Allegato 3b_2

Summer Habitat Suitability Distribution of Alpine ibex and Alpine chamois in Gran Paradiso National Park.

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Introduction

The complex relationship between species ecological niches and geographic distribution of species considering across space and through time is an emerging ecological field (Townsend Peterson et al. 2011) and in this context, Species Distribution Models (SDMs) have become an ecological common practice.

Specie Distribution Models estimate the relationship between species records at sites and the environmental and/or spatial characteristics of those sites. They are based on different statistical methods according to dataset availability (Franklin 2009). They are widely used for many purposes in biogeography, conservation biology and ecology (Elith & Leathwick 2009).

Presence/absence models are frequently used to predict species distribution, but there is a common problem related to the uncertainty in determining absences (Phillips et al. 2006). Many biological databases collected only presence data or systematic biological survey data tend to be sparse and/or limited in coverage. In such cases, methods to model presence-only data such as maximum entropy modelling (MaxEnt), become powerful tools in predicting species potential distributions across new areas (Phillips et al. 2006; Phillips et al. 2008). MaxEnt outperforms a probability distribution of habitat suitability, that is a value representing the relative suitability of the environmental constraint for the target species in each pixel in the study area.

MaxEnt has been used in predictive modelling of species' distribution for different topics as to analyze the relationship between a species and its environment (Tittensor et al. 2009; Siders et al. 2013); to suggest specie migration corridors prediction (Poor et al. 2012), to understand and predict the dynamics of invasive species (Ficetola et al. 2009), to model the species future potential distribution under climate change (Fitzpatrick et al. 2008) and finally to make spatially explicit decisions about conservation planning for vulnerable species (Mateo-Toma & Olea, 2010).

MaxEnt's predictive performance is consistently competitive with the highest performing methods (Elith et al. 2006) and we have decided to select this type of SDM, considering data collection available for alpine ungulate in Gran Paradiso National Park (GPNP) (summer census data).

The principal aim of this action is to determine current and potential distribution of alpine ungulate in GPNP, to quantify the amount and arrangement of their suitable habitats in a certain landscape and to perform the Alpine ibex and Alpine chamois habitat suitability maps.

In GPNP management and conservation plan is fundamental to analyze chamois and ibex distribution and factors that are related to their suitable areas and possible niche overlap between the two alpine ungulates.

Species current niche ecological knowledge could be also useful for future prediction analysis under climate change: the most important predictor variables and their transformations have to be considered in the analysis for a realistic predictive distribution in view of different climate scenarios.

Methods

In order to perform the ibex and chamois habitat suitability map, we decided to use localisation of September census data from 2000 to 2013: standardised dataset, effort and spatial range were representative of the Gran Paradiso National Park territory. The census data localisation was based on a grid of 250x250 mt (seen method of ACTION 3.a.2).The high sampling intensity developed over the entire area by many different park wardens reduced problems of data spatial autocorrelation.

We decided to outperform habitat suitability map for ibex and chamois with a grid resolution of 250x250 mt, considering three period (1993-1999; 2000-2006 and 2007-2013) in order to analyses temporal change in potential species distribution. We selected presence data with high accuracy (1) from 1993-1999 dataset (seen methods in 3.a.1 ACTION) in order to compare standardised accuracy dataset of the three different periods.

For statistical analysis, we used R (version 3.0.3) and software open source Qgis 2.2.0 for GIS analysis and map outputs.

We used MaxEnt version 3.3.3k and accepted recommended default value of convergence threshold (10^5), and default regularisation value (to reduce overfitting). We selected value maximum interaction

(1000) and combination of feature class (quadratic, product and hinge) following the practical guide by Merow et al. 2013.

We selected MaxEnt logistic output, which is an attempt to estimate a probability that the species is present in environment (habitat suitability probability). Logistic output performed species habitat suitability values range from 0 (unsuitable) to 1 (optimal habitat). We selected prevalence value for ibex and chamois ($_{\text{ibex}}$=0.4; $_{\text{chamois}}$=0.7) different from Maxent default value ($_{\text{default}}$=0.5), considering the species attitude and species range in the study area as suggested by Elith et al. 2011.

Model fit was evaluated based on the Area Under the Curve (AUC) of the Receiver Operator Characteristics (ROC), which measures the model probability of correctly distinguishing presence from random locations and good model performance was considered when training and test AUC scores were higher than 0.7 (Phillips et al. 2006).

The AUC was calculated for both a training and a test data set, after partitioning the annual census data localisation by randomly assigning 50% of presences to test (test dataset) and the remaining 50% to train the model (training dataset). We removed duplicate presence localisations collected in the same year. We selected environmental variables considering both topographic and land cover. All chosen covariates are connected to alpine ungulates ecology.

Topographic variables (elevation, aspect, slope and roughness) were derived from Digital models (DEMs) TINITALY/01 DEM (Tarquini et al. 2007; Tarquini et al. 2012) and land cover variables were derived from GPNP fine-scale habitat study (2004) and elaborated in Qgis 2.2.0 to extract distance (m) (measures at a 250 m spatial resolution) to each prevalent (>75%) land cover type grid. We considered as refuge zone, grids where rocks with high slope (ibex: >40°, chamois >30°) were relevant (>50%).

Roughness is the largest inter-cell difference of a central pixel and its surrounding cell, as defined in Wilson et al 2007.

We calculated Pearson’s correlation coefficients (r) to reduce multicolinearity between variables and for the variables highly correlated (r >0.7), we selected the variables with a higher ecological significance according to both the biology of the species and the scale considered.

We decided to use distance to forest in chamois models even if correlated with elevation (r=0.79), because of its ecological importance in species biology.

We used ENM tools (1.4.3 version) to evaluate niche overlap (Warren et al. 2010) in order to quantify transformation in habitat suitability between the three different periods and to assess niche overlap among ibex and chamois during the same period.

CODICE	VARIABILEs
ELEV	Elevation
SLO	Slope
ROU	Roughness
ASP	Aspect categorised in 8 azimuth classes: N, NE, E, SE, S, SO, O, NO
DIST_f75	Distance (m) to forest (>75%)
DIST_sh75	Distance (m) to shrub (>75%)
DIST_me75	Distance (m) to alpine meadow (>75%)
DIST_pa75	Distance (m) to pasture (>75%)
DIST_sc75	Distance (m) to screes (>75%)
*DISTR30_50**	Distance (m) to rock with slope >30° (>50%)
*DISTR40_50***	Distance (m) to rock with slope >40° (>50%)
FOR_COV	Forest
SHR_COV	Shrub
GLA_COV	Glacier
SCR_COV	Scress
ROC_COV	Rock
MEA_COV	Alpine meadow
PAS_COV	Pasture

Table 1. Environmental variables used to model ibex and chamois distribution in Gran Paradiso National Park. Variables are calculated at 250 m grid resolution. (* ibex refuge zone;** chamois refuge zone).

Niche overlap is measured with Schoener's (1968) D index and a measure derived from Hellinger distance called I, where $px_{,i}$ and $py_{,i}$ are the normalized suitability scores for species X and Y in cell $_i$:

Schoener's D Index
$$D\,(px, py) = 1 - \frac{1}{2} \sum_{i} |px_{,i} - py_{,i}|$$

I Index
$$I\,(px, py) = 1 - \frac{1}{2} \sqrt{\sum_{i} (\sqrt{px_{,i}} - \sqrt{py_{,i}})^2}$$

We categorised value of habitat suitability probability in four different classes (<=0.25, 0.26-050, 0.51-0.75, >0.75) to create maps useful for conservation and management planning for both species.

We used Qgis 2.2.0 plugin MOLUSCE (version 3.0) to analyse change in area and type of suitability class with transition matrix, considering the different periods (1993-1999: 2000-2006; 2007-2013).

Results

Ibex Habitat Suitability Distribution

The number of ibex presence data from September census amounted to 3370 in 2000-2006 period and 2932 in 2007-2013 period. We decided not to model 1993-1999 period, because despite the number of data with high localisation accuracy (n= 3492), they were not representative of the whole GPNP territory misleading, for that reason, the map output.

We randomly partitioned 50% of the annual amount for training (2000-2006: n=1688; 2007-2013, n=1468) and remain annual data for testing models (2000-2006: n=1682; 2007-2013, n=1464).

The two period ibex models had a good fit (2000-2006: $AUC_{train} = 0.827$; $AUC_{test} = 0.814$; 2007-2013: $AUC_{train} = 0.820$; $AUC_{test} = 0.814$).

According to Maxent jackknife analysis, the most important environmental variables in determining habitat suitability for both models were first elevation (2000-2006: 26.0 % of model contribution; 2007-2013: 27.1 % of model contribution) and after distance to refuge zone (2000-2006:13.0 % of model contribution; 2007-2013: 17.5 % of model contribution). Forest (2000-2006: 20.4 %; 2007-2013: 21.9 %) and glacier coverage (2000-2006: 12.2 %; 2007-2013: 12.8 %) also contributed to models, but had a different influence and Jackknife test outputs (fig.1-3).

Elevation, distance to refuge zone and forest cover had the highest gain when used alone in both training and test models respectively (fig.3-4). However, the environmental variables that decreased the gain the most when it is omitted is elevation (with minor importance also distance to refuge zone), which therefore had the most information that was not present in the other variables (e.g. forest and glacier cover) (fig.3-4).

Distances to ibex trophic resource decreased only slightly the gain when omitted from both train and test considering the two models.

Finally, high elevation and proximity to refuge zone (rock with high slope) are important environmental variables for species habitat suitability, on the contrary, ibex seems to avoid area with forest and glacier.

Maps of ibex habitat suitability for 2000-2006 and 2007-2013 periods are in fig. 4.

The niche overlap was relevant between 2000-2006 and 2007-2013 suitability maps (I=0.992; D=0.906): area of intermediate suitability class (table 2) slightly increased comparing to extreme classes, this result was highlighted in transition matrix too (table 3).
The ibex potential area, considering habitat suitability probability > 0.50, resulted from the two models corresponds to 7% of all whole PNGP territory (table 3).

Class	*2000-2006*	*2007-2013*	*Δ*	*2000-2006*	*2007-2013*	*Δ*
	Area (ha)	*Area (ha)*	*Area (ha)*	*%*	*%*	*%*
<=0.25	48181	47500	-681	66.01	65.07	-0.93
0.26-0.50	19694	20113	419	26.98	27.55	0.57
0.51-0.75	4969	5269	300	6.81	7.22	0.41
>0.75	150	113	-38	0.21	0.15	-0.05

Table 2. Area change in ibex habitat suitability classes between 2000-2006 and 2007-2013 maps.

Class	*<=0.25*	*0.26-0.50*	*0.51-0.75*	*>0.75*
<=0.25	0.93	0.07	0.00	0.00
0.26-0.50	0.14	0.78	0.08	0.00
0.51-0.75	0.00	0.28	0.71	0.01
>0.75	0.00	0.00	0.58	0.42

Table 3. Transition matrix for ibex habitat suitability classes between 2000-2006 and 2007-2013 maps.

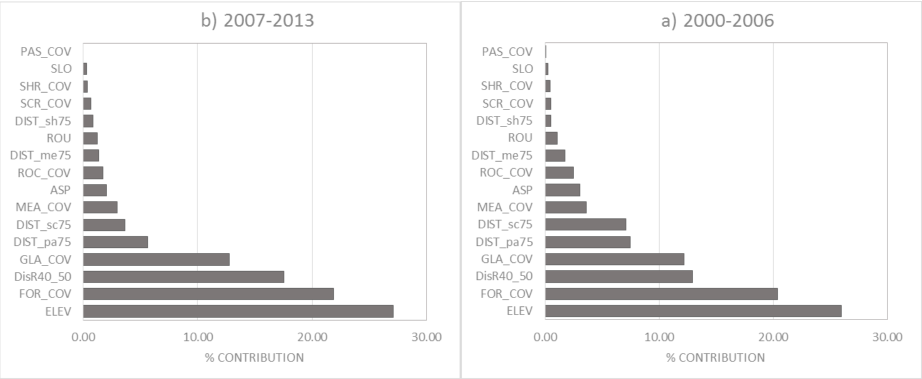


Fig. 1. Relative contribution of the environmental variables to ibex models (2000-2006, 2007-2013).

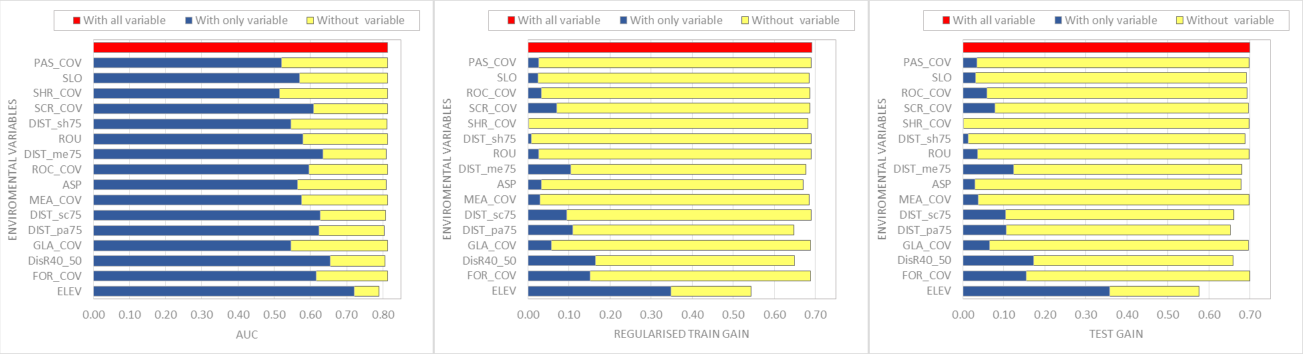


Fig.2. The results of the jackknife test of variable importance for 2000-2006 model, respectively using training gain, test gain and finally using AUC on test data.

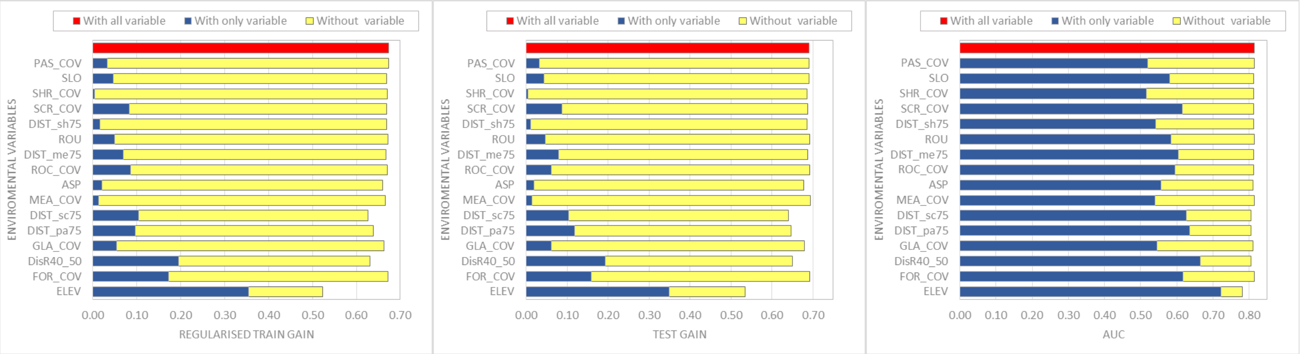
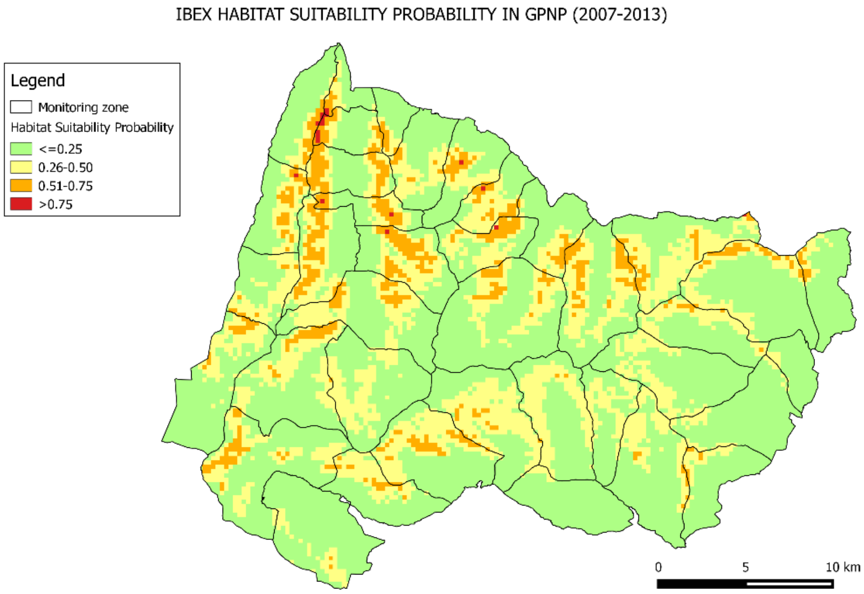


Fig.3. The results of the jackknife test of variable importance for 2007-2013 model, respectively using training gain, test gain and finally using AUC on test data.



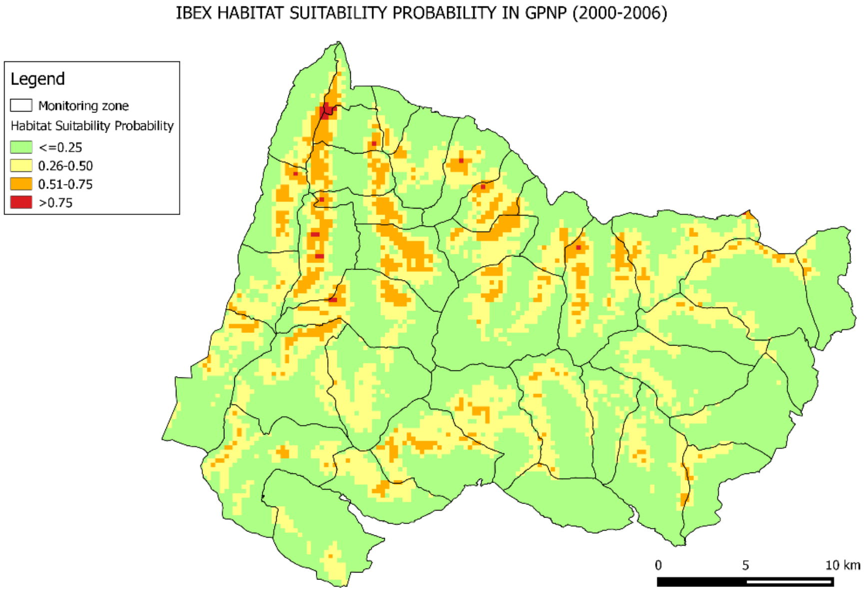


Fig. 4. Maps of ibex summer habitat suitability from 2000-2006 and 2007-2013 MaxEnt models.

Chamois Habitat Suitability Distribution

The number of chamois presence data from September census amounted to 4876 (data accuracy = 1) in 1993-1999, 6647 in 2000-2006 period and 7050 in 2007-2013 period. We randomly partitioned 50% of the annual amount for training (1993-1999: n=2439; 2000-2006: n=3326; 2007-2013, n=3527) and remain annual data for testing models (1993-1999: n=2437; 2000-2006: n=3321; 2007-2013: n=3523).

All three models had an adequate fit (1993-1999: 2 AUC_{train} =0.752; AUC_{test} =0.748; 2000-2006: AUC_{train} = 0.740; AUC_{test} = 0.724; 2007-2013: AUC_{train} = 0.734; AUC_{test} =0.717), less than ibex models because of widespread and abundant chamois localisations. The most important environmental variables in determining habitat suitability for two models were first elevation (1993-1999: 26.5 % of contribution; 2007-2013: 27.0 % 26.5% of contribution) and after meadows cover (1993-1999: 19.8 % of contribution; 2007-2013: 25.8 % of contribution). Meadows contributed most to 2000-2006 model (36.7%) compare to elevation (26.4%), but had a different output in jackknife test (fig.6), where elevation remain the variable with most information for the model. As a matter of fact, considering jackknife test for the three models, elevation, meadows coverage, distance to meadows and distance to forest had respectively the highest gain when used alone in both training and test gain. However, the environmental variables that decreased the gain the most when omitted was always elevation, which therefore had the most information that was not present in the other variables (fig.5-7). In 1993-1999 and 2007-2013 models, distances to trophic resource were important variable for habitat suitability too (fig.5, fig.7). Finally, environmental variables that were relevant in species habitat suitability are elevation and meadows, but also distance to trophic resource could influence distribution, on the contrary, chamois seemed to avoid area with glacier as ibex. Maps of chamois habitat suitability for 1993-1999, 2000-2006, and 2007-2013 periods are represented in fig. 6, fig.8 and fig.10. The niche overlap was relevant between habitat suitability maps of next recent periods like 2000-2006 and 2007-2013 (I=0.997; D=0.953), slightly lower between 1993-1999 and 2000-2006 models (I=0.994; D=0.930) and between 1993-1999 and 2007-2013 models (I=0.993; D=0.924). Area of intermediate and high suitability classes (table 4, table 6) increased respect to lower suitability classes analysing transformations between next periods, this result was also highlighted in transition matrix too (table 5, table 7). The chamois potential area (considering habitat suitability probability > 0.50) resulted from the three models corresponds about 60% of all whole PNGP territory (table 4, table 6).

Class	*2000-2006* *Area (ha)*	*2007-2013* *Area (ha)*	*Δ* *Area (ha)*	*2000-2006* *%*	*2007-2013* *%*	*Δ* *%*
<=0.25	15006	13381	-1625	20.56	18.33	-2.23
0.26-0.50	15331	15119	-213	21.00	20.71	-0.29
0.51-0.75	32493	33300	806	44.52	45.62	1.10
>0.75	10162	11194	1031	13.92	15.34	1.41

Table 4. Area change in chamois habitat suitability classes between 1993-1999 and 2000-2006 maps.

Class	*<=0.25*	*0.26-0.50*	*0.51-0.75*	*>0.75*
<=0.25	0.83	0.16	0.02	0.00
0.26-0.50	0.06	0.61	0.31	0.01
0.51-0.75	0.00	0.10	0.76	0.13
>0.75	0.00	0.00	0.34	0.66

Table 5. Transition matrix for chamois habitat suitability classes between 1993-1999 and 2000-2006 maps.

Class	*2000-2006* *Area (ha)*	*2007-2013* *Area (ha)*	*Δ* *Area (ha)*	*2000-2006* *%*	*2007-2013* *%*	*Δ* *%*
<=0.25	13381	12675	-706	18.33	17.36	-0.97
0.26-0.50	15119	15006	-113	20.71	20.56	-0.15
0.51-0.75	33300	34206	906	45.62	46.86	1.24
>0.75	11194	11106	-88	15.34	15.22	-0.12

Table 6. Area change in chamois habitat suitability classes between 2000-2006 and 2007-2013 maps.

Class	*<=0.25*	*0.26-0.50*	*0.51-0.75*	*>0.75*
<=0.25	0.84	0.16	0.00	0.00
0.26-0.50	0.10	0.69	0.21	0.00
0.51-0.75	0.00	0.07	0.85	0.08
>0.75	0.00	0.00	0.25	0.75

Table 7. Transition matrix for chamois habitat suitability classes between 2000-2006 and 2007-2013 maps.

The niche overlap between chamois and ibex was observed ad it was stable for the two periods analysed (2000-2006: I=0.89; D=0.65; 2007-2013: I=0.89; D=0.65).

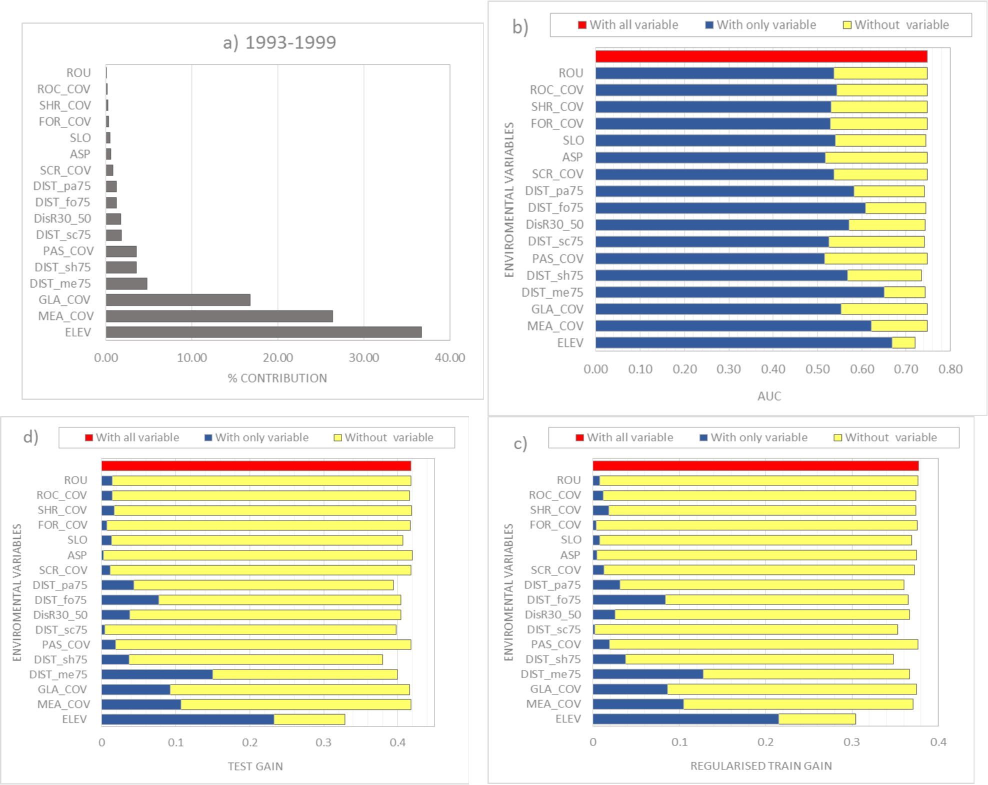


Fig. 5. The result of 1993-1999 chamois model: a) relative contribution of the environmental variables, b-d) the results of the jack knife test of variable importance (AUC on test data, training gain and test gain)

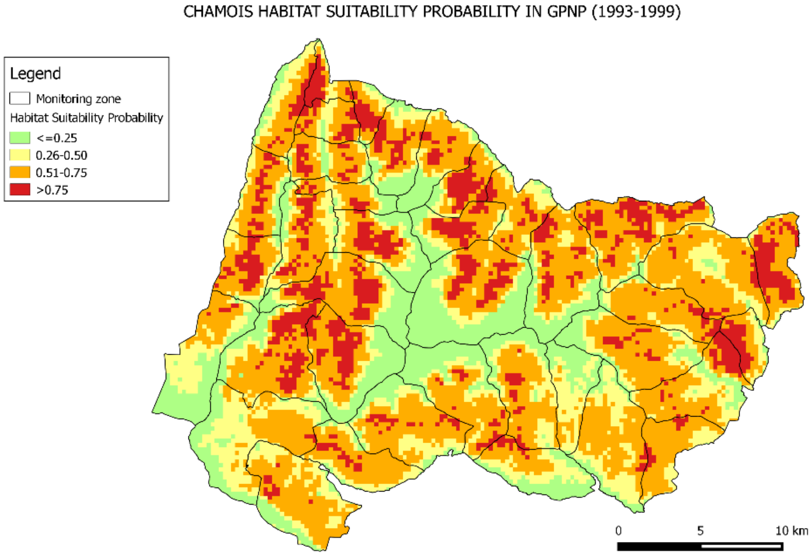


Fig. 6. Map of chamois summer habitat suitability from 1993-1999 MaxEnt model.

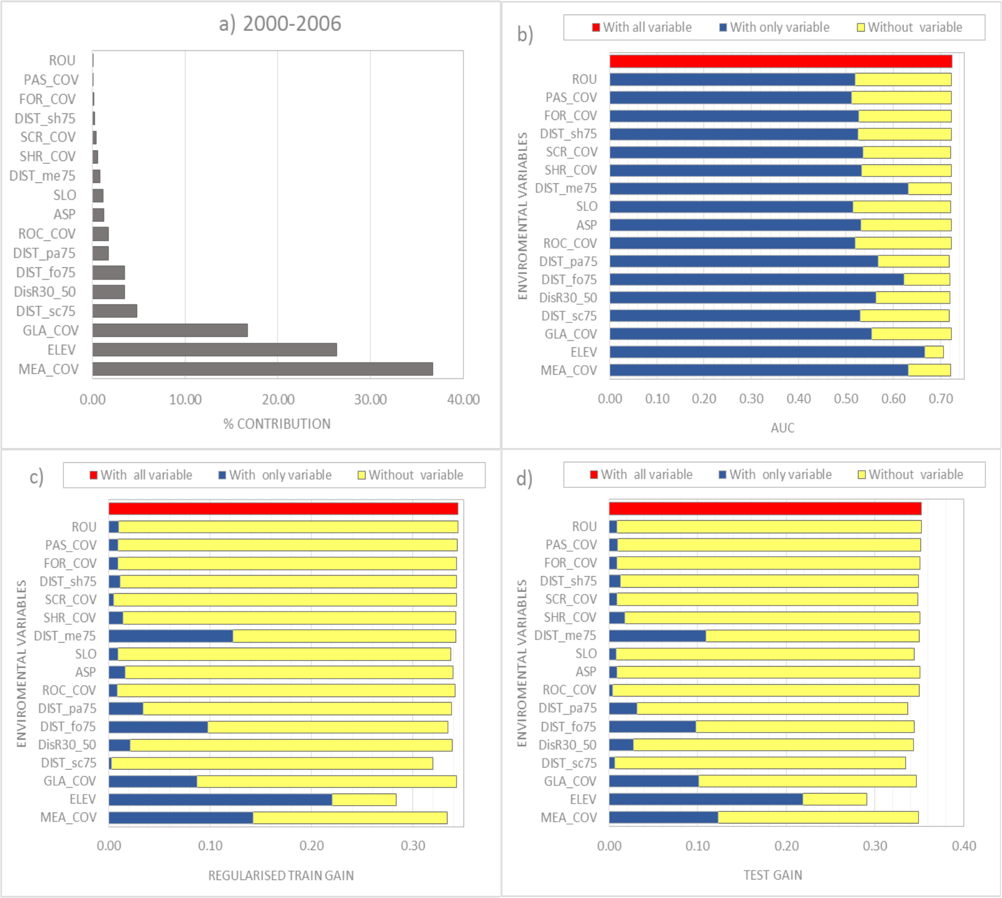


Fig. 7. The result of 2000-2006 chamois model: a) relative contribution of the environmental variables, b-d) the results of the jack knife test of variable importance (AUC on test data, training gain and test gain).

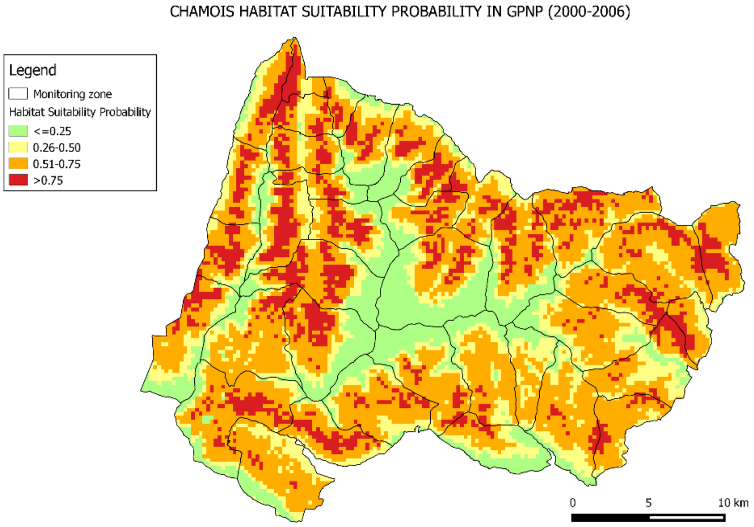


Fig. 8. Map of chamois summer habitat suitability from 2000-2006 MaxEnt model.

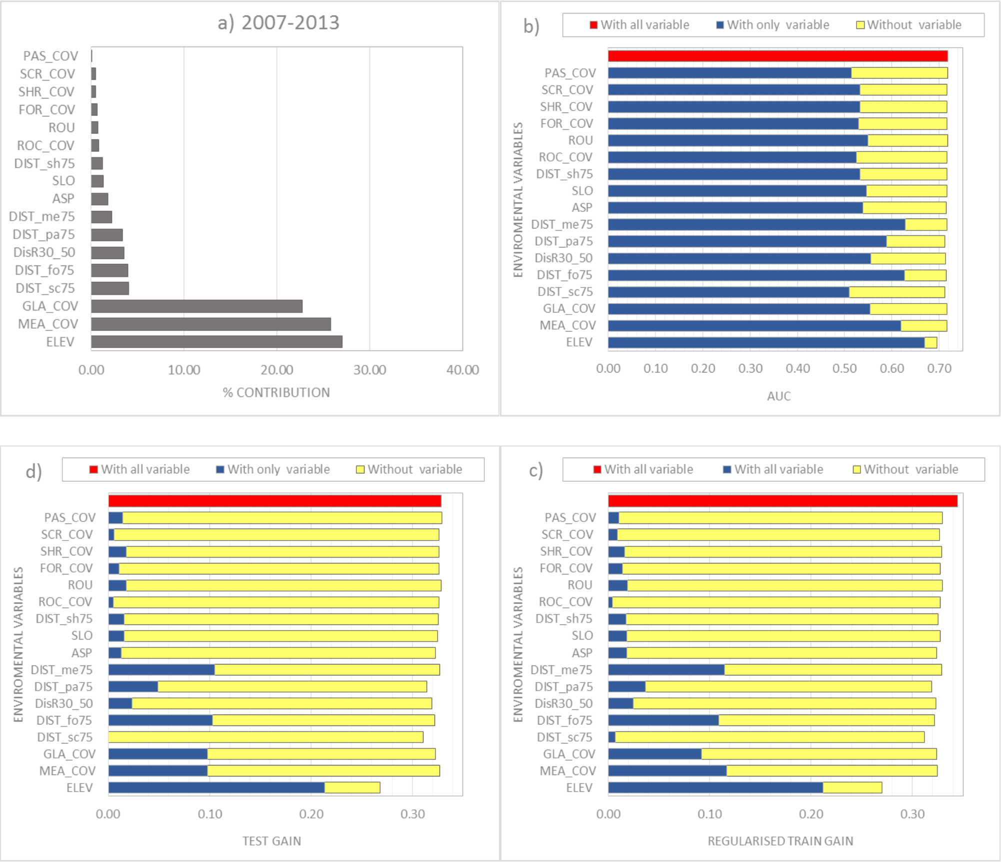


Fig. 9. The result of 2007-2013 chamois model: a) relative contribution of the environmental variables, b-d) the results of the jack knife test of variable importance (AUC on test data, training gain and test gain).

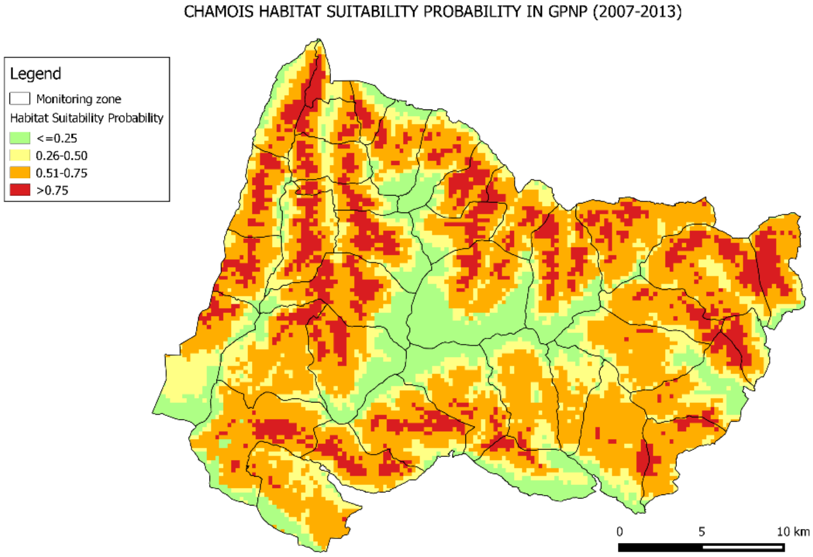


Fig. 10. Map of chamois summer habitat suitability from 2007-2013 MaxEnt model.

Discussion

Our results identify both the most suitable area (calculated with habitat suitability probability) to be occupied by chamois and ibex in Gran Paradiso National Park in summer, and both the factors determining their quality: species potential distribution maps are fundamental tools for conservation aims in a protected area like a National Park helping its monitoring and management.

Moreover, the knowledge of the most important factors that influence alpine ungulate distribution and suitable area is fundamental in future scenarios analysis under climate change, issue of ACTION 3.b.4. All factors strongly related to species habitat suitability have to be considered in the predictions analysis and as well as their future transformation in order to predict a realistic scenario of the species distribution.

For each species (alpine ibex and chamois), the habitat suitable maps of different periods had a relevant niche overlap and quite similar models results, confirming the same predictor variables and their relative importance.

Ecological niche overlap between ibex and chamois was observed comparing species models outputs (I=0.89; D=0.65).

Summer suitable habitat for ibex in GPNP was strongly influenced by elevation, and positively related to proximity to refuge zone (rocks with high slope), which are also fundamental as weaning kids sites in summer. By contrast, ibex tended to avoid forest and glacier.

The importance of elevation as predictor variable in species distribution was concordant with eto-ecological knowledge of this alpine ungulate and with results of precedent studies in the GPNP (Parrini et al. 2003; Grignolio et al. 2004; Aublet et al. 2009). Grignolio et al. (2004) reported that during summer 2001, which was hotter than summer 2002, female ibex had larger home ranges and moved to higher elevations.

A behavioural thermoregulatory tactic hypothesis was suggested to explain the weather-dependent daily altitudinal migration of male ibex (Aublet et al. 2009). Ibex is a stenothermic species and more related to high elevation due to physiological threshold temperature tolerance and its behavioural thermoregulation (Aublet et al. 2009).

In Hirzel et al. 2002 ibex was essentially linked to high-altitude, steep, and rocky slopes and tended to avoid forest and human activities too.

Also for chamois, the elevation was the most important predictor variable for summer habitat suitability, even if less strongly related. An additional relevant factor in chamois models was Alpine meadow. Further proximity to trophic resources (f.i. forest and Alpine meadow) was positively related to suitable area, on the contrary as ibex, chamois tended to avoid glacier. The potential area for chamois seemed to be less distinctive respect to ibex.

Our results in chamois models are concordant to habitat selection knowledge from literature, where high elevation, alpine meadows, forest, also scrubs and bushes are frequented habitat by the species (depending on study area availibility) in summer (Nesti et al. 2010; Unterthiner et al. 2012, Darmon et al. 2012). A study conducted in Valle Orco valley in GPNP, revealed a different sex habitat use in chamois during the warm months. In this research migrant males reached high altitudes (2100–2600 m asl) and they used alder shrubland, wet meadows and bogs, pasture and meadows, screes, grassland and rocks in proportion to their availability, otherwise resident chamois male selected pasture and meadows between 1900 and 2250 m asl (Nesti et al. 2010). Further female reached higher altitude in warm season and used rocks, pasture, meadows and grassland at 2100-2600 m asl (Nesti et al. 2010).

Anyway, chamois is relatively eurythermic, adapted to a wide range of temperatures, and it is found across a broad altitudinal range in the Alps (500–3100 m asl) (Shackleton 1997).

Altitudinal migration could not play a primary role in behavioural thermoregulation in chamois, due to considerable plasticity in activity budgets, which can ameliorate the consequences of substantial diurnal fluctuations in temperature (Mason et al. 2014).

A study conducted in GPNP suggested modest elevation migration in chamois when ambient temperatures were higher, on average 8–11 m upslope per 1 °C increase in air temperature. An important factor that strongly increased this effect was the interspecific local competition with sheep (Mason et al. 2014). Presence of sheep in GPNP territory is spatially and temporal localised in few valleys, so this effects is unlikely identifiable with a wide-ranging specie distribution model.

To sum up, in order to analyse future alpine ungulate distribution under climatic change, our results confirmed that ibex is the alpine species strongly related to altitude.

Ibex could be more sensitive to the effect of global warming and a direct consequence of the increasing temperature in the Alp region will be the species migration at higher elevation modifying its elevation range distribution. On the contrary, chamois seems to be less sensitive to this effect and other factors could influence its distribution, as for example trophic resource related to land cover.

Otherwise, all significant predictor variables in species habitat suitability and their future transformations have to be first examine and then included in predictive distribution under different climate scenarios. In general ibex could be more vulnerable respect to other ungulate considering global warming effects because it is a summit species, moreover it has a however an upper limit imposed by glacier and perennial snow as well as a lower limit imposed by forest regrowth.

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