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Abstract Modelling species distribution is an important aspect of conservation ecology. Empirical models are most commonly used. However, collecting data for these models is time-consuming and expensive. Expert models may be a good alternative method, though previous studies have found mixed results. The purpose of our study was first to create an expert model and evaluate it with independent lynx data, and second to use two discrete types of experts to control for prior radio-tracking experience. Two habitat suitability expert models (scientific and local experts) were constructed in a Geographical Information System using the Analytical Hierarchy Process and Compromise Programming. The models were evaluated with lynx data, taken from the study area in the northwestern Swiss Alps, using Resource Selection Index and Spearman correlation. The correlations showed that both models fitted the data well. However, the local expert model was better (rs = 0.964, P < 0.001) than the scientific expert model (rs = 0.833, P < 0.001). The models were also evaluated in the Jura Mountains to test the local nature of the models. It was found that the local expert model performed less well (rs = 0.939, P < 0.001) than the scientific expert model (rs = 0.967, P < 0.001) as expected. Comparison between weights for each expert group revealed some interesting differences, which showed the local nature of answers and how personal experience and theoretical knowledge can lead to different answers. Our study shows that expert knowledge, and especially local knowledge, can be employed to create a good habitat suitability model. This has important implications for conservation and science because it shows not only that expert knowledge may be used when no other data exist, but also that local 'ground workers' should be employed more often in the development of habitat suitability models or conservation plans. However, there are limitations to the models and, as expert models are relatively new in ecology, more research is needed. Nevertheless, in a climate where there is pressure to keep up with human exploitation of natural resources and to adopt a more strategic approach to conservation, the findings of our study are encouraging.

Testing expert groups for a habitat suitability model for the lynx *Lynx lynx* in the Swiss Alps

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Key words: conservation, local experts, Lynx lynx, multi-criteria decision-making, scientific experts, Switzerland

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Habitat suitability models are often crucial tools in conservation for the development of proper wildlife management plans. They depict the likelihood of the occurrence of a species and enable conservationists to find the landscape properties of a species' preferred habitat. This is important as exhaustive surveys are often impossible (Manel et al. 1999). Suitability models are typically based on empirical data and their usefulness in conservation has been well established (Austin et al. 1996, Corsi et al. 1999, 2000, Osborne et al. 2001). Empirical models based on radio-telemetry data, however, may not always accurately reflect the distribution of the whole population as they follow a few individuals and often make errors about absences (Corsi et al. 2000, Fielding 2002, Gu & Swihart 2004). Moreover, the collection of the data is time-consuming and expensive (Store & Kangas 2001). With growing pressure on agencies to produce fast and effective models to keep up with human exploitation of the natural environment, alternative methods that are low-cost and fast to produce are needed.

Alternatives to empirical habitat suitability models are Habitat Suitability Index (HSI) models and expert models. HSI models summarise the conceptual understanding of the habitat relationship of the target species, based on various sources of information through the definition of functions of selected environmental variables (Storch 2002). These models have received much criticism because they often use arbitrary classification schemes and are rarely tested with independent data (Roloff & Kernohan 1999). Expert models are relatively new in ecology and as such do not have an evidence base with comparable longevity to the aforementioned models, though their usefulness has been implied (Store & Kangas 2001, Pearce et al. 2001, Clevenger et al. 2002). There is a great number of potential techniques available for incorporating expert opinion into habitat suitability models (Carver 1991, Jankowski 1995, Pearce et al. 2001, Pereira & Duckenstein 1993, Store & Kangas 2001, Clevenger et al. 2002) making them attractive as the choice of method often depends on the purpose of the model, the species and the data (Manel et al. 1999).

Expert models

Expert opinion can be incorporated through rule-based methods, such as Hopkins' rule of combination (Hopkins 1977), through variable selection or refinement of maps (Pearce et al. 2001), or through Multiple Criteria Decision Making (MCDM) techniques (Carver 1991, Jankowski 1995). The central aim of MCDM is to "assist the decision maker in selecting the best alternative from a number of choices under the presence of multiple choice criteria and diverse criterion priorities" (Jankowski 1995).

Constructing a habitat suitability model can be viewed as a MCDM problem because of the need to find the best combination of variables that explain species presence. MCDM comprises a vast array of techniques. One of these techniques is the Analytical Hierarchy Process (AHP), which is based on the priority theory (Saaty 1977), and which is attractive for use in ecology as it allows for decisions to be made using the relative importance of habitat features for a selected species. Moreover, part of the AHP methodology is incorporated as a decision support tool in the Geographical Information System (GIS) program Idrisi (Eastman 1999).

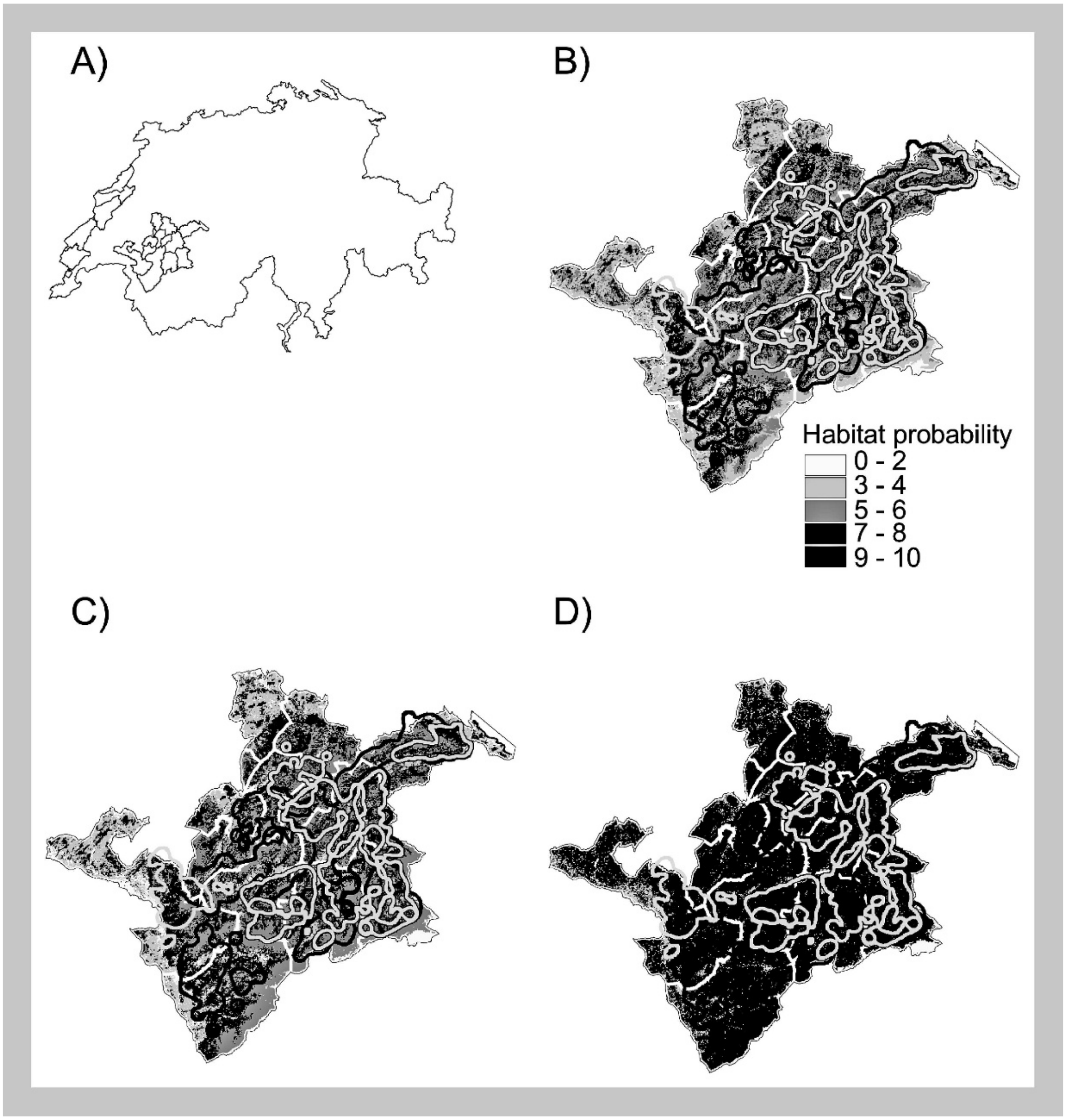

Figure 1. Local expert habitat suitability maps showing A) location of the study area (NWSA) and the validation area (Jura Mountains) in Switzerland; B) shows the output from the local expert models p1, C) p2 and D) p10. The white outlines in B-D show the district location of the game wardens who completed the questionnaires, while the black and grey outlines, respectively, show male and females lynx home ranges (95% Kernel; Breitenmoser-Würsten et al. 2001).

Expert-based models have shown mixed results when reviewed; Pereira & Duckenstein (1993) found that their model fitted presence data well, three other papers concluded that expert models are promising (Kangas et al. 1993, Tamis & Van't Zelfde 1998, Store & Kangas 2001) and Pearce et al. (2001) and Clevenger et al. (2002) concluded that although expert models are not as efficient as are empirical models, there is scope in conservation for them when time and data do not exist for constructing empirical models. Each of these papers used a different combination of techniques and a varying number of experts. The criteria for selection of variables, in these studies, were comparable to the criteria employed in empirical or HSI models. However, this may not be suitable when creating expert models as the aforementioned models tend to require the smallest significant number of variables. Expert models may benefit from including many variables as there is no calibration involved.

The wide array of techniques and its relative novel use in the development of habitat suitability models make it difficult to say which technique is best suited for achieving the purpose of the model. In our paper, we present a promising method such as used by Pereira & Duckenstein (1993), as it seemed best suited for the species; AHP and Compromise Programming, (CP; Zeleny 1973, 1982) a distance metrics similar to the Mahalanobis Distance Statistic. We also employed a set of variables as comprehensive as possible. We chose the reintroduced lynx *Lynx lynx* population in Switzerland because of its long monitoring history (> 10 years; Nowell & Jackson 1996), the well studied behaviour of the cats *Felis* sp. (Sunquist & Sunquist 2002) and the good GIS database (GEOSTAT - database of the Federal Office of Statistics). We decided to produce models for two discrete types of experts; scientific experts and game wardens, to see whether the type of expert interviewed would influence the model output. We used scientific experts from different European countries, who all were experienced in monitoring and radio-tracking the lynx and were thought to have 'universal' knowledge of lynx. We also used state game wardens, so-called local experts, and although they had no prior experience from telemetry, they had detailed knowledge of lynx behaviour and their whereabouts from their everyday working practice. Also, these two groups were made distinct to control for prior radio-tracking experience. Furthermore, local experts would be more readily available than scientific experts if this approach would be chosen for another region or species.

Material and methods

Experts and study area

There were 12 experts in each group. The first group, 'scientific experts' (S) consisted of researchers from Switzerland, Austria, Germany, Italy and Slovenia, who all had experience with radio-tracking of lynx. Originally, we contacted 30 scientific experts but only 12 replied. The second group, 'local experts' (L) consisted of game wardens from the western part of the northwestern Swiss Alps (NWSA; Fig. 1A). We chose this region because local experts had about 20 years of experience with lynx, and because lynx telemetry data existed for evaluation of the models.

The NWSA cover about 2,800 km^2 and are limited to the northeast by the valley of the Aare river with the lakes of Brienz and Thun, to the northwest by the Swiss Plateau, to the west by the Rhone valley with the Lake of Geneva, and to the south by the Bernese Alps rising up to 4,000 m a.s.l. The valley bottoms have been deforested and are densely populated. The human population reaches a density of 28/km^2 in most parts of the study area and people living in the lowlands use the Alps intensively for recreational activities such as skiing and hiking. Forests cover 30% of the study area, but they are highly fragmented. They extend along steep slopes up to the timberline at 1,800-2,200 m a.s.l. Lower ridges and gentle slopes have been deforested early and provide summer pastures for cattle and sheep. From late spring to autumn, domestic sheep *Ovis aries* graze unguarded on remote mountain meadows. The lynx's main prey in the study area is roe deer *Capreolus capreolus* and chamois *Rupicapra rupicapra* (Breitenmoser & Haller 1993), and lynx occasionally prey upon sheep (Angst et al. 2000).

Development of the expert models

We used the Analytical Hierarchy Process (AHP) to produce a set of weights rating the relative importance of lynx habitat variables and Compromise Programming (CP) to create the expert habitat suitability models.

Environmental variables used to describe the lynx habitat (Table 1) were selected by expert opinion and also based on the existing literature (e.g. Breitenmoser et al. 1993, Nowell & Jackson 1996, Zimmermann 1998, Zimmermann & Breitenmoser 2002, Zimmermann & Breitenmoser 2007). Certain variables were selected because of their effect on, or relationship with the biology and ecology of the lynx (e.g. forested areas, prey items and proximity to artificial structures), while others were selected to conform with the GIS layouts (e.g. slope, aspect and other topographical variables).

We put the variables into a hierarchy (Fig. 2), which then formed the basis of pairwise comparison matrices (Appendix I), in accordance with the AHP. Pairwise comparisons were completed by each expert using Saaty's (1977) nine-point continuous scale (Table 2). We constructed a questionnaire consisting of six pairwise matrices (i.e. land cover, topography, aspect, disturbance, prey and

Table 1. Environmental variables selected for the model.

Variables	Code	Units	Source	Description
Open forest	Ofor	Ha/km^2	GEOSTAT	Tree covered area including glades & rides
Closed forest	Cfor	Ha/km^2	GEOSTAT	Densely tree covered area
Other wooded areas	Owa	Ha/km^2	GEOSTAT	All other areas covered by some trees & shrubs
Cultivated areas	Ca	Ha/km^2	GEOSTAT	Surfaces with crop cultivation, gardens (outside towns) & golf courses
Pasture	P	Ha/km^2	GEOSTAT	Surfaces with grazing domestic animals, grassland, highland & fallow
Water bodies	W	Ha/km^2	GEOSTAT	Sea, lakes, ponds, rivers & streams
Glaciers	G	Ha/km^2	GEOSTAT	Glaciers
Built areas	Ba	Ha/km^2	GEOSTAT	All surfaces with constructions (e.g. car parks, industry, towns, camping sites.)
Elevation	E	Metre	GEOSTAT	(0 m - 4617 m)
Slope	S	Degree	GEOSTAT	0° - 80°
Aspect	A	(Sinus)	GEOSTAT	Flat, North, East, South and West
Proximity to:				
towns and villages	Pt	Metre	GEOSTAT	(100 × 100 m) distance from which the species is found
motorways	Pm	Metre	GEOSTAT	(100 × 100 m) distance from which the species is found
roads	Pr	Metre	GEOSTAT	(100 × 100 m) distance from which the species is found
railways	Prw	Metre	GEOSTAT	(100 × 100 m) distance from which the species is found
Roe deer	Rod	Ind/ha	[1]	
Chamois	C	Ind/ha	[1]	Also reindeer[2]
Red deer	Rd	Ind/ha	[1]	Also moose, ibex and wild boar [2]
Domestic animals	Da	Ind/ha	[1]	E.g. sheep, goats
Lagomorphs	L	Ind/ha	[1]	E.g. hares, rabbits
Rodents	R	Ind/ha	[1]	E.g. mice, squirrels
Tetraonids	T	Ind/ha	[1]	E.g. grouse, ptarmigan
Other birds	Ob	Ind/ha	[1]	
Carrion	Car	Ind/ha	[1]	Carcasses

[1] The variable was not included in final analysis as no data were available for the GIS.
[2] The animals were selected together when they were not in the same geographic range.

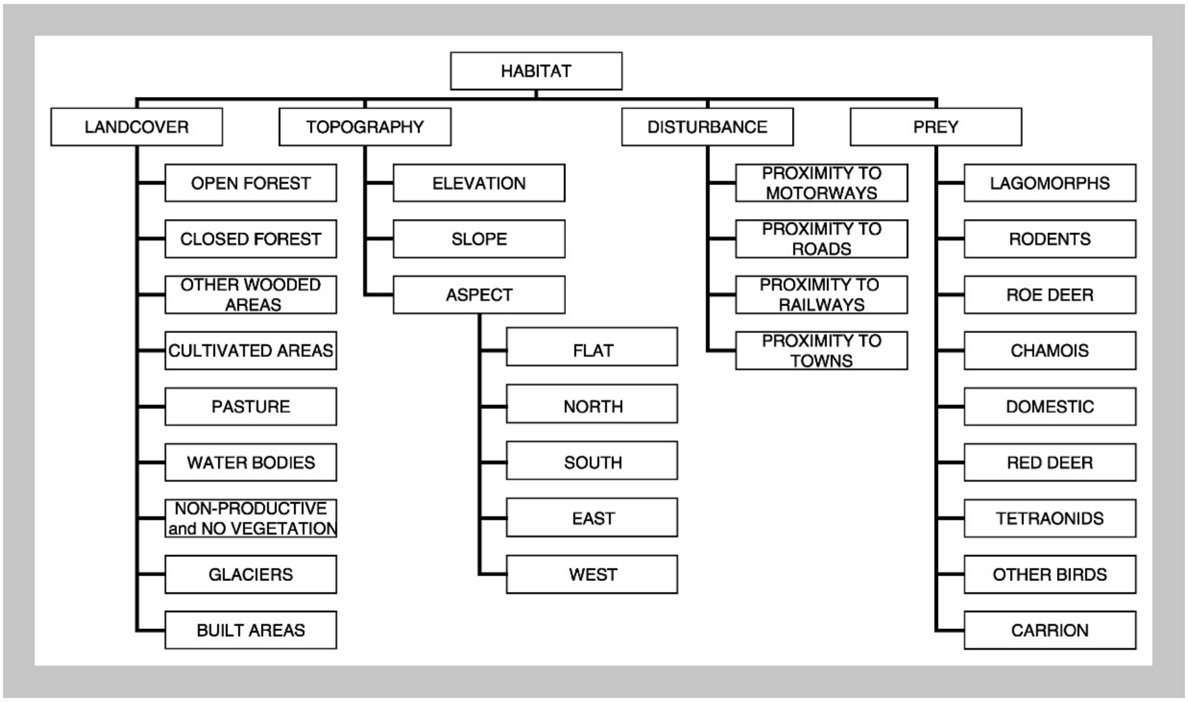

Figure 2. Hierarchy of the ecological variables and landscape features influencing lynx distribution used in the questionnaires and to compute the habitat suitability maps.

Table 2. Scale for the pairwise comparison matrix and its description according to Saaty (1977).

Intensity of importance attributed to criteria	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Weak importance of one over the other	Experience and judgement slightly favour one factor over the other
5	Essential or strong importance	Experience and judgement strongly favour one factor over the other
7	Demonstrated importance	A factor is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one factor over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgements	When compromise is needed

habitat) in relation to the hierarchy (see Fig. 2) and consisting of a series of questions for continuous variables such as elevation, slope and proximity to motorways, to determine range of values suitable for lynx habitat (see Appendix I). We also included a foreword in the questionnaire explaining how to complete the questionnaire (Doswald 2002). We sent the questionnaires to the scientific experts by mail, whereas the questionnaires to the game wardens were completed in individual face-to-face interviews so that it was ascertained that the English questionnaire would be understood. All experts were asked to give their ratings according to their personal experience and knowledge. Time of completion of the questionnaires was recorded.

We evaluated all matrices for consistency, i.e. the reliability of information supplied by an individual, as suggested by Saaty (1977). The consistency ratio must be ≤ 1 for the matrix to be considered consistent. If any matrix was $\beta > 1$, it was re-evaluated. We analysed the pairwise comparisons to produce the weights (βi; $\beta > 0$, $\Sigma\ \beta_i = 1$; Pereira & Duckenstein 1993) for each variable using the eigenvalue technique developed by Saaty (1977) and also implemented in the Idrisi software (Eastman 1999). The weights derived for the prey variables were not included in the development of the final models as there were no data available for the GIS and, as we assume, the habitat preferred by lynx already expresses the presence and availability of prey (Zimmermann & Breitenmoser 2002).

We took the medians of the weights for all the experts. To see the variation in weights, we established the Median Absolute Deviation about the Median (MAD). This was calculated by taking the difference between the median and the individual weights and then calculating the median of the differences.

We normalised the weights of two groups of variables (land cover: open forest - built areas, and aspect: flat - west) and the continuous variables to a [0,1] scale according to the procedure from Kamenetzky (1982):

$$S_{i/j} = \left(w_{j/i} - \min(j) w_{j/i}\right) / \left(\max(j) w_{j/i} - \min(j) w_{j/I}\right) \quad (1),$$

where: $w_{j/i}$ = the relative weight of j in comparison to i. We did this to create a common value scale where 0 is the least preferred value and 1 is the most preferred (Pereira & Duckenstein 1993). The other variables were not normalised as their weights (β_i) were used as such as demanded by AHP and formula 2.

The weights and normalised values were put into the GIS (Idrisi 32; Eastman 1999) using the Compromise Programming (CP) technique (Zeleny 1982):

$$d_P = \left[\sum_{i=1}^{I} \beta_i^P \left(x_i^* - x_i^k\right)^P\right]^{1/P} \quad (2),$$

where β_i ($\beta_i > 0$, $\Sigma\ \beta_i = 1$) = weights assigned to the criteria, x^* is a vector representing the ideal point ($x^* = 1$), x_i^k is the i^{th} of k normalised weighted environmental layer, and p ranges from 1 to ∞.

Varying p affects the relative contribution of individual deviations from the ideal point, a greater emphasis being given to larger deviations as p tends towards ∞. There are three strategic values p = 1, 2 and a nominal ∞ (i.e. $p \geq 10$; Pereira & Duckenstein 1993). When p = 1, total compensation between criteria is assumed, meaning that a decrease of one unit of one criterion can be totally compensated by an equivalent gain on any other criterion. For p = 2 there is only partial compensation and p = ∞ represents a totally non-compensatory situation (Zeleny 1982).

In order to compare the maps with the three strategic values of p, we had to discretise each map into 10 habitat quality classes at the ordinal level (Pereira & Duckenstein 1993) because the values of the cells differed considerably, i.e. the value for the worst site from p = 1 was very different to the value for the worst site from p = 2,.... A value of 1 represents cells of ideal habitat whereas a value of 10 represents cells of the worst habitat. This classification then had to be reversed to get a habitat suitability index (HSI) for the evaluation of the models. The maps were then transported into Arc View (ESRI, 1996a,b,c) and masked, so that only the study area was analysed.

Lynx data

We used telemetry data from 15 lynx (nine females and six males; Breitenmoser-Würsten et al. 2001) located in the area of the local experts in the NWSA (see Fig. 1) during 1997-2001 to estimate home ranges using a fixed-kernel estimator. Females were followed for an average of 902 days (range: 347-1,429) with 219 locations (range: 81-438). Males were followed for an average of 577 days (range: 321-763) with 135 locations (range: 65-333).

We also used telemetry data from seven lynx (five females and two males; Breitenmoser-Würsten et al. 2007) in the Jura Mountains (see inserted map in Fig. 1A) to validate the models in a new area. Females were followed for an average of 565 days (range: 232-1,096) with 224 locations (range: 127-314). The two males were followed for 756 and 1,055 days with 336 and 670 locations, respectively.

Home ranges were defined as the areas containing 95% of the estimated utility distribution. The calculations were done in ArcView (ESRI 1996a,b,c) using the animal movement extension (Hooge & Eichenlaub 2000).

Evaluation of the models

As radio-telemetry produces presence data, but no absence data, we could not use methods such as Goodness-To-Fit or Receiver Operating Characteristic (ROC) plot methodology (Guisan & Zimmermann 2000), which both need presence and absence data, to evaluate the models. Instead we decided to use a resource selection approach.

Habitat suitability for the lynx, as referred to by the models, can also be tested as habitat preference by the lynx using the radio-telemetry data. To measure preference, it is necessary to compare the usage of certain habitats (or HSI) with the availability of all habitat (or HSI) types (Johnson 1980, Boyce et al. 2002). We used the Resource Selection Index (RSI; Manly et al. 1993, Krebs 1999, Boyce et al. 2002, McLoughlin et al. 2002) as a measure of preferential use of HSI by lynx, which could then be correlated with HSI to examine the performance of the models. The RSI was calculated as:

$$w_i = \frac{\text{proportion used}_i}{\text{proportion available}_i} \quad (3).$$

These ratios were then standardised to a [0,1] scale as suggested by Manly et al. (1993):

$$b_i = \frac{w_i}{\sum_{i=1}^{H} w_i} \quad (4),$$

where i ranges from 1 to H, and H = number of habitat types (HSI).

We calculated this for each individual lynx using the home range data and habitat data. The results were then averaged over the entire study area. Spearman correlations were performed between the RSI for the study area and the HSI, and between each individual lynx home range and HSI, to see how well the models predicted for individual lynx as these were thought to vary.

A positive correlation between RSI and HSI would indicate that the models performed well. This is because the higher HSI have been modelled as the most suitable habitat for the lynx and the lower HSI as the worst. Therefore, if the models are suitable, then the lynx should use the higher HSI classes more than the lower HSI classes. Resource selection is normally used to determine which habitat type the animals prefer. However, we were not using this method to measure actual lynx habitat preference as the HSI are arbitrary categories that measure habitat suitability. Therefore, although the method may have its limitations, such as non-independence of proportion (Aebischer et al. 1993), we only used it as a measure of model performance.

Results

The average time of completion of the questionnaire was 48 minutes (range: 30-60 minutes) for the local experts (L), which were interviewed, and

61 minutes (range: 30-120 minutes) for the scientific experts (S), which had to read the instructions. Only one matrix out of a total of 144 matrices had to be re-evaluated because of inconsistency.

Variables

The variables deemed most important to determine lynx habitat were similar in both groups of experts. These variables were land cover, forested areas (especially open forest), aspect and south. The prey variables that were deemed most important for the lynx were roe deer and chamois. The overall matrix showed different weights before it was edited to remove the prey variable. The results were for prey 0.541 (S), 0.606 (L); topography 0.076 (S), 0.079 (L); disturbance 0.088 (S), 0.076 (L); and land cover 0.295 (S), 0.239(L). This shows that the two groups were very consistent regarding the importance of resources and landscape features allowing lynx to exist, and that prey was considered most important, followed by land cover, disturbance and topography. In the edited matrix land cover came out as the most important (Table 3).

There was a great difference between median weights/continuous variables for the L and S as the non-overlapping ranges showed (see Table 3).

Table 3. Median weights and continuous variables for local experts (L, game wardens; N = 12) and scientific experts (S; N = 12). Q1 and Q3 represent the first and third quartile of the range. See Table 1 for variable codes.

	Median weight/variables		Median absolute deviation about the median		Range (Q1-Q3)	
Variable	L	S	L	S	L	S
Land cover	0.621	0.669	0.080	0.061	0.333-0.665	0.605-0.718
Topography	0.238	0.182	0.157	0.101	0.081-0.485	0.081-0.273
Disturbance	0.141	0.149	0.080	0.059	0.061-0.247	0.090-0.249
Ofor	0.282	0.263	0.043	0.050	0.251-0.326	0.211-0.309
Cfo	0.196	0.252	0.098	0.053	0.118-0.244	0.195-0.307
Owa	0.234	0.197	0.011	0.039	0.210-0.246	0.150-0.233
Ca	0.052	0.064	0.007	0.009	0.283-0.569	0.050-0.075
P	0.103	0.094	0.029	0.026	0.073-0.157	0.059-0.123
W	0.013	0.015	0.001	0.002	0.011-0.027	0.013-0.023
Np	0.082	0.087	0.017	0.041	0.076-0.106	0.031-0.124
G	0.015	0.015	0.002	0.001	0.013-0.018	0.132-0.175
Ba	0.020	0.015	0.005	0.002	0.016-0.035	0.014-0.022
E	0.253	0.337	0.079	0.139	0.126-0.333	0.114-0.521
S	0.286	0.310	0.180	0.056	0.104-0.466	0.230-0.561
A	0.460	0.351	0.126	0.153	0.333-0.649	0.104-0.631
Flat	0.100	0.133	0.054	0.063	0.041-0.142	0.067-0.15
North	0.085	0.146	0.041	0.077	0.045-0.140	0.066-0.223
East	0.182	0.173	0.072	0.053	0.108-0.252	0.115-0.228
South	0.353	0.343	0.087	0.080	0.257-0.430	0.242-0.425
West	0.276	0.192	0.123	0.054	0.142-0.381	0.133-0.307
Pt	0.215	0.046	0.057	0.078	0.168-0.289	0.041-0.157
Pm	0.091	0.220	0.007	0.131	0.050-0.095	0.085-0.305
Pr	0.324	0.451	0.057	0.132	0.199-0.367	0.193-0.506
Prw	0.367	0.204	0.064	0.088	0.324-0.476	0.135-0.412
Elevation:						
Minimum (m)	600	0	240	0	400-1000	0-475
Maximum (m)	2000	1900	200	100	1800-2300	1800-2000
Slope:						
Minimum (°)	0	0	0	0	0-15	0-0
Maximum (°)	50	75	10	5	45-60	52.5-80
Distance to:						
motorway (m)	50	75	50	60	1-100	12.5-250
railway (m)	50	10	50	10	1-100	0-82.5
roads (m)	50	10	50	10	1-100	1.3-42.5
town (m)	100	100	100	50	15-200	100-187.5
Land cover (prey) [1]	0.214	0.296	0.039	0.055	0.146-0.253	0.235-0.371

[1] Median weight of land cover in the non-edited matrix, i.e. with prey as a variable.

These were cultivated areas, north, proximity to town and land cover (in the prey matrix before editing of matrix to remove the prey variable). For the continuous variables, minimum elevation and maximum slope also did not overlap between experts groups.

Both L and S assigned a wide range of weights to certain variables (see Table 3). This was especially the case for elevation, aspect and slope and the disturbance variables (see Fig. 2) where the standard deviation for both groups was large. The scientific experts created a range of weights for north, whereas the game wardens' responses differed in regards to the overall variables (see Fig. 2) and the distances from motorways, roads, rail and town.

Habitat models

The habitat maps resulting from applying CP to the study area with the game warden derived weights are depicted in Figure 1. Sensitivity analyses for the three values of p yield distinct maps. Visual comparison reveals the sharpest contrast between p = 1 and p = 10. Maps with p = 10 have less overall categories and class more habitat as suitable whereas the reverse is seen for p1 maps. The p2 maps show an intermediate view point.

The number of cells in HSI classes greater than five are for local experts: 103,827 (p1), 135,145 (p2),

Table 4. Correlation matrix between scientific (S) and local expert (L) models (p1, p2, p10).

	Scientific expert			Local experts		
	S p10	S p2	S p1	L p10	L p2	L p1
S p10	1	-	-	-	-	-
S p2	0.796	1	-	-	-	-
S p1	0.691	0.970	1	-	-	-
L p10	0.965	0.844	0.722	1	-	-
L p2	0.752	0.989	0.968	0.807	1	-
L p1	0.697	0.941	0.959	0.719	0.965	1

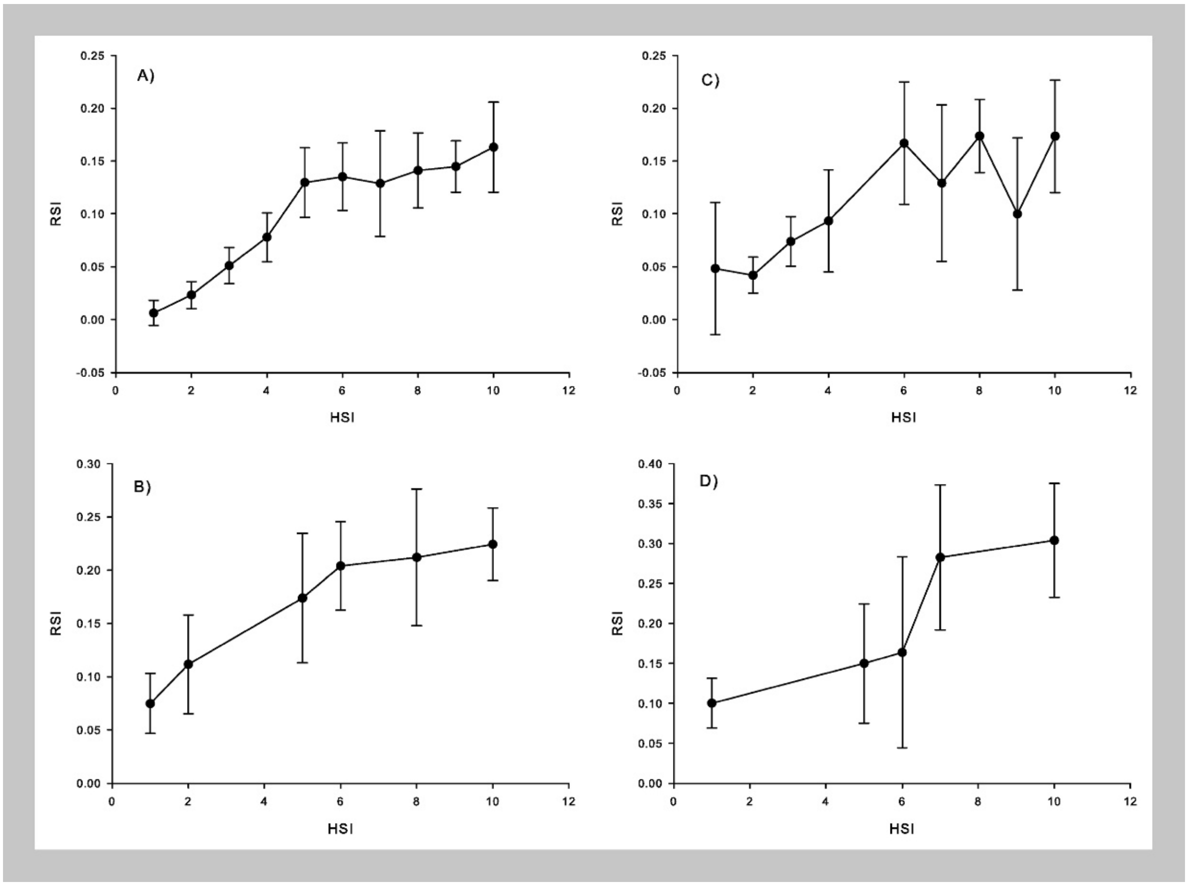

Figure 3. Relationship between habitat use expressed as resource selection index (RSI) and the habitat suitability index (HSI). A) and B) depict the local expert models p1 and p2, respectively, and C) and D) depict the scientific expert models p1 and p2, respectively. The circles in each graph depict the mean RSI per habitat suitability category. Not all habitat classes are represented in each model (p1 and p2); therefore the number of dots differs in each correlation.

Table 5. Correlation coefficients (rs) and significance (P) for individual lynx in the NWSA for the local expert models (L) p1 and p2 and the scientific expert models (S) p1 and p2. M indicates male lynx and F indicates female lynx.

	L p1		L p2		S p1		S p2	
Lynx id.	rs	P	rs	P	rs	P	rs	P
M_{Atos}	0.927	<0.001	0.429	0.397	0.567	0.112	0.500	0.391
M_{Yaro}	0.903	<0.001	0.886	0.019	0.333	0.381	0.800	0.104
M_{Kobi}	0.903	<0.001	0.943	0.005	0.367	0.332	0.700	0.188
M_{Rodo}	0.733	0.016	0.486	0.329	0.617	0.077	0.800	0.104
M_{Nico}	0.685	0.029	0.657	0.156	0.783	0.013	0.700	0.188
M_{Nero}	0.818	0.004	0.771	0.072	0.433	0.244	0.600	0.285
F_{Case}	0.685	0.029	0.771	0.072	0.600	0.088	0.600	0.285
F_{Tina}	0.867	0.001	0.543	0.266	0.583	0.099	0.800	0.104
F_{Rena}	0.806	0.005	0.657	0.156	0.800	0.010	0.800	0.104
F_{Kora}	0.709	0.022	0.771	0.072	0.667	0.050	0.600	0.285
F_{Tana}	0.612	0.060	0.771	0.072	0.750	0.020	0.900	0.037
F_{Saba}	0.855	0.002	0.771	0.072	0.783	0.013	0.700	0.188
F_{Fram}	0.867	0.001	0.943	0.005	-0.033	0.932	0.700	0.188
F_{Raja}	0.855	0.002	0.943	0.005	0.550	0.125	0.800	0.104
F_{Mila}	0.867	0.001	0.829	0.042	0.483	0.187	0.800	0.104

198,208 (p10) and for scientific experts: 151,175 (p1), 170,467 (p2), 198,208 (p10).

A correlation matrix was calculated in ArcView (ESRI, 1996a,b,c; Table 4), and it showed that the maps between expert groups were very similar and that the greatest difference lay between maps p1 and p10.

Validation

The correlations for the NWSA showed that the local expert models performed the best (Fig. 3A and 3B) and fitted the data well (model p1: rs = 0.964, $P < 0.001$; model p2: rs = 1.000, $P < 0.001$). The scientific expert model p1 (Fig. 3C) was also significant at the 95% confidence level (model p1: rs = 0.833, P = 0.005; model p2: rs = 1.000, $P < 0.001$). All models with p10 were discarded as they had far too few HSI classes and classed virtually all the study area as suitable. The correlation results for individual lynx for each model revealed that p1 models were better (Table 5) as all p2 models had more non-significant correlations. Moreover, the L model was better than the S model in that only one lynx had a non significant correlation as compared to 10 for the S model.

The results of the correlations for the Jura Mountains show that the scientific expert model p1 (rs = 0.967, $P < 0.001$) performed better than the local expert model p1 (rs = 0.939, $P < 0.001$). This was also shown by the better performance of the S model for individual lynx, as all the S correlations were significant compared to only four out of the seven in the L model (Table 6).

Discussion

The variables which were deemed most important for lynx habitat reveal some interesting points. The fact that land cover and forested areas have been deemed important by experts is unsurprising as these variables are often used in other habitat mod-

Table 6. Correlation coefficients (rs) and significance (P) for individual lynx in the Jura Mountains for the local expert models (L) p1 and p2 and the scientific expert models (S) p1 and p2. M indicates male lynx and F indicates female lynx.

	L p1		L p2		S p1		S p2	
Lynx id.	rs	P	rs	P	rs	P	rs	P
M_{Momo}	0.964	<0.001	0.886	0.019	0.867	0.002	0.600	0.285
M_{Amos}	0.612	0.060	0.657	0.156	0.950	<0.001	1.000	<0.001
F_{Nina}	0.418	0.229	0.371	0.468	0.983	<0.001	0.900	0.037
F_{Roya}	0.442	0.200	0.200	0.704	0.900	0.001	0.600	0.285
F_{Amba}	0.976	<0.001	0.886	0.019	0.800	0.010	0.700	0.188
F_{Aida}	0.927	<0.001	0.943	0.005	0.850	0.004	0.600	0.285
F_{Lora}	0.503	0.138	0.371	0.468	0.833	0.005	0.900	0.037

els for the lynx (Schadt et al. 2002, Zimmermann & Breitenmoser 2002), and as Eurasian lynx in Europe is known to be a forest living species. The variable elevation was also rated quite highly, although this variable is not directly important in the lynx-environment relationship. However, as elevation limits the tree line, prey availability, and also determines the presence of, and the land-use by, humans (mostly in the lower elevations), this variable can be indirectly implicated in the distribution of lynx. Elevation was also found to be an important factor in a model created for the lynx in Switzerland by Zimmermann & Breitenmoser (2002), and it was concluded that this was a result of the local nature of the model.

The disturbance weights demonstrate the belief that the proximity to motorways and towns are thought more disruptive to the lynx than the proximity to railways and minor roads. There is some evidence showing that these former infrastructures do have a negative impact on large mammals (Palma et al. 1999, Osborne et al. 2001), and the expert models reflect this. Indeed, distance to major towns was positively correlated with lynx presence, but not distance to roads in another study (Zimmermann 2004).

The scores given by experts in each group varied widely especially for geographical variables such as aspect, slope and elevation. These variables are perhaps only indirectly important for lynx ecology, and therefore make scoring difficult. Indeed, indirect gradients often have a good correlation with observed species patterns but are only useful within a limited geographical extent without great errors (Guisan & Zimmermann 2000). Because the (scientific) experts came from different areas, the importance of indirect gradients to the lynx will be different. However, CP allows for such variability by the use of the exponent p, which provides varying compensation. Nevertheless, it seems that the scientific experts, despite coming from different areas, were in agreement for slightly more variables than the game wardens. This could be an indication of the use of theoretical knowledge rather than personal and local experience. Indeed, although the questionnaire specified to rate the pairwise comparison from personal experience, one expert expressed the difficulty of separating personal experience and theoretical knowledge. This is clearly demonstrated when looking at the differences in weighting between game wardens and scientific experts. Scientific experts put the minimum elevation for the lynx habitat at 0 m whereas the local experts put it at 600 m. Of course lynx can live at sea level. However, none of the local experts' personal experience included such low elevations, and due to the presence and interference of humans most areas < 600 m in Switzerland are unsuitable for the lynx. The local nature of the ratings can also be seen by the significant difference in the weight of the aspect. There is a general belief that cats prefer sunny south slopes and that south-facing areas may be more productive and thus attract more lynx prey. Indeed, both S and L rated south highly (see Table 3). However, local experience revealed more differentiation, as aspect and distribution of forests on certain aspects may change from one district to another. These differences can be seen in Table 3. Of interest is also that the scientific experts believed that the presence of towns would be a greater disturbance to the lynx than what the local experts believed. This is due to the frequent sightings of the lynx near towns, and therefore to the game wardens, towns do not seem to disturb the lynx as much as infrastructures such as motorways.

The prey variables were not included in the modelling due to lack of data. One of the matrices was therefore altered and the prey variable removed before analysis. This editing showed a great difference in the value of the variables though the ranking in each model remained the same. Whether this editing introduces error in the final model is not known as no data on prey exist for verification. It can be assumed that removing the prey variable influences the power of the model. The availability of prey is crucial for the distribution of any carnivore species. However, the distribution of prey is strongly correlated to habitat and land cover, whereas most large carnivores are only habitat specific in so far as certain habitats offer sufficient prey or access to prey, respectively (Zimmermann & Breitenmoser 2002). Therefore, adding a prey layer may be seen as overfitting the model as it may be duplicating habitat layers. However, this is speculation as prey data do not exist. Acquiring data on prey availability and their subsequent incorporation within the GIS is difficult because prey species (roe deer and chamois) on which lynx feed are dynamic in space and time. Furthermore, the presence of prey does not mean that it is available, as this is also depends upon the hunting ability of the lynx, which may be influenced by habitat structure. The creation of a prey layer and testing its usefulness is a challenge for future work.

The Spearman correlation coefficients for the NWSA suggest that the local expert models consistently performed better than the scientific expert models. Although the models p2 received higher rs, they performed less well for individual lynx. This is because these models had fewer HSI classes and therefore, there were fewer points available for the correlation. This may be due to the fact that the p2 models allow partial compensation between variables (Zeleny 1982), and maybe also due to the fact that the models were originally created for the whole of Switzerland. In a study done over the whole of Switzerland comparing expert models for Swiss and non-Swiss experts, p2 models always performed better and fitted the lynx data well (Doswald 2002). The correlation matrix (see Table 4) indicates that the models among experts are very similar. It is therefore surprising that the Spearman correlation gives a distinction between the models. However, the number of cells that are classed as good HSI, i.e. > 5, shows that there are less cells suitable for the lynx in the game warden model than in the scientific expert model, which could explain the difference in the regression results.

The good agreement between the models and the lynx data suggests that the models can predict lynx distribution through habitat suitability/preference. The higher performance of the local expert models in the NWSA is not surprising as they have direct knowledge of the area. It could be assumed that if this model were verified in another part of Switzerland, for example, it would not perform as well as the scientific expert model. This hypothesis was tested by validating the model in the Jura Mountains from which lynx radio-telemetry data were available. As predicted, the local expert model did not perform as well as the scientific expert model. However, the good performance of the scientific expert model in the Jura Mountains may also be explained by the fact that some of the scientific experts have had experience of working in the Jura Mountains and some of the experts come from regions (e.g. Slovenia) with landscapes similar to the Jura Mountains. This may serve, however, to further show the local nature of the model as the experience makes the difference to the performance of the expert model.

Although our results suggest that the models can successfully predict lynx habitat suitability (and hence potential lynx distribution), it would be a fallacy to say that expert models have been definitively verified (Oreskes et al. 1994) as other studies have obtained mixed results (Clevenger et al. 2002, Kangas et al. 1993, Pereira & Duckenstein 1993, Pearce et al. 2001). Our study, however, shows that the debate about the usefulness of expert models is not yet closed. The good correspondence of the expert model with habitat use by lynx derived from telemetry data suggests that in areas or for species where such highly reliable data sets are not available, expert models may offer a fast and cheap first approach. Such models may support the design of field surveys, research projects, or the development of conservation strategies considerably.

There are several advantages of the method presented here. First, it is flexible, allowing input from many experts, and unlike previous expert models (Clevenger et al. 2002, Kangas et al. 1993, Pereira & Duckenstein 1993), it does not require all experts to provide their data in a group setting, thus allowing each expert to give their opinion uninfluenced by other respondents. The questionnaire format was easily understood and needed few explanations. Using AHP and Saaty's pairwise comparison matrix to analyse the data requires little training, and consistency can be verified. Time of completion varied among experts, but was relatively consistent, about 50 minutes. Secondly, an assortment of GIS tools designed to incorporate expert opinion is available, especially in Idrisi, and it is relatively inexpensive and easy to use.

Conversely, there are several limitations to this model. Two problems are associated with the AHP method. First, because the environmental variables need to be classified using a limited number of classes (nine at most - see Saaty 1977), the classification of variables may lead to loss of information. For example in the category 'non-productive and no vegetation', nival zones, rocks and bare areas were incorporated, and although some may be beneficial for the lynx (e.g. rocks for resting upon or as cover when approaching prey), others are not. Second, the structure of the hierarchy can affect the results due to the fact that the lower levels in the hierarchy will inevitably have a smaller affect on the weighting than the higher levels as the total weight is the composite of all levels (Store & Kangas 2001). Moreover, a more accurate model may have been produced by the evaluation of weights with large standard deviations. This process could have removed any outliers. However, the outliers were never consistently associated with any one of the experts, and therefore, it was difficult to remove this aspect of the data. Furthermore, the small sample size and the fact that we were dealing with subjective viewpoints further added to this difficulty. In future, it may be easier to tackle this problem with the new methods for reducing uncertainty (Store & Kangas 2001) and thus improve model performance. Indeed input data variability is a common source of poor model performance (Roloff & Kernohan 1999). It is difficult to say how the wide-ranging answers in both groups of experts affected the models. It is probable that the variability in responses for variables is not uniform in the way it affects the models. The environmental variables of most importance in the lynx-environment relationship will affect the accuracy of the model more if they are not correctly inputted.

A further problem with the developed habitat suitability model was that it paid little attention to the spatial requirements of the lynx. Territory size was not included, for instance, and neither were population dynamics. The result was that some areas were classed as suitable when in fact they were not big enough to contain a lynx, let alone a population.

An obvious shortcoming of our study was the lack of independence within the scientific expert group. Indeed, among the 12 scientific experts, nine had worked on the Swiss lynx project. The Swiss lynx project is a long-standing project, which has been running for > 20 years. The experts who have worked on this project have done so individually and at different times. They are therefore independent of each other temporally and by the work they have done. Moreover, independence in data sets is a theoretical requirement, which is difficult to fulfil in practice. Indeed, it is virtually impossible to find many experts who are independent of one another and who have worked on a large species in a given region without there being some cooperation at some point.

Despite the limitations outlined above, this expert model for the lynx successfully shows that local expert knowledge can be used to model lynx habitat suitability and hence the potential distribution. This has important implications for the conservation. Not only because of the aforementioned advantages, but also because it shows that local experts or those working on the ground should be included in the production of habitat suitability models. Those with hands-on experience could be employed in other research areas and for other species, as their local knowledge has proven to be accurate in this research. This has implications for science in general because in the past, widespread and readily available local informants such as game wardens, hunters or rangers have not been viewed as reliable observers of the environment, and their daily experience has been dismissed as of less validity than academic experts. Instead, their wealth of knowledge should be utilised. However, it is acknowledged that it may be more difficult to gage the trustworthiness and objectivity of the data produced by local experts, although our results indicate that models based upon local expert knowledge are locally reliable, but probably less suited to be extrapolated over large areas. Nevertheless, our research shows that local expert knowledge can be used to create a good habitat suitability model.

Recommendations for further research

Our study discloses the need for further research in a few areas. First, it is important to compare our model with another model type such as empirical models or HSI models to test how efficient it is against empirical models. It is unlikely that an expert-based model will replace the invaluable knowledge gained through radio-tracking of individuals, but it might be an aid for conservation bodies to perform a quick and cheap assessment. Second, it is questionable whether our method reproduced for a different animal or for plants would give such good results. Cats are specialists and therefore they possess well-known preferences in terms of food and (indirectly) for habitat. They are also adaptable, which allows for some errors in the input data. Moreover, the Eurasian lynx has been well studied (e.g. Breitenmoser et al. 1993, Jędrezejeski et al. 1996, Jędrezejeski et al. 1999) and all the experts have had long-standing experience with it. It may be difficult to construct an expert model for a generalist species or for one on which little expert knowledge exists. Finally, few MCDM techniques have been used for expert model creation and their relative merits require evaluation.

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APPENDIX I

Questionnaire

Name:

Please state time taken for completion of the questionnaire: minutes

A) Matrices for the variables

To your knowledge (personal experience) are the criteria on the left more beneficial for the lynx's habitat in comparison with the criteria on the top.

Enter your answer in the matrix using the scale 1-9 where 9 means that it is extremely more beneficial for the lynx's habitat and 1 means that they are equal in importance as explained earlier.

A1) Land cover

	Open forest	Closed forest	Other wooden areas	Cultivated areas	Pastures	Water bodies	Non productive/ no vegetation	Glaciers	Built areas
Open forest	1	2	½	5	3	5	3	7	9
Closed forest	½	1	½	5	3	5	3	7	9
Other wooden areas	2	2	1	5	3	5	3	7	9
Cultivated areas	1/5	1/5	1/5	1	1/5	3	1/5	5	9
Pastures	1/3	1/3	1/3	5	1	5	1	7	9
Water bodies	1/5	1/5	1/5	1/3	1/5	1	1/3	3	7
Non productive /no vegetation	1/3	1/3	1/3	5	5	3	1	1	3
Glaciers	1/7	1/7	1/7	1/5	1/7	1/3	1	1	3

A2) Topography

	Elevation	Aspect	Slope
Elevation	1	1	1
Aspect	1	1	1
Slope	1	1	1

A2.1) Aspect

	Flat	North	South	East	West
Flat	1	5	1/3	1	1
North	1/5	1	1/5	1/3	1/3
South	3	5	1	3	3
East	1	3	1/3	1	1
West	1	3	1/3	1	1

A3) Disturbance

Which disturbance is less a problem to the lynx? The least problematic gets a 9 (like the most beneficial in the earlier matrices) and those equal a 1 as explained earlier.

	Proximity to motorway	Proximity to roads	Proximity to railways	Proximity to town
Proximity to motorway	1	1/5	1/3	5
Proximity to road	5	1	1	7
Proximity to railway	3	1	1	7
Proximity to town	1/5	1/7	1/7	1

A4) Prey

Which species would be more important than the other ones to allow lynx to live in a certain area?

	Roe deer	Chamois/Reindeer	Red deer	Domestic	Lagomorphs	Rodents	Tetraonids	Other birds	Carrion
Roe deer	1	2	2	5	3	9	5	9	9
Chamois/reindeer	1/2	1	1	5	3	9	5	9	9
Red deer/ibex/moose/wild boar	1/2	1	1	5	3	9	3	9	9
Domestic	1/5	1/5	1/5	1	1	9	1	7	7
Lagomorphs	1/3	1/3	1/3	1	1	5	1	9	9
Rodents	1/9	1/9	1/9	1/9	1/5	1	1/7	1	1
Tetraonids	1/5	1/5	1/3	1	1	7	1	7	5
Other birds	1/9	1/9	1/9	1/7	1/9	1	1/7	1	1/3
Carrion	1/9	1/9	1/9	1/7	1/9	1	1/5	3	1

B) Matrix for the overall variables

To your knowledge are the criteria on the left more beneficial for the lynx's habitat in comparison with the criteria on the top?

Enter your answer in the matrix using the scale 1-9 where 9 means that it is much more beneficial and 1 means that they are equal as explained earlier

	Land cover	Topography	Disturbance	Prey
Land cover	1	3	5	1/7
Topography	1/3	1	5	1/7
Disturbance	1/5	1/5	1	1/9
Prey	7	7	9	1

C) Questions for the continuous variables

C1) What is the range (min. and max.) for the elevation at which lynx establish their core area?
(0-4617 m)

min. = 0 m
max. = 2200 m

C2) What is the range (min. and max.) for the slope at which lynx have their territories?
(0-80°)

min. = 0°
max. = 80°

C3) At what distance (the range) do lynx live (0-∞ m)? Use 'infinity' when there is not really a superior range or if the number is very large

a) from the motorway
b) from the road
c) from the railway
d) from towns and villages

a) 0-infinity m
b) 0-infinity m
c) 0-infinity m
d) 100-infinity m