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Potential distribution of the alpine marmot in Southern Pyrenees

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Alpine marmots were introduced in the French Pyrenees between 1948 and 1988. The exact number of re-introduced individuals is unknown, but it oscillated around 400. The likely preference of marmots for the southern sunny slopes rapidly facilitated their expansion to the southern Pyrenees, where the lack of both natural predators and of important interspecific competitors also likely facilitated an important expansion of this species. There is only one attempt to broadly calculate the population of marmots in the southern Pyrennes, estimating a population of around 10,000 individuals. However, there exist no reliable data to calculate the potential distribution of this new colonizing species in the southern Pyrenees, and a map of the potential distribution of the species is necessary to see whether alpine marmots can potentially establish in sites where it might be necessary to manage its populations for various reasons. We developed a map of potential distribution based on census carried out in summer of 2007 in an area of more than 600 km. We censused more around 300 colonies together with around 300 random points to characterized habitat selection variables. A map with a pixel size of 15 × 15 m has been obtained based on preferred habitats and also on distances to other habitats for the whole southeastern Pyrenees.

KEY WORDS: alpine community, invasive species, *Marmota marmota*, mammal.

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INTRODUCTION

Alpine marmots were widespread in Europe until the early Holocene (Couturier 1955, Besson 1971), when they disappeared except in the Alps and the Tatra mountains. The species was introduced in the French Pyrenees between 1948 and 1988 in order to feed golden eagles (*Aquila chrysaetos*) and brown bears (*Ursos arctos*), both endangered species, and, at the same time, to decrease the predating pressure of eagles on alpine chamois (*Rupicapra pyrenaica*). The exact number of re-introduced individuals is unknown, but it oscillated around 400 (Ramousse et al. 1992). The likely preference of marmots for the southern sunny slopes (González-Prat et al. 2001, Palomo & Gisbert 2002) rapidly facilitated their expansion to the southern Pyrenees, where the lack of both natural predators and of important interspecific competitors also likely facilitated an important expansion of this species. Some studies carried out early in the expansion process in the southern Pyrenees already pointed to a fast expansion of alpine marmots in different sectors of the region (Canut et al. 1989; González-Prat et al. 1989, 2001; Herrero et al. 1992). There is only one attempt to broadly calculate the population of marmots in the southern Pyrenees, estimating a population of around 10,000 individuals (Herrero et al. 2000, Palomo & Gisbert 2002), so it is evident that alpine marmots have colonised most areas of the southern Pyrenees, reaching very high densities in some areas, or still in a colonisation phase in others.

However, there exist no reliable data to calculate the potential distribution of this new species in the southern Pyrenees. In this area, which covers ca 146,000 ha, alpine marmots are considered a hunting species with a special protection against hunting, and a future management plan of the species is likely to be redacted. To do that, a map of the potential distribution of the species is necessary to see whether alpine marmots can potentially establish in sites where it might be necessary to manage its populations for various reasons. For instance, alpine marmots can establish in farms and their burrows can be a potential danger for cattle, or marmots can also settle in ski stations where marmot burrows might affect some of their infrastructures; on the other hand, since marmots are active herbivores, it might be necessary to exclude their presence in sites where endemic plant species need special protection, or even exclude by competition other endangered vertebrate species such as rock ptarmigan (*Lagopus muta*).

The main objective of this study was building a map of the potential distribution of alpine marmots in the Catalan Pyrenees, an area that covers ca 146,000 ha. We also developed a web-based tool to check for the accuracy of the predicted map.

MATERIALS AND METHODS

Distribution of alpine marmots

Sixty-four 1 km plots, all containing marmot colonies, were intensively sampled during spring and summer of 2007 in the southern Pyrenees, and all burrow sites in each plot were georeferenced (Garmin GPSMap 60CSx). In order to assess the variables that influenced habitat selection, a number of random sites without marmots were also measured within each plot, so the number of random sites was the same as that of burrow sites. In case random sites were too close to burrow sites, so they could be part of the nearby marmots' home range, they were discarded and new random sites were chosen. After checking for the quality of field data, a total of 591 sites were used for the analysis, 310 with and 281 without burrow sites, respectively. All these points were introduced to MiraMon©, a Geographic Information System (GIS) software developed in the CREAF research center (http://www.creaf.uab.es/miramon).

Statistical analysis and map construction

The map of habitats of the Catalan countries comprises 83 categories in our study area. We reduced this classification to 31 categories, according to similitude of habitats or to expert knowledge based on the differences among them that were not likely to influence the presence or absence of marmots (Table 1). In addition to the habitat that corresponded to the sampled points, we calculated the shortest distance of sampled points to all habitats, including urban areas and water sources.

All statistical analysis were performed using the R package (R Development Core Team 2006). To estimate the habitat selection variables of marmots, we combined Generalized Linear Models (GLM, R-base package) and Tree Models (mvpart R-package). GLMs allow the analysis of data that either do not have constant variance or that are not normally distributed, like count data and proportion data (Crawley 2006, 2007). We used GLMs to detect the significant variables affecting the establishment of marmots in a given site. Firstly, we calculated univariant models for all variables against the Presence/Absence of burrow sites. Collinearity among the resulting significant variables was controlled via two approaches: (1) a pairwise correlation analysis; and (2) an analysis of collinearity via analysis of Variance Inflation Factors (vif, car R-package). The resulting significant variables were introduced to a new database in order to perform tree analyses.

Tree analyses were performed to obtain distance thresholds and their corresponding probabilities of finding marmots for each significant variable. 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, one 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 deviances 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. Tree analysis was performed, on one hand, to assess whether there was a hierarchization of

Table 1.

Description of the 31 habitat types summarized from the former 83 categories of the habitat types of Catalonia (Id. = Identification number).

Habitat Id.	Description
1	Water
2	Forest
3	*Calluna vulgaris* meadows, acidic soils
4	*Rhododendron ferrugineum* shrubs, acidic, high snowfall rates, high mountain
5	*Genista balansae* shrubs, silicic, generally sunny slopes, high mountain
6	Other shrubs (*Buxus sempervirens*, *Rosmarinus officinalis*, ...), intermediate elevations
7	*Pinus uncinata* forest
8	*Carex fusca* wetlands, low acidity
9	Calcareous talus, generally with *Stipa calamagrostis*
10	Silicic talus
11	Calcareous talus
12	Calcareous canyons
13	Silicic canyons
14	Agricultural fields
15	Urban area
16	Abandoned agricultural meadows
17	*Nardus stricta* meadows, acidic and hygrophile, high mountain
18	*Festuca eskia* meadows, acidic
19	*Arrhenaterum elatius* meadows and similar communities
20	*Festuca paniculata* meadows, low acidity, generally in rocky slopes
21	*Festuca gautieri* meadows, and similar communities, mesoxerophiles and calcicoles
22	*Festuca airoides* or *F. yvesii* meadows, acidic
23	*Selseria coerulea*, *Cirsium acaule*, … meadows, calcicoles and mesoxerophiles
24	Calcicoles and mesophile meadows, with *Festuca nigrescens*, *Plantago media*, *Galium verum*, *Cirsium acaule*, …
25	Basic and xerophile meadows, with *Festuca ovina, Avenula iberica, Bromus erectus, Brachypodium phoenicoides, Seseli montanum, Teucrium pyrenaicum*
26	Meadows with *Astragalus sempervirens subsp. catalaunicus, Sideritis hyssopifolia, Festuca ovina, Avenula pratensis*, …, calcicoles and mesoxerophiles
27	Meadows of *Ononis striata, Anthyllis montana, Globularia cordifolia*, … calcicoles and xerophiles
28	Shrubs and fields of *Aphyllanthes monspeliensis* and associated *Thymus communities*, calcicoles
29	Silicic and mesophile meadows, with *Agrostis capillaris, Festuca nigrescens, Anthoxanthum odoratum*
30	Acidic and mesophile meadows, with *Festuca nigrescens, Deschampsia flexuosa, Primula intricata, Gentiana acaulis*, …, generally in calcareous soils
31	Silicicole and xerophile meadows with *Agrostis capillaris, Seselimontanum, Festuca ovina, Dichanthium ischaemum*, …

factors influencing the presence of marmots; and, on the other hand, to determine the threshold of each significant factor on the presence of marmots (Fig. 1).

Each node of the tree was noted as a threshold for each variable, and each leaf of the tree had an associated probability for each side of the node. For instance, a probability of 0.32 of finding marmots in a site would occur in points at distances below 20.9 m from *Pinus uncinata* forests and below 130.6 m of *Nardus stricta* meadows. Based on these results, we created as many raster maps (with pixels of 15 × 15 m) from the vector of habitat types of the Pyrenees as many habitat types that appear in the nodes of the tree. In other words, for each path from the first node until each leaf, we obtained as many rasters as nodes. All the rasters of the same path were then multiplied, and we finally multiplied the probability of the leaf to the former operation. This was done for all possible paths, with a total of 3 final rasters. All of these maps were then combined to a final map with the combinations of probabilities of the different former layers, obtaining Fig. 2A. Another map of preferences based on the habitat types of each exact point of each burrow site was built. For each habitat type, we calculated the probability with respect to the total points of all burrows (Table 2).

The vector of habitat types is organized in polygons, and each polygon is labelled as its main habitat type. But the metadata of each polygon also contain information about the percentage of other habitat types within it. So, we created as many raster maps as habitats for each polygon, for all habitats. Each 15 × 15 m pixel of the raster map had the associated probability in Table 2. A final step consisted on summing all raster maps to obtain the probability of having marmots in each pixel (Fig. 2B).

We finally combined the distances raster map with the habitat preferences one into a new raster with the combined probabilities for each 15 × 15 pixel of each raster. Two final corrections to this map were done: (1) since we had not found any burrow site below 1000 m a.s.l. neither in our field data nor in the bibliography, all points below this elevation were reclassified as probability zero to have marmots; and (2) we also classi-

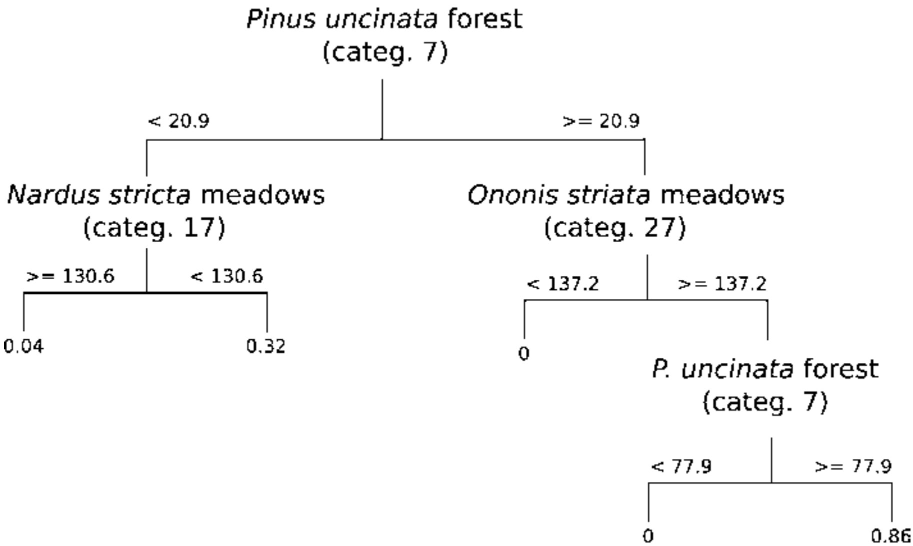

Fig. 1. — Regression tree to obtain the hierarchization of variables affecting the presence of marmots depending on distances to habitats. Leaves represent the probability of finding marmots for a given path from the first node until the leaf.

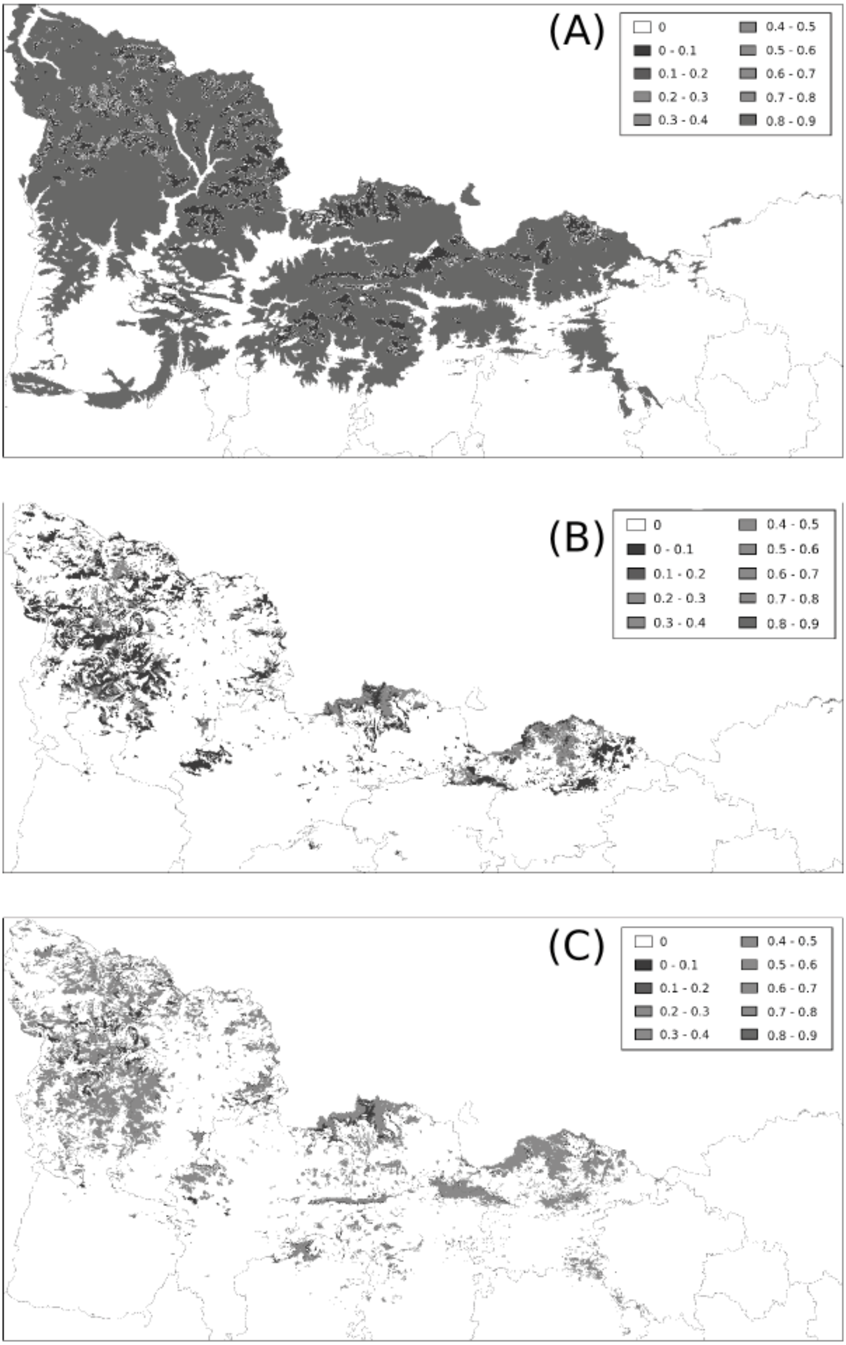

Fig. 2. — (A) Map of potential distribution based on significant distances to habitats from the GLM analysis and on the thresholds obtained from the regression tree. (B) Maps of potential distribution based on the probabilities of being in the different habitat types summarized in Table 2. (C) Combination of the two former maps with the two final corrections mentioned in the text, resulting in the final map of potential distribution of alpine marmots in the southern Pyrenees.

Table 2.

Number and percentage of burrow sites found in each habitat type, see Table 1 for the description of habitat types (Id. = Identification number).

Habitat Id.	Frequency (N)	Frequency (%)
2	2	0.67
4	11	3.73
5	10	3.39
24	8	2.71
28	3	1.02
29	13	4.41
31	1	0.39
17	91	30.85
18	20	6.80
22	91	30.85
21	8	2.71
19	2	0.67
7	8	2.71
8	2	0.67
10	19	6.44
11	2	0.67
14	4	1.36

fied as zero probability those pixels with less then 2.5% of having marmots. The resulting map, i.e., the map of potential distribution of alpine marmots, is shown in Fig. 2C.

Checking field observations

To verify the presence of marmots in predicted sites we developed a web-based portal with integrated GoogleMaps (http://faunacat.ecomood.net). The web portal permits either entering latitude and longitude values in case they are known, or directly pointing to the place where marmots had been observed in a map. The accuracy of this method is very high due to the high quality of GoogleMaps in Catalonia. Forest services and other experts will be asked to place all known sites with known presence of marmots during spring and summer of 2009. In addition, we compared our maps with the only two existing maps of the distribution of alpine marmot in the southern Pyrenees: (1) GONZÁLEZ-PRAT et al. (2001) in 5 × 5 km UTM grid for a relatively small region, and (2) PALOMO & GISBERT (2002) in a 10 × 10 km UTM grid for the whole southern Pyrenees.

RESULTS AND DISCUSSION

The output of the map based only on distance thresholds (Fig. 2A) can be a priori surprising. Among the former 31 habitat types to which distances were calculated, only 11 were significant in the GLM model, and only 3 appeared in the tree. Thus, it is not surprising that this map presents so full an area of potential distribution, because we need to take into account that this map only shows the points that are at given distances of the selected habitats, and this has nothing to do with the habitats where marmots are able to establish. In a way, it just gives the limitations of the potential distribution. Therefore, it is necessary to complement this map with the map based on points where burrow sites have been observed in the field, i.e. Fig. 2B. In this map, only habitats where marmots have established have probability values above 0. The combination of both maps, lately also corrected by elevation, is the map of potential distribution, with all 15 × 15 m pixels with their associated probabilities.

As observed in Table 3, the potential distribution of marmots in the southern Pyrenees covers an area of 146,450 ha. It also appears clear that the Pyrenees are not globally a very good region for marmots, since probabilities are not very high. Most of the usable area (66%) has probabilities between 0.4 and 0.5 of being occupied by marmots, and only a 15% of these 146,450 ha have probabilities of being occupied between 0.6 and 0.7. It is worth noting that 10% of the usable territory, i.e. 14634.7 ha, is usable with probabilities below 0.1, while 336 ha, i.e. only 0.2% of the usable territory, has the highest probabilities of hosting marmots. However, although proabilities are not generally high in most of the areas, marmots can expand through the whole Pyrenees without much trouble in sites above 1000 m, and thus can be present in most alpine and subalpine communities.

González-Prat et al. (2001) censused the population of marmots in the southeastern limit of the Pyrenees and provided a map of distribution in their area (fig. 2 in their paper). Keeping in mind that their level of resolution (5 × 5 km) is much lower than ours (15 × 15 m), and, so, it is easy to find coincidences between the two maps, the degree of overlapping between them is complete (Fig. 3). There is also another map of the distribution of the alpine marmot for

Table 3.

Area potentially occupied by alpine marmots and their associated probability in southeastern Pyrenees.

Probability range	Area (ha)	Area (%)
0.0-0.1	14634.7	10.0
0.1-0.2	4364.0	3.0
0.2-0.3	217.7	0.1
0.3-0.4	3569.4	2.4
0.4-0.5	97333.9	66.5
0.5-0.6	22582.3	15.4
0.6-0.7	3412.2	2.3
0.7-0.8	335.9	0.2
Total	146450.1	

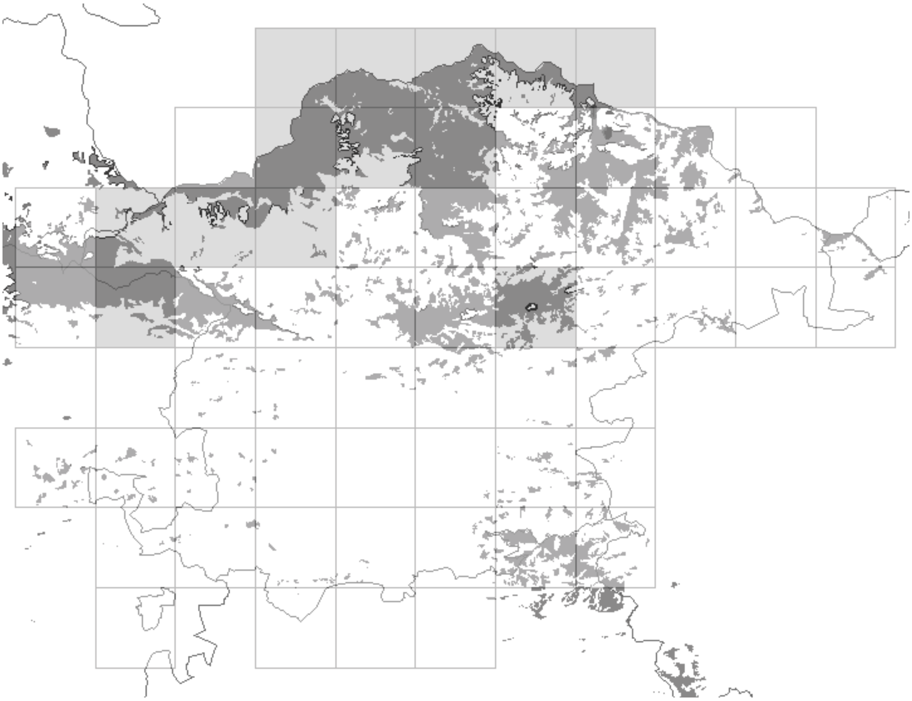

Fig. 3. — Comparison of the map provided by GONZÁLEZ-PRAT et al. (2001) in the Ripollès region and our map of potential distribution. The grid is of 5 × 5 UTM km.

all southern Pyrenees (PALOMO & GISBERT 2002), but in this case the resolution is still lower (10 × 10 km). Again, all squares where they report the presence of marmots are also predicted by our map, in addition to other sites that we predict but are not present by PALOMO & GISBERT (2002) map (Fig. 4). It is also likely that both maps present fewer sites with marmots because their information comes from studies carried out before 1996, when the level of expansion of the alpine marmot in the southern Pyrenees was probably much lower than at present. Nevertheless, the coincidences with both maps confirms the level of accuracy and prediction of our map of potential distribution.

Thus, the Pyrenees, despite appearing as not being an optimum site for marmots, seem to be able to host a big population of marmots. The likely fast expansion rate of the species supports this. Although there are no data on the real population of alpine marmots in the southern Pyrenees, HERRERO et al. (2000) broadly calculated it on more than 10,000 individuals after only 40 years of their first site in the southern Pyrenees. Although forcedly broad, this estimate already suggests that marmots have been very successful in colonising the southern slopes of the Pyrenees, which is also in agreement with our potential map of distribution. HERRERO et al. (1992, 2000) and GARCÍA-GONZÁLEZ et al. (2006) suggested that, in the Pyrenees, marmots are not occupying their natural home range. In their former habitats in the Alps,

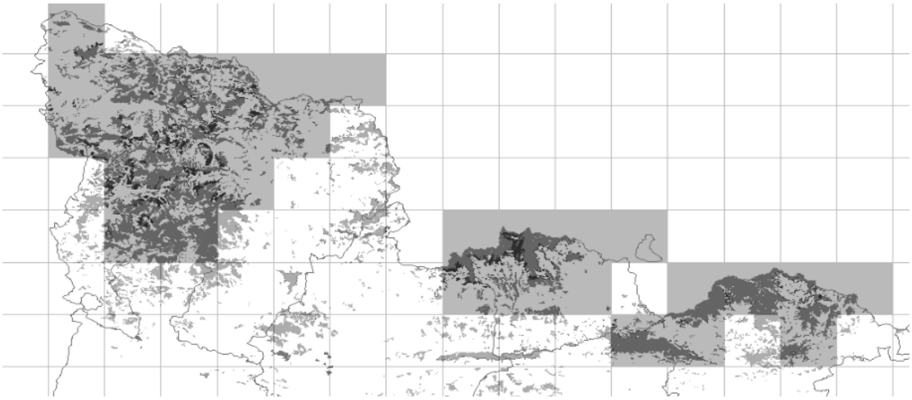

Fig. 4. — Comparison of the map provided by PALOMO & GISBERT (2002) in the southern Pyrenees and our map of potential distribution. The grid is of 10 × 10 UTM km.

marmots are generally above 1600-1700 until elevations of more than 2500-3000 m, where alpine meadows are still present. In the Pyrenees, although marmots have been observed at the highest altitudes (more than 3000 m, personal observations), at these elevations vegetation is very poor and most sites are dominated by talus, so primary productivity seems insufficient to support marmot colonies. On the other hand, at lower elevations, the traditional management of the Pyrenees has moved the natural tree-line downward. So, enormous new anthropogenically-created extensions of subalpine meadows have appeared during the last century, which have become, also thanks to good climatic conditions, the main habitats of marmots. However, this landscape, mainly due to this non-natural origin, is very fragmented, which, coupled to its high level of detail (pixels of 15 m), can explain why the map of the potential distribution of alpine marmot is not very continuous in some sites.

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