlands without tree cover.
Map A: Stands where the share of birch is at least 50 % of stand volume, or the share of birch is at least 10 % and birch is the tallest tree species; stands fulfilling the conditions shaded.
Map B: Proportion of conifers of the stand volume.
Map C: The mean tree height.

3.2 Evaluations

A total of 15 experts evaluated the alternatives using pairwise comparisons. An evaluation was made, not on the plans themselves, but of the predicted final state of the forest, due to the implementation of the plans. The plans were only a means of producing different habitats.

Two plans at a time were compared by the expert, and the priority ratio, determined by the expert, was recorded on a sheet. The number of comparisons was 45 ((10 · 9) / 2 = 45). Each expert was given written instructions, and the procedure was also thoroughly explained to the expert by one of the authors.

The experts represented wildlife researchers, hunters, biologists and foresters; quite often the expert came into more than one of these classifications (e.g. forester and hunter, or wildlife researcher and hunter). The time needed for the evaluations varied from 1 to 5 hours.

A consistency ratio was computed for the evaluations of each expert. The pairwise comparisons were converted into relative priorities using the methodology of the Analytic Hierarchy Process (Saaty 1977, 1980). The mean priority of all 15 experts was used as the predicted variable in the habitat suitability model.

4 Results

4.1 Consistency of evaluations

Generally, the pairwise comparisons by the 15 experts in this study were rather consistent. However, the evaluations were clearly inconsistent in two cases, and in five cases the consistency ratio was slightly higher than 10 % (Fig. 2). These results may be interpreted to infer that the evaluation of plans is not usually too difficult a task, and that some inconsistencies in the pairwise

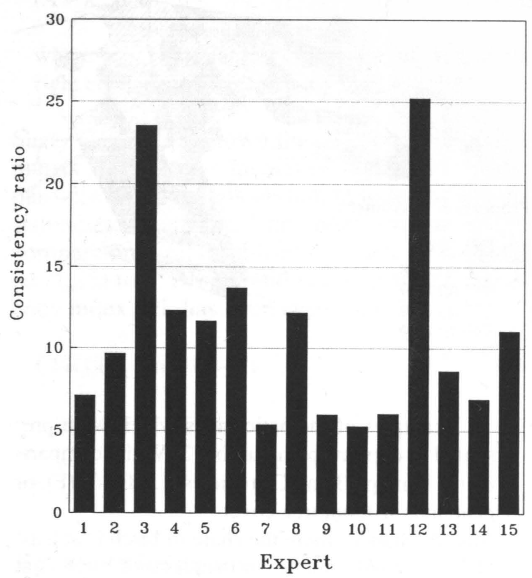

Fig. 2. Consistency ratios of pairwise comparisons made by experts.

comparisons do not invalidate the overall worth of the habitat model.

4.2 Priorities

The priorities given to different plans by the 15 experts varied from 0.0161 to 0.3010 (Table 1). The priorities of an expert typically included ten-fold differences between the best and poorest plan, but there were clear differences among the experts in the range on variation. This indicates that the experts may have used different scales in the evaluations, or that their opinions were different.

Plans 3 and 7 were among the best ones, according to most experts, while plans 1 and 4 were often considered to result in a poor habitat (Table 1). There were a few plans that were considered good by some experts but poor by other experts (plans 2, 6, 8 and 10). Expert 2 had clearly different priorities from the others; for example, he considered that plan 4 would produce a good habitat, and plan 3 a poor one, although the opposite was true for the other experts. Expert 1 had also slightly different opinions from the majority.

Otherwise the priorities of the experts were quite similar. This similarity resulted in clearly different mean priorities for different plans: the best plan (number 3) had a mean priority 4.6 times higher than the poorest plan (number 1). In plan 3, the proportion of birch and the length of boundaries between distinct stands were the greatest, and the proportion of young and middle-aged forest stands (20–60 years) were high. In plan 1, the proportion of birch was the smallest: stands which were clearcut were planted for spruce and pine.

4.3 Habitat suitability function

The mean priority correlated positively with the share of birch in the standing volume, and with the proportion of such stands in which birch was the dominant or tallest species (Table 2). The proportion of stands with a significant birch mixture explained on its own 80 % of the variation in the mean priority.

The correlation was negative for the volume of pine and for the share of conifer stands, although it is known that young pine stands are a relevant element of a good habitat for black grouse (e.g. Marcström et al. 1981, Marjakangas 1986). However, the share of young sapling stands (stand height 5–15 m) correlated positively with the mean priority, as well as the share of stands with a high pine mixture.

On the basis of these calculations, it seems that a good habitat for black grouse should include plenty of birch-dominated stands and, at the same time, young pine stands in the sapling stage. In addition, old conifer stands with a high stand volume should not be too common.

The prediction model for the habitat suitability was devised after testing several combinations of two or three variables. The best 2- and 3-predictor models were the following equations:

$$\ln(HSI) = -5.832 + 1.038 \ln(Birch) + 0.041 \ln(Pine) \quad (5)$$

where HSI (habitat suitability index) is the mean priority of 15 experts; Birch is the proportion of birch in the whole forest (% of standing volume); and Pine is the proportion of such stands (%) where the share of pine is at least 40 % of the standing volume

$$\ln(HSI) = -9.991 + 0.946 \ln(Birch) + 1.439 \ln(Height_{5-15}) + 0.023 \ln(Pine) \quad (6)$$

Table 1. Relative priorities of different plans according to 15 experts. The three highest priorities of each expert are written in boldface, and the three lowest priorities in italics. Stdv means standard deviation.

Expert	Plan number									
	1	2	3	4	5	6	7	8	9	10
1	*.0176*	*.0258*	**.1806**	**.1309**	.1244	.1125	.1061	*.0440*	.0942	**.1639**
2	.0599	*.0240*	*.0533*	**.2323**	.0839	**.1180**	.0861	*.0275*	.0793	**.2356**
3	*.0337*	*.0409*	**.1995**	.1241	*.0429*	.0861	**.1539**	.0542	.0536	**.2111**
4	*.0257*	.0616	**.3010**	*.0173*	.0683	.0355	**.1779**	.1247	**.1687**	*.0195*
5	*.0207*	.0598	**.1324**	*.0256*	.0905	.0758	**.2975**	.0977	**.1475**	*.0524*
6	.1168	**.1412**	**.1669**	*.0233*	.0608	*.0410*	.0894	**.2493**	.0838	*.0274*
7	*.0211*	*.0347*	**.2543**	*.0667*	.0953	.0631	**.1729**	.0756	**.1474**	.0690
8	*.0269*	.0883	**.2662**	*.0464*	.0840	*.0580*	**.1469**	.0615	**.1576**	.0642
9	*.0329*	.0544	**.2300**	*.0251*	.0929	.0518	**.2458**	.1047	**.1261**	*.0362*
10	.0838	**.1273**	.1057	*.0444*	.0813	*.0480*	**.1268**	**.2074**	.1123	*.0629*
11	*.0259*	.0504	**.2041**	*.0336*	.0930	.0483	**.1555**	**.2388**	.1166	*.0340*
12	.0622	.0898	**.2023**	*.0161*	.1199	*.0349*	.1173	**.2050**	**.1322**	*.0203*
13	*.0348*	**.1359**	**.1722**	*.0345*	.1026	.0324	**.2261**	.0966	.1238	*.0411*
14	*.0214*	.0799	**.1840**	*.0600*	.1127	.0896	.0998	**.1592**	**.1252**	*.0682*
15	*.0238*	**.1895**	**.1561**	*.0229*	.0730	.0478	.0959	**.2182**	.1342	*.0386*
Mean	*.0405*	.0802	**.1872**	*.0602*	.0884	*.0629*	**.1532**	**.1310**	.1202	.0763
Stdv	.0283	.0487	.0629	.0595	.0219	.0276	.0625	.0758	.0314	.0692
Rank	10	6	1	9	5	8	2	3	4	7

where $Height_{5-15}$ is the proportion of stands in which the mean height of trees (weighted by the basal area) was between 5 and 15 meters; others as in Equation (5)

Equation (5) explained 93 % of the variance of the mean priority (Adjusted $R^2 = 0.91$). The error variance was 0.02011, and the relative standard error of estimate 5.9 %. Both predictors were highly significant.

Equation (6) explained 98 % of the variance of the mean priority (Adjusted $R^2 = 0.97$). The error variance of Equation (6) was 0.0073. The relative standard error of estimate was 3.7 %. All three predictors were highly significant.

Table 2. Correlation of the mean priority with some variables describing the forest area.

Variable	Correlation
Standing volume, m^3/ha	–0.47
Share of pine, % of standing volume	–0.86
Share of birch, % of standing volume	0.74
Share of birch-dominated stands[1], % of area	0.92
Share of 5–15 m high stands, % of area	0.74
Share of 20–40 year old stands, % of area	–0.21
Share of stands with plenty of conifer[2], % of area	0.49

[1] Stands where the proportion of birch is at least 50 %, or the share of birch is at least 10% and birch is the tallest tree species.
[2] Stands where the share of conifers is at least 40% of stand volume.

5 Discussion

Estimating production functions or other models for calculating the suitability of habitats for wildlife species on the grounds of objective data is difficult and time-consuming, and such models are not available at the moment. However, there is an urgent need to take wildlife management considerations into account in forest planning. Until production functions or other evaluation procedures on the basis of objective information have been compiled, wildlife management in the context of forest planning has to rely on expertise.

The approach of modelling expert knowledge concerning the needs of wildlife populations, and the method developed in this study, proved to be very promising. The priorities estimated by applying the method can be utilized in incorporating wildlife management into forest planning carried out using numerical optimization techniques. In this study, habitat suitability function was estimated, as a test of the method, for black grouse. The same estimation process could be applied to any wildlife species.

Consistency of pairwise comparisons carried out by experts was mainly good. In addition, the evaluations made by different experts were quite similar – except for one person. There are several explanations why Expert 2 had such exceptional priorities. One may be insufficient concentration on the evaluation, or misunderstanding of the comparisons. However, the consistency of his evaluations was good. It is therefore more probable that he really had distinctly different opinions from the others. It may be assumed that the opinions of the majority of the experts are more correct than those of the one expert who turns out to be an exception. The choice of experts have to be made with care: the more familiar experts the more accurate models.

Most experts found the comparisons rather difficult (scale: very difficult, difficult, rather difficult, not difficult nor easy, rather easy, easy, very easy, can not say). Causes of difficulties, mentioned by the experts, included: different factors have different effects on the priority of habitat and all the effects have to be dealt with simultaneously in the comparisons, black grouse has different needs during different seasons, characteristics of undervegetation were not known in the evaluation process, and lack of knowledge of the minimum factors related to the needs of black grouse.

Instead of comparing forest areas holistically, comparisons could be made separately for each factor. However, using this approach all the factors considered should be decided before comparisons, and, for calculating overall suitability, weights of factors should be determined. Furthermore, scaling problems might arise: factors have to be made commensurable. Correspondingly, comparisons could also be carried out separately with respect to each season. Concerning the lack of information on undervegetation, the situation is the same in practical forest planning: information on undervegetation is not available in evaluation of decision alternatives.

Equations (5) and (6) indicate that black grouse needs both stands with a high birch mixture and stands with a high pine mixture. The same conclusion can be found in the literature available on black grouse (e.g. Marcström et al. 1981, Marjakangas 1985, 1986). The importance of stands in which the mean height of trees is 5–15 meters has also appeared in empirical investigations; for example, according to Seiskari (1962), black grouse prefers forest stands where the height of trees is 7–18 meters.

Contrary to prior information (e.g. Kolstad et al. 1984), the models did not contain the effect of the boundary zones of distinct forest stands, although it was tested as a predictor. This was most probably due to the material evaluated: variation of the total length of boundaries of distinct stands was not large enough (from 9015 to 11881 meters). If there was more variation in the material with respect to the total length of boundaries, it might have been included in the model. If the total length of boundaries of distinct forest stands was a predictor in the equation, the equation could not be applied using mathematical programming. In this case, for example, the HERO heuristic optimization method of Pukkala and Kangas (1993), which can deal with non-additive objectives, could be applied.

Because the material did not contain enough variation with respect to many potential predictors, the models estimated in this study are not generally applicable. They have to be considered as prototypes of habitat suitability functions, estimated in a study where testing a new method was the main task. On the basis of the experience of this study, more generally applicable habitat suitability functions will be estimated.

In the estimation of habitat suitability functions to be used in practical forest planning, the material should contain more variability with regard to potential predictors. In this study, only one forest area, with the same state of forest as the starting point in planning calculations for each plan, was applied. Perhaps several forest areas could be included in the material. More than ten alternatives, at least, should be evaluated. For decreasing the amount of comparisons needed, the material could be arranged into sets of alternatives: the alternatives within each set could be compared to each other, and the priorities of alternatives of different sets could be scaled using the scaling method presented by Kangas et al. (1993).

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