MACRO-HABITAT SELECTION OF THE ALPINE MARMOT (MARMOTA MARMOTA) IN the SOUTHERN PYRENEES
B.C. López, A. López, D. Potrony, M. Potrony

To cite this version:
B.C. López, A. López, D. Potrony, M. Potrony. MACRO-HABITAT SELECTION OF THE ALPINE MARMOT (MARMOTA MARMOTA) IN the SOUTHERN PYRENEES. Vie et Milieu / Life & Environment, 2009, pp.189-197. hal-03253699

HAL Id: hal-03253699
https://hal.sorbonne-universite.fr/hal-03253699
Submitted on 8 Jun 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
ABSTRACT. – Around 500 individuals of Alpine marmots were re-introduced in the French Pyrenees between 1954 and 1988. Marmots soon crossed the mountains to settle in the sunniest southern slopes. After 40 years or so, estimations of the marmot population in the Pyrenees suggested that there were 10000 individuals. Queries about the presence of marmots in Cerdanya, a 595 km² region of southeastern Pyrenees, were given to forest services and mountain guides and sites visited to verify data. Afterwards, sixty-four plots of 1 km² that contained marmot populations were intensively sampled in search of burrow sites. GIS-based analysis was performed for the whole area in order to compare 1 km² plots with and without marmots. Regression trees and Generalized Linear Models showed that the marmots positively selected plots with low mean March temperatures, small areas of calcareous soils and big areas of meadows. Furthermore, the density of burrow sites was positively associated with the presence of talus and wetland vegetation.

INTRODUCTION

Marmots (Marmota marmota) were widespread in Europe from the late Pliocene to the early Holocene (Coutrier 1955, Besson 1971), when they disappeared except in the Alps and the Tatra mountains. The species was re-introduced in the French Pyrenees between 1948 and 1988 in order to feed two endangered species: golden eagles (Aquila chrysaetos) and brown bears (Ursus arctos), and decrease the predation pressure of eagles on Alpine chamois (Rupicapra rupicapra). The exact number of re-introduced individuals is unknown but oscillated around 500 (Ramousse et al. 1992). The likely preference of marmots for the southern sunny slopes (Allainé et al. 1994, González-Prat et al. 2001, Lenti Boero 2003) rapidly facilitated their expansion to the southern slopes of the Pyrenees, where the lack of both natural predators and important interspecific competitors allowed an important expansion of this species.

The first observations of marmots in Cerdanya, a region in NE Spain of around 600 km², occurred in 1981, and some studies (Canut et al. 1989, González-Prat et al. 1989, Herrero et al. 1992, González-Prat et al. 2001) carried out earlier during the expansion process already pointed to a fast expansion in different sectors of the region. It is commonly considered that marmot habitat in the Pyrenees has an altitudinal range between 1300 and 2900 masl (González-Prat et al. 2001), with an estimated population of around 10000 individuals (Herrero et al. 2000).

Few studies on the population of marmots in the southern Pyrenees were conducted. Most of the information on this species in this region comes from observations made during the late 90’s in the central Pyrenees (Herrero et al. 1992, Herrero et al. 1987, 1994, 1996, García-González et al. 2001), and the only existing study in the eastern Pyrenees was carried out in 1999 (González-Prat et al. 2001). So, there is a lack of updated information about alpine marmots in the whole area, but especially in the southeastern Pyrenees region. Marmots are not considered as a problematic species in Catalonia yet, but they are classified as a cinegetic species with a special protection that prevent them from being chased (http://mediambient.gencat.cat/eng/). However, given their fast colonization of the territory, updated information on Alpine marmot is needed in order to anticipate a control of this species in a near future. Personal observations indicate that some colonies were established in farms and their burrows were already a potential danger for cows and sheep.

The main objective of this study was to assess habitat selection traits of the southern populations of marmots at a macro-scale level and provide us with reliable statistical data that could be used as an extrapolation tool, at least for the southern Pyrenees. We also aimed to determine the most important variables that influence the density of burrow sites that is family units, in the study region.

MATERIALS AND METHODS

Study Area: The Cerdanya region spreads over 1086 km² between France (49.7 %) and Spain (50.3 %) where this study was carried out. Cerdanya occupies a depression between the Cadi-Moixeró Mountains and the Pyrenees, with an altitudinal range between 950 and 2842 masl. It consists of two big relief components: the depression itself, flat and highly exploited by
humans, and the mountain slopes that surround it with a traditional but decreasing use of forests and meadows. Precipitation, rain or snow in winter at higher elevations, is abundant throughout the year and oscillates between 800 and 1000 mm. Autochthonous vegetation ranges from Quercus dominated forests at low elevation to Pinus sylvestris and Pinus uncinata dominated forests with increasing elevations. Abies alba stands are also present in the shaded areas, and above 2100-2300 m, sub-alpine and alpine meadows are the dominant vegetation types.

Plot occupancy: The whole territory of the Cerdanya was divided into plots or squares of 1 km² based on Universal Transverse Mercator coordinate system (UTM), resulting in a total of 595 plots. From January to March 2007, questionnaires accompanied with several 1:50000 maps that covered the whole territory were given to forest services, mountain guides, shepherds, etc. in order to locate marmot colonies up to their most exact position. Queried people were asked to locate the marmot burrows on the maps and answer questions such as the first year of observation, the season and the number of individuals observed. A total of 15 complete questionnaires were answered by 20 different persons. To avoid that previously filled maps could bias the answers of new queried persons, each person was provided with a different map. To validate this information, randomly selected plots supposed to have or not marmot burrows were intensively visited during spring and summer 2007. Queries were carried out till no new information could be collected.

All plots were then characterized according to several variables obtained with MiraMon©, a Geographical Information System and Remote Sensing software developed in the CREAF laboratory (http://www.creaf.uab.es/miramon). Among all available variables, only those that could somehow affect marmot establishment were chosen (Table I). In the case of air temperature, a previous analysis including February to June temperatures revealed that only March temperature was affecting marmot presence, and so only March temperature was included in the dataset.

Statistical Analysis: All statistical analyses were performed using the R software (R Development Core Team 2006). Statistical methods used to analyze the data were Tree Models, Generalized Linear Models (binomial error) and Linear Models (see Breiman et al. 1984, Crawley 2006, 2007 and Roff 2006). The general aim of Tree Models is to produce a binary tree in which each node of the tree represents a binary division of the data present at that node. Breiman et al. (1984) developed a method for pruning trees to a given size that gives the smallest deviance of all possible pruned trees. The technique employed in this paper, described by Roff (2006) and Breiman et al. (1984) is a 15-fold cross-validation, although in Roff (2006) a 10-fold cross-validation is proposed. The data are set to randomly split into 15 equal components, 1 retained for testing and the other 14 combined to generate the model. Testing is done by calculating the deviance using the estimated tree as the predictor. Tree size is varied and deviations calculated for each value. The set used for testing is then incorporated into the estimation set and one of these set aside for testing: thus this procedure yields 15-cross-validation results, which can then be averaged. The mean value is the optimum size of the pruned tree. As a further test, the whole procedure can be repeated to yield more estimated curves. We repeated the 15-fold cross-validation 100 times. However, we could not be absolutely sure that through questionnaires the whole area had been covered. And since it was also impossible to intensively visit all the 595 plots of the region, 50 random subsets of 60 % of the data were used to perform tree regression and classification analysis. Analysis of the variables that mostly appeared in more than 60 % of the cases were compared to those resulting from trees calculated with the whole dataset.

Generalized Linear Models (GLM) allow analysis of data that either do not have constant variance or are not normally distributed like count data, proportion data or other data that follow Gamma distribution as in data on time to death (Crawley 2006). In our case, we had binary response variables (present or absent), and we used as explanatory variables those suggested by the best pruned tree. GLMs models are fitted in the usual way, and the significance is tested by deletion of terms from the maximal model and comparing the change in deviance with chi-square. A Linear Model (LM) was used to fit the density of burrow sites with all important explanatory variables resulting from the regression tree.

Table I. – Explanatory variables used in the datasets. All variables were obtained at http://mediambient.gencat.net. Details about each of them can be found in http://mediambient.gencat.net/cat/el_departament/cartografia/

<table>
<thead>
<tr>
<th>Variable</th>
<th>Categories / Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban surface</td>
<td>ha</td>
</tr>
<tr>
<td>Road length</td>
<td>m</td>
</tr>
<tr>
<td>Lithology</td>
<td>12 categories (ha)</td>
</tr>
<tr>
<td>Water surface (rivers and/or lakes)</td>
<td>m²</td>
</tr>
<tr>
<td>Land use</td>
<td>19 categories (ha)</td>
</tr>
<tr>
<td>March temperature</td>
<td>4 categories: 50 % or more of the total surface of the plots having mean March temperatures between -2 and 0°C (categ: 1), between 0 and 2°C (categ: 2), between 2 and 4°C (categ: 3) and between 4 and 7°C (categ: 4)</td>
</tr>
<tr>
<td>Precipitation</td>
<td>3 categories: mean annual precipitation of the plot lower than 600 mm (categ: 1), between 600 and 850 mm (categ: 2), and higher than 850 mm (categ: 3)</td>
</tr>
</tbody>
</table>

Vie Milieu, 2009, 59 (2)
Habitat selection: Habitat selection was estimated using tree models and GLMs. Predictors obtained by the best pruned tree were added to the Generalized Linear Model, but to ensure that no important variable was excluded by the regression tree analysis, those variables that were not present in the final set were individually added to the model, and so possible effects or interaction effects could be controlled. A final GLM was performed with the most contributing variables and their interactions on the presence of marmot colonies.

Density of family units
Sixty-four 1 km² plots hosting marmot colonies were intensively inspected during spring and summer 2007 by teams of 3 to 5 persons. Occupied burrows were distinguished either because marmots gave loud alarm calls at the moment they detected the teams, or by burrow characteristics such as hole size, signs of recent activity, fresh -or relatively fresh- scats. A marmot colony is formed of one or more family units and can be easily identified by its distinct main burrows, usually between 2 and 4, more intensively occupied. Burrows separated by less than 400-500 m were considered to be part of the same burrow site (family unit), unless clearly separated by topographic features (e.g. opposite sites of a ridge). Counts of burrow sites provided density values per km², and so the term “density” in this paper refers to density of family units or burrow sites per km². A similar approach with the presence/absence data was performed with these data, but the final model was not a GLM but a linear model (LM), with “density” log-transformed to match normality.

RESULTS

Presence/Absence
After running the 15-fold cross-validation 100 times, two regression trees appeared in similar percentages: 58 with 4 leaves (FT1), and 41 with 6 leaves (FT2). Another tree, with only 3 leaves appeared only once and is not taken into account in this paper. Differences between FT1 and FT2 were only observed in one of the leaves (Fig. 1), which were more expanded in FT2 at the level of meadows bigger than 16.85 Ha. In this case, high values of road length and high March temperatures result in low probabilities of finding marmots. Resulting variables from the validation of the regression and classification trees were exactly the same as those from the regression and classification trees performed with the whole dataset (not shown).

FT1, with only the 3 most influencing predictors, showed that March temperature is the most important one, with a threshold at 1.5 (between -2°C and 2°C, see Table I for details on codes), which corresponds to a temperature of around 1.5°C in at least 50 % of the plot. At the lower side of this node, the area of calcareous soil clearly separates two leaves at 1.06 Ha, one with a probability of 0.84 of finding marmots (low surface of calcareous soils) and another one with a probability of only 0.13 (higher calcareous soil surface), and therefore classed as “Absent”. At the higher side of March temperatures (i.e. > 1.5), the presence of meadows is the next most influential predictor. If plots contain more than 16.85 Ha of meadows, the probability of containing marmot colonies is 0.25. Results derived from the observation of FT2 are very similar but a bit more detailed when the plots have more than 16.85 Ha of meadows. Marmots will be present with a probability of 0.68 if there are few roads (road length < 238 m) and March temperatures below code 2.5 (corresponding to around 3°C). With more roads, probability is zero, and with fewer roads but high March temperatures, the probability is very low (0.2).

Both the GLM analysis with FT1 and FT2 predictors as factors gave similar results (Table II). Thus, road
length, the extra factor in FT2, resulted non significant. The rest of the factors had significant effects on the presence of marmots with the two models. Both March temperature and calcareous soils’ effects on the presence of marmots were negative, and Meadows’ effect on the presence of marmots was positive. The revision of the fit of the model for each individual variable was graphically performed as suggested by Crawley (2006) (Fig. 2). In addition to the significant and negative effects of March temperatures on the presence of marmots, Fig. 2 shows that the fit of the model is very good in all cases, except when March temperatures are between 0 and 2°C in at least 50% of the plot area. The fit of the area of calcareous soil within plots, with slightly negative effects, is very good at both the highest and lowest sites, while with intermediate percentages (20-60%) the fit is not very good. Concerning the percentage of meadows within plots, the fit of the model is good for low percentages of meadows,
relatively good for intermediate percentages and very bad when this percentage is high.

**Density**

Again, running the crossvalidation routine resulted in two trees, one of them appearing 86 times and the other one only 14, so only the first one is considered. In the regression tree on density (from now on, DT) (Fig. 1) only 3 predictors appeared as essential: talus, wetland vegetation and shrubs. The highest mean densities (14.67 burrow sites/Ha, n = 6) were found in plots with more than 3.24 Ha of talus, and more than 0.51 Ha of wetland vegetation. Containing less than 0.51 Ha of wetland vegetation, low shrubland cover (less than 0.24 Ha) was a condition for high density as well (mean = 10.2 burrow sites/Ha, n = 5). Low densities were found either with low cover of talus or low wetland vegetation and relatively high shrubland cover.

The LM analysis showed significant and positive effects of talus (p = 0.0002) and negative effects of shrublands (p = 0.036) (Table III). Wetland vegetation, on the other hand, was in the limit of significance (p = 0.07), with a positive effect on density. Only one interaction among those already suggested by the tree models was significant: WetlandVegetation*Shrubland (p = 0.043).

**DISCUSSION**

Marmot colonies in southern Pyrenees are the most southern population of marmots in Europe. Their rapid expansion from the first release in 1948 is characteristic of an invasive species, with high expansion rates and fast occupancy of available sites. Our results provide interesting information about the factors that have enabled marmots to colonise the sampled region in this study, and also provide helpful tools to assess the proba-
Table III. – Output of the LM analysis for burrow density. Only the single and two-interactions effects were included in the model.

| Variable                          | Estimate | t value | Pr (> |t|) |
|-----------------------------------|----------|---------|-------|
| Talus                             | 0.082    | 4.017   | 0.000 |
| Wetland vegetation                | 3.701    | 1.837   | 0.072 |
| Shrubland                         | -0.012   | -2.137  | 0.037 |
| Talus * Wetland vegetation        | -0.379   | -1.780  | 0.081 |
| Talus * shrubland                 | -0.001   | -0.383  | 0.703 |
| Wetland vegetation * shrubland    | -2.323   | -2.067  | 0.043 |

It is noticeable that factors affecting the establishment of marmots in a relatively large plot (1 km²) are completely different from those that influence the density of a given plot of the same size. Despite the fact that the two data sets (the one for presence/absence and the one for density) had the same initial explanatory variables, the final trees do not share any of these variables. So, it seems that results concerning the presence and absence of marmots indicate that “global” characteristics of sites (in our case, 1 km² plots) would impose a first filter for establishment. Once “passed”, other characteristics of the site would take the place of influential factors, which are likely to be more important at a local level. This is in agreement with results reported by Armitage (1991) about yellow-bellied marmots, that females settle where resources are at least adequate for survival, but where reproductive success may be uncertain, which has an important effect on density. The resulting “global” characteristics of our analysis are March temperature and the presence of calcareous soil and meadows. March temperature is the root node, which indicates that it is the most important factor affecting the presence of marmots. This is also indicated by the good fit of the model and the significance of this factor. March temperature is a direct indicator of elevation (March temp. (°C) = 107.97-0.05*Elevation (m), r² = 0.98, N = 17187), but it was used instead of elevation because it also reflects the state of snow melting, a factor that has proven to be important in some marmot populations: alpine (Lenti Boero 2001), yellow-bellied (Armitage 1991) and Vancouver (Bryant 1998) marmot species. The correlation between March temperature and elevation is clearly visible in FT2, where the node “MarchTemp < 2.5”° is more likely to be indicating an elevation dependence than a temperature dependence. March temperature is also somehow integrating aspect, but this variable has not been used in this analysis because of its high variability within plots of 1 km². Road length only appeared in FT2, and even though it was not significant in the GLM analysis, the pattern that FT2 reveals is worth considering, because one of the two leaves after that node ends with a high probability of containing marmots (0.68). In a way, road length indicates elevation as well, because the higher the elevation, the lower the road length value; but it surely also indicates to some extent that marmots prefer avoiding the proximity to these structures and so to humans (Allainé et al. 1994). However, we have observed an isolated burrow site beside an important road at very low elevation (1050 m) at the end of a quite populated valley, which could well be an example of the low quality habitats in the “ideal free distribution” model (Fretwell 1972, modified by Krebs 2001).

The negative effect of the presence of calcareous soils is clear when observing Fig. 3. It is somehow surprising that even at the macro-scale analysis of this work, marmot selection against this variable is quite strong. This is evident throughout the study region. García-González et al. (2006) stated that in the first phases of colonization in the central and western Pyrenees, some marmots settled in calcareous environments, with very shallow burrows. With increasing densities, the proportion of marmots establishing in more deep soils also increased. González-Prat et al. (2001) also reported one satellite family established in calcareous soils, but the rest in gneiss and schists. This is not likely to have occurred in the study region, since there are no signs of marmot burrows in calcareous soils sites, and also probably because calcareous soils are not near the border with France. Despite the fact that we do not have related data, one could consider that the real factor affecting the presence of marmots is the vegetation associated with this soil type than the soil type itself. Aldezábal et al. (1988) and García-González et al. (2006) provide a list of species that were part of the diet of marmots in the central Pyrenees. The list is diverse both in terms of genus and soil preference, and, for instance, they report a preference of marmots for feeding on common dycotyledoneous species such as Laserpitium siler, which can be found in both calcareous and silicic soils, and for much more scarce species like Crepis albida, which grows better in calcareous soils (Bolos & Vigo 1984-2001). Without local data it is therefore difficult to assess this correlation. Soil depth could also play a role, but more at a microscale than at the level of our approach.

Something similar but with the opposite sign appears when observing the relation between the presence of meadows and that of marmots. Specially on the northern
side of Cerdanya, almost all meadow communities have marmots (Fig. 3). There are, though, still some “empty” spots: meadows in the southern side of Cerdanya are almost all empty. Some reasons might explain it: 1) it is necessary to cross the urbanised region (roads, cities,...) to get there, and habitable sites are not abundant there, but there are some; 2) the terrain is very steep to get there from the north, and many sites are likely to be very bad for marmots to settle in, with highly vertical walls mostly facing north; and 3) maybe it is still too soon for marmots coming from the north and the east to get there. It is also noticeable that even though at a macro-scale level the presence of meadows is positively associated with marmots, this correlation is not constant. Thus, the fits of the model for meadows are very good at intermediate percentages of meadows (50-70 %), but quite bad with almost no meadows and with increasing percentages of meadows. There is, however, a good fit in sites with low percentage of meadows, very difficult to interpret at a macro-scale level. This is likely to indicate, as also showed by our results, that marmots prefer mixed habitats, specially with talus. However, this would require a more detailed study of their home range in southern Pyrenees. The absence of meadows should prevent the establishment of marmots, since their burrows are almost only in. On the other hand, the lower fit of the model when percentage of meadows is too high suggests that marmots do not like being in completely open sites, which was also

Fig. 3 – Map of Cerdanya showing areas with predominant calcareous soils (shadowed) and sampling plots (●) (top), and areas with meadows (shadowed) and sampling plots (●) (bottom)
stated by Lenti Boero (2003). This is evident when observing the DT figure. Marmots like talus because they offer good observation spots and they can quickly hide between the rocks in case of danger (Allainé et al. 1994). Furthermore, as reflected with the positive and marginally significant relation of density with wetland vegetation, which is associated with small rivers, they surely feed from plants that preferably grow there. In a preliminary review by Lenti Boero (2003), among the 8 studies that had reported results on geological preferences of alpine marmots, in 6 of them, marmots preferred to have few rocks in their territory. Armitage (1991) and Floyd (2004) also stated that yellow-bellied marmots occur at high elevations, usually above 2000 m, and occupy the open areas relatively free of trees and shrubs, but containing talus, rock outcrops or scattered boulders under which burrows are constructed.

Climatic change in southern Europe will mostly be expressed by an increase in temperature (IPCC 2007). Our data clearly reveal that March temperature is the most important factor affecting the presence of marmots at global scale. A direct effect of this increase is an advanced snow melting season, which normally occurs between March and May in the Pyrenees. López-Moreno et al. (2007) found that the positive trend observed in the NAO index during the second half of the 20th century lead to a decrease in the occurrence of sites that favour snow accumulation in large areas of the Spanish Pyrenees and an increase in unfavorable conditions for snow pack. The observed elevational range of alpine marmots in the Pyrenees was reported between 1300 and 2400 m (García-González et al. 2006), similar to altitudinal ranges reported in the Alps (Couturier 1955, Huber 1978, Solari 1988). The altitudinal limit for pine forests in the Pyrenees (around 2400 m) is a bit higher than in the Alps (around 2100 m), due to their more southerly situation (Ozenda & Borel 1991). García-González et al. (2006) suggest that marmots could colonize the Pyrenees because the forest limit was anthropogenically changed to elevations around 1700-2000 m, and so they found artificially created meadows that coincided with the subalpine habitat. This explanation can be applied to the lower elevational range, but at high elevations what seems to be limiting marmots establishment is only the snow cover. At high elevations, climatic change could play a role in two different directions. On one hand, a decrease in snow cover and an advance in snow melting could potentially benefit marmots, so they could colonize all the Pyrenees from the forest limit upwards. On the other hand, some models also predict that at high elevations, precipitation and therefore snow could increase. The inability of marmots to survive hibernation is one of the most relevant causes of marmot mortality. Thus, the increase in snow cover at high elevations could prevent very low temperatures to reach the hibernacula, and so positively affect the possibility of marmot survival at high elevations. GCM models also predict a change in timing of precipitation events, notably increasing at late winter. For instance, snow precipitation in May 2008 has been, in southeastern Pyrenees, the most important of the season. One of the direct consequences of climatic changes is an important effect on the phenology for primary productivity of marmots, particularly at the beginning of the season. Future studies should focus on these factors that somehow counterbalance each other. However, there is also another actor playing a likely important role: the increase in temperature might promote an upslope creeping of the vegetation, and so reducing the lower limit of the elevational range of the alpine marmot.

ACKNOWLEDGEMENTS. — The authors wish to thank all the students of the “MarmoTeam” who collaborated in the field work of this study. We also wish to thank Dr D Sol for his help in the experimental design. This study was funded by the project “Estat d’expansió de la marmota a la comarca de La Cerdanya” (Generalitat de Catalunya, ACOM 2006ACOM 0020).

REFERENCES


Fretwell SD 1972. Populations in a seasonal environment, Princeton, NJ, USA.

Vie Milieu, 2009, 59 (2)


Received March 6, 2008

Accepted June 2, 2008

Associate Editor: J Boissier