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A wolf habitat suitability prediction study in Valais (Switzerland)

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Abstract

In recent years, the European wolf (*Canis lupus*) population has expanded its southern range from the Italian Peninsula to the Maritime Alps (Italy and France) and to Piemonte (Italy); establishing small sub-populations. Hence re-colonisation of the Swiss Alps is now likely to occur. In 1995–1996 the wolf reached the southern part of Switzerland (Canton of Valais) from where he got extinct 150 years ago. Actual conflicts of interests between livestock breeders, local political authorities and nature conservation parties, as well as federal authorities defending the protected status of wolf, require serious management investigations.

In order to check wolf habitat suitability of an alpine landscape, like the Valais, subjected to dynamic landscape–ecology processes since the extinction of wolf, we present herein an application of a predictive wolf habitat model, using a stochastic model involving logistic regression. As no data were available in the Canton of Valais, the regression coefficients for the retained variables such as urban area, population density, arable land, minimal altitude, northwest exposure and wild ungulate diversity index, were derived from data collected in the northern Apennine (Northern Italy), where habitat variables were related to data of wolf presence. The selection of the parameters for the Canton of Valais has been performed in respect of their predictive power, as well as their availability and geo-morphological importance for the alpine landscape under consideration. Using the geographic information system (GIS), the simulation pointed out that 19% (1142 km^2) of the total grid surface (5821 km^2) are suitable for wolf presence. Moreover, it reveals that especially areas at lower altitudes (minimum altitude $<$ 800–900 m a.s.l.), due to the high anthropic activity, and areas at high altitudes (minimum altitude $>$ 1800–2000 m a.s.l.), due to lack of prey and severe geo-morphological conditions, present a reduced habitat suitability. The geomorphological and demographic situation of the alpine area lead to a wolf habitat of a partially fragmented and linear aspect, affecting overall habitat suitability.

The strengths of the application is not only the visualisation of the present habitat quality of an alpine landscape re-colonised by wolves, but also that it allows to make investigations in order to manage the different conflicts of interest.

Keywords: Gray wolf; Swiss Alps; Habitat suitability; Canis lupus; Landscape–ecology; Logistic regression; GIS

1. Introduction

In central and western Europe wolf *(Canis lupus)* has nearly been exterminated 150 years ago. Expansion of human settlements, threats to livestock, competition for game species (Breitenmoser, 1998) as well

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as the negative image partially mediated by the clergy, caused a considerable persecution and wide range killing of wolves in central and western Europe. In spite of these factors, several isolated wolf populations remained in the Iberian Peninsula, in the Balkans and in Italy (Boitani and Ciucci, 1993; Promberger and Hofer, 1994). In the early 1970s the Italian wolf population was estimated with about 100 individuals (Boitani and Zimen, 1975). As a result of the legal protection of the wolf in Italy in 1976 and the reintroduction of wild ungulates, wolf population increased from 100 to about 500–1000 individuals in the end of 1990; expanding from the central and southern Peninsula to the Maritime Alps (Italy and France) and to Piemonte (Italy). The recolonisation of the Swiss Alps is now likely to occur — the Canton of Valais representing the first step.

In 1995–1996 first wolf observations have been made in the south of Switzerland (Canton of Valais) where about 100 sheep have been killed. During the winter of 1998–1999 another 40 sheep have been killed and two wolves were found dead because of poaching and traffic incident. These events initiated a fierce contention between nature conservation parties, federation authorities and livestock breeders in the Canton of Valais. Partly supported by local political authorities claiming that their return being not accordable with the actual way of stock-breeding (e.g. free-grazing sheep) and outlying that the alpine landscape would not be suitable for wolves, because of the increased anthropic activity (infrastructure, tourism, etc.). Indeed, since the eradication of wolves 150 years ago fragmentation of landscape increased but, opposed to public opinion, habitat conditions for large carnivores improved as a result of recovered wild ungulate populations and expansion of woodland (Breitenmoser, 1998). Despite illegal hunting new wolves immigrations will occur from established wolf populations in France and Italy.

In this paper, we will try to answer to the question raised especially by public and political parties whether the alpine landscape, which since the eradication of wolf has undergone different human-induced landscape–ecological processes, does still present suitable habitat for the re-colonising wolves. Therefore, we present herein a wolf habitat analysis of the Canton of Valais using a stochastic model based upon logistic regression. The model has initially been fitted on data collected in the northern Apennines (Massolo and Meriggi, 1998).

Up to now only a few studies included spatial factors determining wolf presence. Fuller et al. (1992), Thiel (1985) and Mech et al. (1988) revealed the effect of road density by simple correlation analysis. Mladenoff et al. (1995) used, as Massolo and Meriggi (1998) in the northern Apennines, a multivariate logistic regression approach to make predictions about wolf habitat suitability. Mladenoff et al. (1995) demonstrated the influence of road density and fractal dimension of the landscape on the presence of wolf in the northern Great Lakes region. Finally, Corsi et al. (1999) developed a large-scale model of wolf distribution in Italy using multivariate analysis.

2. Study region

The Canton of Valais is situated in the southern part of Switzerland, flanked by Italy and France; see Fig. 1. It is a typical alpine region, with a main valley (Rhone-valley) and altitudes ranging from 372 (Lake Geneva) to 4634 m a.s.l. (Dufourspitze). The climate is continental with an average yearly temperature fluctuating from -0.9°C (2479 m a.s.l) to 10.2°C (482 m a.s.l.). Of the total of 5224 km^2, 22.2% are covered with forest, 21.7% are agriculture land (pastures included), 2.5% are urban area and 56.6% are unproductive zones. The population density is about 51.93 individuals per km^2 (ind./km^2). The highest densities (up to 500 ind./ km^2) are in the valley bottom, where most of the agglomerations are located. For a more detailed look of land-use and population density in function of altitudinal ranges of alpine vegetation zones see Table 1.

As for other regions in the Alps tourism activity is high in summer (e.g. hiking) as well as in winter (e.g. skiing). Therefore, even at higher altitudes, infrastructure is well developed (road network, funiculars). Stock-breeding is important, but considered more as cultural and landscape–ecological need. It is subsidised partially by the Swiss Federation and the Canton of Valais. It results that, in opposition to France or Italy, the proportion of non-professional livestock owners is considerable, i.e. 85% of the sheep owners.

The four main wild ungulate species present in the study region are the red deer (*Cervus elaphus*;

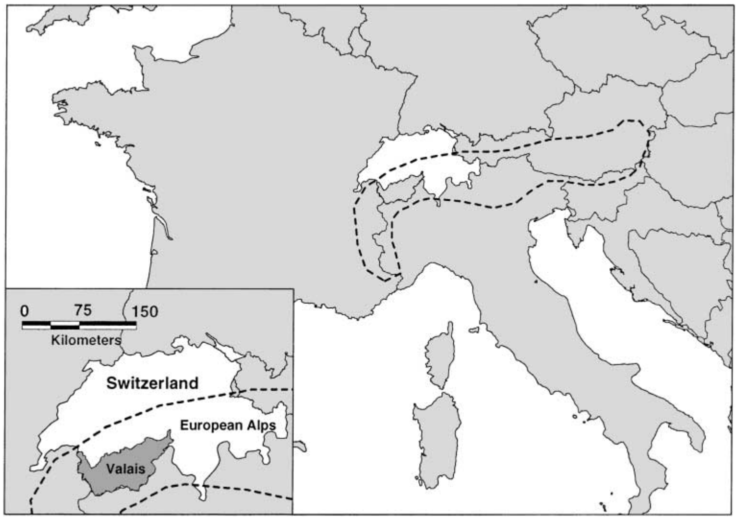

Fig. 1. Geographical localisation of the study region within the European Alps.

3409 ind.), the roe deer (*Capreolus capreolus*; 3788 ind.), the chamois (*Rupicapra rupicapra*; 14,966 ind.) and the ibex (*Capra ibex*; 4110 ind.). Considering the little amount of wild boar (*Sus scorfa*) and mufflon (*Ovis musimon*) both have been excluded from the analysis.

3. Methods

3.1. Initial model

The habitat analysis was performed using a stochastic model based upon logistic regression fitted to northern Apennines data by Massolo and Meriggi (1998). They used the 'Universal Transverse Mercator' (UTM) system to spot 143 sample squares of 23 km^2 each — a scale considered as appropriate (15–20% of the estimated wolf home range). In each sample square 58 variables were assessed of which 10 for vegetation types, 5 for environmental complexity, 8 for anthropic variables, 11 for large prey availability, 12 for physical characteristics and 12 for climatic variables. The sample squares were classified in absence of wolf (a), irregular presence (b), regular presence (c) and regular presence with reproduction (d). The classification has been carried out in function of the seasonal frequency of wolf tracings, which were determined by scat collection, wolf-howling, snow-tracking, direct observations and by predation records. The relation between habitat variables and regular wolf presence, (c) and (d), — observed in 50 sample squares — has been statistically examined and prediction of wolf presence

Table 1
Land-use and population density per altitudinal range of alpine vegetation zones in the Canton of Valais

Vegetation zone (m a.s.l)	Hilly (0–900)	Montenous (900–1600)	Sub-alpine (1600–2200)	Alpine (2200–3000)	Nival (>3000)
Population density (ind./km^2)	414.86	67.53	7.04	0.02	0.00
Urban area (%)	19.83	6.53	1.29	0.12	0.00
Arable lands (%)	36.14	13.42	0.96	0.00	0.00
Forest cover (%)	31.77	60.20	37.21	0.43	0.00
Shrubs and bushes (%)	0.88	3.35	11.30	1.28	0.00
Pastures (%)	1.25	7.72	26.20	20.25	0.00

sites were performed using a dichotomous logistic regression model (Massolo and Meriggi, 1998). Of the initial 58 habitat variables, 28 were found having significant statistical correlation with the presence of wolf. By applying the step-wise procedure 10 habitat variables were selected to be entered into the model. The multiple regression model was based on the function

$$\mathrm{logit}(p) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n, \quad n = 10$$

$$\text{and} \quad \mathrm{logit}(p) = \log\left(\frac{p}{1-p}\right)$$

resulting in

$$p = \frac{1}{1 + \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n)}$$

Note that p is the probability of occurrence of an event, β_i are the regression coefficients and X_i, $i = 10$, the different habitat variables. Once the habitat variables have been selected, wolf presence predictions for other regions can be carried out by estimating the regressions coefficients using a classical maximum-likelihood approach.

3.2. Model selection for the Canton of Valais

The available data for the Canton of Valais allows the definition and testing of several statistical models. Clearly, the latter are not optimal from the perspective of a statistical criterion (such as the maximum likelihood) used by Massolo and Meriggi (1998) to build their model. Nevertheless, we believe that for our problem other criteria for selecting the variables that enter into the regression model have also to be considered.

These criteria are

- *Availability of the data*. In order to make a regional analysis of the whole landscape of the Canton of Valais, the availability of the corresponding environmental information is a pre-condition. Not all the variables determined by Massolo and Meriggi (1998) are readily available for the Canton of Valais with the required spatial coverage. This considerably restricted our choice.
- *Clear and established ecological significance for the wolf*. Credibility of the model, especially in extrapolation, is enhanced if the selected variables have a sound basis in the present understanding of ecology of wolf. In particular, ecological reasoning should suggest that they remain valid in the conditions of the Canton of Valais.
- *Significant statistical correlation with the presence of wolf in the Apennines*. As no data is available for the Canton of Valais, we had no choice to consider the correlations determined for the Apennine data set. Therefore, from the initial 58 variables we retained for further analysis only the sub-set of 28 variables that show significant correlation with the presence of wolf.

To adjust the logistic regression model, variables selection was done through the 'forward stepwise method' applied to a reduced set of 11 habitat variables considering the criteria mentioned before. Model selection was made on the basis of the classification performance of the response variable and the χ^2 goodness-of-fit (P-value $= 0.000$) on the Apennine data. The selected model, composed of the six habitat variables urban areas, inhabitant density, arable lands, minimum of altitude, northwest exposure and the wild ungulate diversity index (WUDI), is mainly based on anthropic activity, physical characteristics and wild prey availability.

Following Mattioli et al. (1995) and Massolo and Meriggi (1998) food resource stability (richness, diversity) and human activity, through poaching and traffic incidents, are the most limiting factors for wolf presence. Therefore, human activity (pressure, disturbance) is represented by urban area, arable lands and inhabitant density. In order to respect geo-morphological conditions in the study area, physical characteristics, like minimum altitude and northwest exposure, were also integrated in the analysis. Increasing altitude entails increased geo-morphological complexity and climatic severity, which is also valid considering northwest exposure (Fischesser, 1982).

3.3. Data sources and habitat variable calculations

Data for the calculations of the habitat variables were available from the GEOSTAT data base of the Swiss Federal Statistical Office (SFSO) and the fish and hunting service of the Canton of Valais. Together with the selected habitat variables these are listed in Table 2.

Table 2
Data sources of the habitat variables

Habitat variable	Origin and resolution of data
Urban areas (%)	Land–use map (1992–1997), SFSO's GEOSTAT (hectometric raster)
Inhabitant density (Ind./km^2)	National census of the population 1990, SFSO's GEOSTAT (aggregation ha)
Arable lands (%)	Land – use map (1992/97), SFSO's GEOSTAT (hectometric raster)
Minimum of altitude (m a.s.l)	Topographical data, SFSO's GEOSTAT (hectometric raster)
Northwest exposure (%)	Topographical data, SFSO's GEOSTAT (hectometric raster)
Wild ungulate diversity index (WUDI)	Wild ungulate distribution map (Hausser, 1995), 1 km grid, Cantonal census of wild ungulates (1998), Fish and Hunting service (Valais)

Data of the SFSO were directly available in digital form and have been stocked in a geographical information system GIS, using the software package MapInfo. Data for the calculation of the wild ungulate diversity index were in numerical and cartographical form and have been processed for further analysis in GIS. The habitat variables were calculated on a 4 km^2 grid, in order to consider pronounced variations of the geo-morphological conditions in the study region, as well as its environmental and demographic peculiarities. The chosen scale of 4 km^2 is assumed not to influence negatively the representativity of the initial model. To optimise data exploitation and to respect the neighbourhood aspect three different grid shifts of 1 km have been performed. Overlaying the four grids, associating for each simulation the result of the probability calculation to the centroids of each of the 4 km^2 squares, a grid of 1 km mesh was reproduced; squares of 1 km^2 representing the result of a probability calculation on a square of 4 km^2; see Fig. 2.

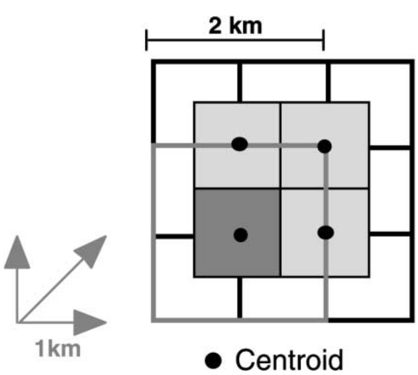

Fig. 2. Representation of the Grid-shift (1 km) and the overlay of the four new grids (4 km^2 $\rightarrow$ 1 km^2).

The habitat variables as urban areas, arable lands and northwest exposure were described as proportions (%) of the considered surface (4 km^2). For the calculation of the wild ungulate diversity index, the wild ungulate distribution maps for roe deer, red deer, chamois and ibex (Hausser, 1995) were combined with the detailed cantonal census of wild ungulates, i.e. the amount of wild ungulates inside and outside protected areas. Based on the relative abundance and the number of ungulates species present in each of the 4 km^2 squares, the wild ungulate diversity index has been calculated following the procedure defended by Massolo and Meriggi (1998).

Data about the location of the summering pastures and the number of sheep for 1997 were available from the veterinary service of the Canton of Valais.

4. Results

4.1. Model result

The Chi-square test indicates an overall validity of the formulated dichotomous logistic regression model (P-value $= 0.0000$). Referred to the 143 samples squares of the Northern Apennines, the model classified 90.32% of the squares without wolf presence correctly and 70.00% of the squares with regular wolf presence (cut-level at $P = 50\%$). It yields that the reformulated model reveals a percentage of correct classifications of 83.22% of the Apennine data, compared to 93.00% of the model of Massolo and Meriggi (1998). The loss of prediction quality with respect to the model of Massolo and Meriggi (1998) is moderate.

We observed that, considering the values of the partial correlation (R), the population density, the

Table 3
Habitat variables with the regression coefficients

Habitat variable	Estimates β_i	Standard error	Wald statistic	P-value	R
Urban areas (%)	−0.6453	0.3340	3.7329	0.04	−0.0968
Inhabitant density (ind./km^2)	−0.0798	0.0255	9.8132	0.00	−0.2054
Arable lands (%)	−0.0986	0.0321	9.4505	0.00	−0.2006
Minimum of altitude (m a.s.l)	−0.0033	0.0014	5.6495	0.01	−0.1404
Northwest exposure (%)	−0.0289	0.0151	3.6469	0.04	−0.0943
Wild ungulate diversity index	3.4865	0.9643	13.0722	0.00	0.2446
Constant (β_0)	3.9664	1.2527	10.0248	0.00	–

arable lands and the wild ungulate diversity index had the highest effects on the model. Finally, of the six variables considered in the analysis only wild ungulate diversity index showed a positive influence on wolf presence; see Table 3.

4.2. Result of the model application

In Fig. 3, the simulation result, achieved through a rectangular (bilinear) interpolation of the calculated probabilities, is represented. One can observe that of the initial study area surface, 19% or 1142 km^2 provide suitable wolf habitat conditions ($P \geq 50\%$), following mainly forested areas (∼40% forest cover) along the main valley (Rhone-valley) and the smaller side valleys.

To obtain indications about the habitat composition of the suitable wolf area (SWA) and the non-suitable wolf area (NSWA), the average values and the standard deviation of the mean (SDM) for the initial selected 11 habitat variables have been calculated. In Table 4 the result of the six habitat variables, which were integrated in the model, are shown.

Compared to the studies of Massolo and Meriggi (unpublished data) and Mladendoff Mladenoff et al. (1995) which revealed average values for urban areas,

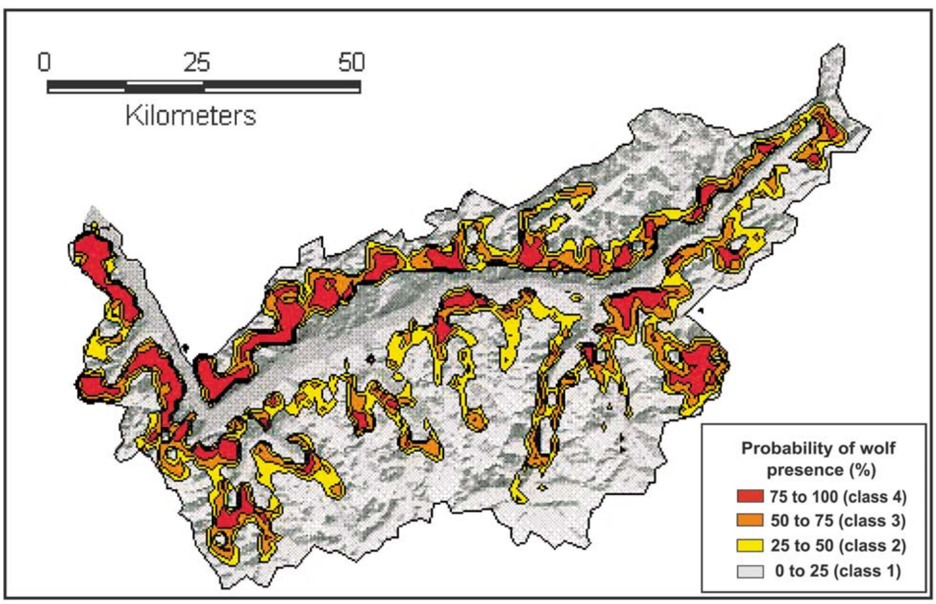

Fig. 3. Presentation of the suitable wolf sites in the Canton of Valais (overlaid to a numerical altitude map of the SFSO).

Table 4
The average values of the habitat variables (with standard deviation of the mean (S.D.M))

Habitat variables	Suitable wolf area (SWA)	Not suitable wolf area (NSWA)
Urban areas (%)	0.34 ± 0.02	2.47 ± 0.09
Inhabitant density (ind./km^2)	1.07 ± 0.11	52.82 ± 3.01
Arable lands (%)	1.07 ± 0.07	6.61 ± 0.21
Minimum of altitude (m a.s.l)	1.303 ± 9.98	1.929 ± 11.93
Northwest exposure (%)	11.24 ± 0.14	12.37 ± 0.21
Wild ungulate diversity index	0.65 ± 0.01	0.25 ± 0.00

arable lands and population density in SWA of 0.45%, 9.51% and 21.63 ind./km^2, respectively 0.00%, 2.34% and 1.52 ind./km^2 one can recognise that the Canton of Valais still prevails suitable wolf habitat with low human presence and low human activity.

The altitudinal distribution of the suitable wolf habitat is visible in Fig. 4, which is a scatterplot of minimal altitude versus probability. Superposed is a kernel smoother with a bandwidth selected automatically by cross-validation; for more details see Bowman and Azzalini (1997). The figure reveals, that mainly at minimum altitudes under 800–900 and over 1800–2000 m a.s.l, habitat is unsuitable for wolf. The former because of high anthropic pressure and the latter especially because of lack of prey and increased geo-morphological complexity. Note that within a sample square, altitudes can vary for several hundred meters. As already mentioned before and presented in Table 1, human activity is concentrated mainly at lower altitudes (hilly zone) of the Rhone-valley, being therefore unsuitable for wolf; see Fig. 3. This activity can also be visualised by the use of road density (km/km^2) — not selected by the step-wise method by reason of high correlation with already integrated habitat variables. In the SWA the mean road density was 0.20 km/km^2, which is lower compared to the levels of habitat suitability given by Thiel (1985), Mladenoff et al. (1995) and Mech et al. (1988), with 0.58, 0.23 and 0.29 km/km^2. The mean road density below a minimum altitude of 900 m a.s.l. was for comparing 1.59 km/km^2, and for the complete NWA (including the squares with minimum altitude > 3000 m a.s.l) still 0.38 km/km^2.

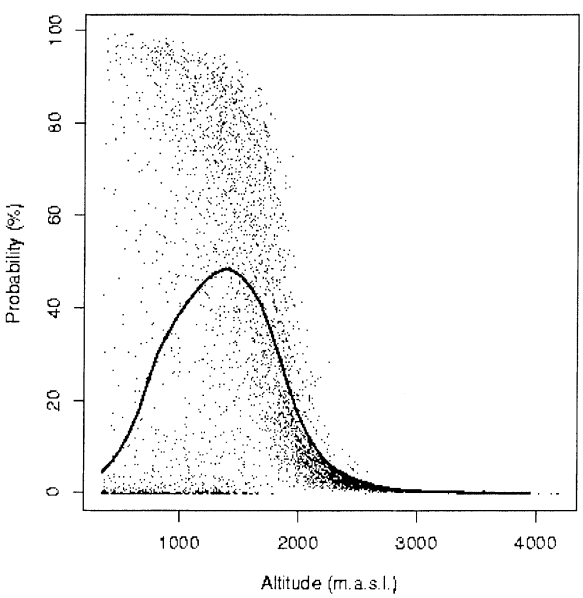

Fig. 4. Scatterplot of minimum of altitude vs. probability of presence with superposed kernel smoother.

5. Discussion

The results of the habitat composition of suitable and non-suitable wolf areas, as well as their altitudinal distribution reflect well the strong landscape–ecological transformations, which especially the valley bottom had undergone since the extinction of wolf 150 years ago. The increased interest of industry (e.g. hydroelectricity) engendered by making the Alps accessible to transportation (e.g. trains, trucks) and the increased economical competition of traditional agriculture products from mountain regions (e.g. milk, meat) resulted in a emigration of prior rural people living in little mountain villages to the economical centres at the valley bottom (Fischesser, 1982; Perrottet-Müller, 1987; Franz, 1994). Hence, human activity increased and urban zones expanded. As massive human pressure enhances competition for space, which is one of the main factors discriminating wolf reproduction to non-reproduction sites (Massolo and Meriggi, 1998), another human activity of importance in the Alps, tourism, should not be neglected in the final evaluation of the simulation result. In the model only the density of the native population has been considered, but in the last decades, mass tourism developed strongly in the Alps transforming society and landscape even at higher altitudes (sub-alpine, alpine level). Actually, tourism activity is seasonally highly increasing in tourist stations, like in Zermatt (1616 m a.s.l.) from 4400 to about 15,000 people. Where as in summer activity is more widespread (e.g. hiking), in winter it is mainly concentrated locally, nearby tourist stations (e.g. skiing). In future wolf habitat studies in the Swiss Alps, these seasonal fluctuations of population density have to be considered too.

The wild ungulate diversity index is the habitat variable with the strongest influence on the model ($R = 0.2446$); outlying that the final simulation result testifies a high wild ungulate diversity and abundance in the Canton of Valais, as confirmed by cantonal hunting guards. Following Dale et al. (1994) a multi-prey system gives a greater stability to the ecosystem by limiting greater fluctuations in prey densities. This is an important point considering alpine regions, where prey availability is seasonally changing. In winter all of the abundant wild ungulate species are located in or near to forested areas (limited foraging sites), whereas in summer ibex and chamois move to habitats at higher altitudes of more complex topography (cliff/step slopes), and are, therefore, less available for wolf (Meriggi and Lovari, 1996; Poulle et al., 1997).

In the Alps wild ungulate abundance and diversity is actually much higher, than at the time of wolf eradication 150 years ago. At that time, ibex had been exterminated, red deer, roe deer and wild boar were virtually extinct and only chamois survived in little numbers. Incidental hunting right restrictions, reforestation initiatives, spontaneous re-immigration of wild ungulates from neighbour countries (France, Germany and Austria) and translocations, engendered a rapid increase establishing again quite stable wild ungulate populations (Breitenmoser, 1998). This increase was supported by long-lasting management of game species by the cantonal fish and hunting service in collaboration with the local hunters. The latter consider the re-colonising wolves as non-desired game resource competitors. In addition to the wild prey, the domestic prey is also very important, especially in regions with a considerable stock-breeding activity (Branggi et al., 1991; Cozza et al., 1996; Meriggi et al., 1996). This is precisely the case for the Canton of Valais, where during the summer period about 60,000 sheep are free-grazing on alpine pastures without any human survey. Note that in this alpine area, stock-breeding has not especially an economical, but more a cultural and a landscape–ecological role (e.g. maintenance of alpine pastures). Fig. 5 represents data of the summering period of 1997 (radius $\sim \ln(N)$).

As suitable wolf habitat is overlapping with the location of the summering pastures (see Fig. 5), high depredation rates are expected; being confirmed in 1995–1996 and 1998–1999. At any time, the so called ‘‘surplus-killing’’ by wolf could be observed. The reason why wolves kill several sheep (up to seven) per attack is because sheep lost their natural anti-predator behaviour due to the several centuries breeding tradition. The steadily grouping of the sheep herd favours repeated wolf attacks. Following Fritts and Mech (1981) and Meriggi and Lovari (1996) high diversity and richness of wild ungulates guilds could engender a decrease predation on livestock, but a real effect can only be expected if they are accompanied by an adaptation of local breeding practices to decrease availability and profitability of domestic prey. Actually several investigations are in progress, like introducing livestock-guarding dogs (Landry, 1998) to protect the sheep herds and to diminish depredation rates, which is important also for public and political acceptance of wolf re-colonisation.

Next to habitat composition, configuration — size and spatial organisation — of wolf habitat is another important aspect regarding its overall suitability. Physical, biological and anthropic conditions in the alpine area influence strongly the configuration of the suitable habitat; resulting in a more linear and only partially compact aspect. The linearity of the habitat in some regions will have a supplementary negative effect on wolf habitat quality, because of the increased edge effects, i.e. an increased exposition to human

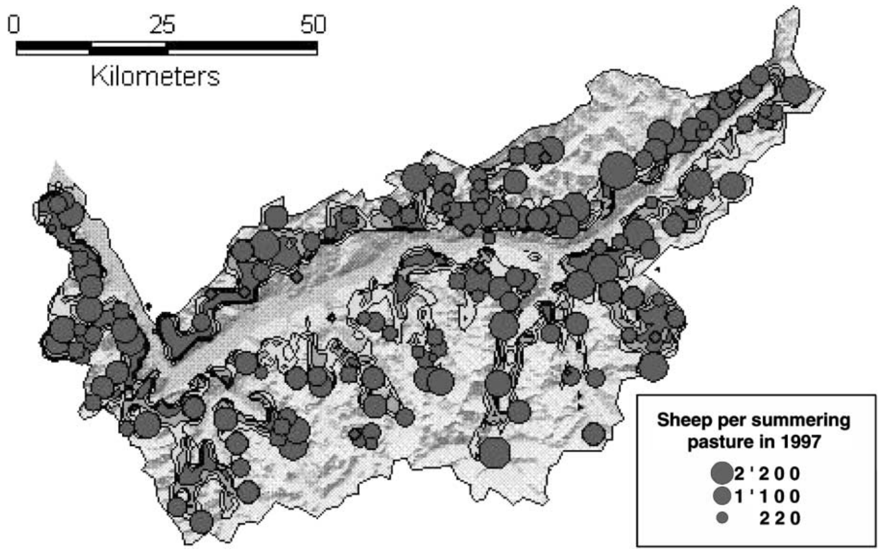

Fig. 5. Representation of number of sheep per summering pastures in 1997.

perturbations (Farina, 1998). The isolated patches of only some square kilometres are too small to present a potential territory for a wolf population, but in relation to other patches in adjacency they can act as stepping stones and assure connectivity (Forman and Godron, 1986; Farina, 1998). For analysing connectivity a more detailed study of quality and composition of the inter-patch area is needed, like determining natural (e.g. rivers, cliffs) and artificial barriers (e.g. highways) and verifying their difficulty to overbear by wolf.

Up to now the complex configuration of the suitable habitat renders a funded estimation of the number of possible wolf territories difficult, if not impossible. Less is known about the use of such habitat types by re-colonising wolves and their influence on territory size, as factors as prey availability, pack size and human disturbance (e.g. tourism, hunting) are also of importance (Zimen, 1976; Bibikov, 1988). The same rules can be obtained analysing the wolf carrying capacity; demanded by public and political parties in the Canton of Valais.

5.1. Model limitations

We acknowledge that using a statistical regression model in spatial extrapolation is a very delicate exercise and carefulness is needed in interpreting the results. Indeed, the validity of the statistical habitat model in the conditions of the Canton of Valais cannot be firmly established, as the geo-morphological and demographic conditions are slightly different compared to the northern Apennines and as no site-specific data is available. In particular, historical data is unreliable and only qualitative in nature. Moreover, the landscape of the Canton of Valais suffered large human-driven modifications since the wolf disappeared. Recent information is also very sparse and consists only of some depredation records, snow traces and analysis of hair samples of the few wolfs that briefly sojourned in the Canton of Valais. As a consequence there is an unquantifiable, but potentially significant, uncertainty associated with such an extrapolation. Therefore, presently and on the medium term extrapolating models or modelling results obtained elsewhere is the only tool that can be used in this context. A scientific program aiming at the collection of relevant site-specific information, using the radio-collar technique among others, is planned. However, in 1999 this program was not started yet. Several years of observation are necessary before such information will allow the validation of a spatial habitat model.

Meanwhile, environmental managers have to take important decisions and any sound scientific input to inform them is welcome. We argue that, accompanied by the transparent statement of its hypotheses and associated uncertainties, our model is able to bring valuable insights for the issue of habitat suitability for the wolf in the Canton of Valais and for examining the consequences of different management options. Moreover, we believe that a progressive confidence build up in the modeling results is possible.

The following steps can be taken to enhance confidence.

- The model in extrapolation mode on other similar high mountain environments where validation data is available can be used.
- Similar models developed elsewhere on the Apennines and the Canton of Valais data base can be used and predictions with those of the model we developed can be compared.
- Most importantly, site-specific data should be used as soon as they became available to validate and possibly update the model parameters (e.g. using a Bayesian procedure).

Considering the cited model limitations, the cartographic representation of the results has to be adapted by replacing the probability values with a relative classification (class 1 from 0 to 25%, class 2 from 25 to 50%, class 3 from 50 to 75% and class 4 from 75 to 100%); see Fig. 3. It can be assumed that this relative classification of habitat suitability reflects the real suitability levels of the alpine area under consideration.

6. Conclusion

Identifying areas suitable for wolves by spatial extrapolation through a habitat model can provide a useful tool not only for resource planners charged with managing restoration of wolves (Mladenoff et al., 1999), but also for other public or political parties, which intend to decrease man–wolf competition for resources and space. In this sense the model of Massolo and Meriggi (1998) applied to an alpine region prevailed, although based on Apennine data, an useful way to conceive a first insight in the suitability of the landscape for wolf. It revealed that the Canton of Valais, despite landscape–ecological transformations since the extinction of the wolf, still presents suitable wolf habitat. Always being aware that differences in environmental and topographical conditions, between initial and actual study areas, entail limitations of the representativity of the simulation results.

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