Allegato 3b_3

Climate change effects on summer distribution of Alpine ibex and Alpine chamois in the Gran Paradiso National Park

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Introduction

Global warming has been particularly marked in high-mountain areas in the last half century (Beniston et al. 1997) with significant effects on wildlife species living in mountain habitats, which are particularly vulnerable due to their adaptation to extreme and very specific conditions. Climate change can affect animal species both directly (through energy expenditure, water requirements, mobility) and indirectly, by changes in snow amounts (Terzago et al. 2013) and climate-induced vegetational shifts (Walther et al. 2005). This is particular important for herbivore species such as ungulates, for which changes in plant communities mean variations in quantity, quality and availability of food resources.

In summer, both Alpine ibex *Capra ibex* (Grignolio et al. 2003) and chamois *Rupicapra rupicapra* (Darmon et al. 2012) selected areas located at high altitudes, above the timberline, characterized by the presence of Alpine meadows (to accumulate as much fat as possible for the winter) and fallen rocks or stone ravines.

At high temperature, the cost of thermoregulation may overtake the benefit of feeding, and animals can set up their behaviour to face this condition, as autonomic thermoregulation can be much more energetically expensive than behavioural thermoregulation (Maloney et al. 2005). Alpine ibex, for example, increase their feeding activity in early morning and reduce it at midday and evening as daily temperature and solar radiation increase (Aublet et al. 2009). Moreover, they move to higher elevations to find their comfort temperature (less than 15–20°C) and changes in forage quality and availability apparently do not explain this daily altitudinal migration (Aublet et al. 2009, Grignolio et al. 2004).

If increases in temperature conform to recent climate models, the two mountain ungulates could be forced to move further upward, with a reduction in suitable habitat and consequent conservation issues. However, while Alpine ibex is strictly a high-mountain animal, *Rupicapra* species make large use of wooden areas at least during the cold season (Michallet et al. 1999) and sometimes stably inhabit montane/subalpine forests (Herrero et al. 1996). Therefore we expect global warming to have a much higher impact on Alpine ibex than Alpine chamois.

Aim of this study is to detect climatic effects on the average summer altitude of the populations of ibex and chamois in the Gran Paradiso National Park, Italy, and to predict their distribution in face of expected climate change.

Methods

Meteorological data

Daily temperature (mean, minimum and maximum) and precipitation were collected in the Gran Paradiso National Park (hereafter GPNP) by three meteorological stations of the Piedmont Regional Agency for Environmental Protection (ARPA Piemonte), with data available from 1999: the Bertodasco station, at an elevation of 1120 m, the Ceresole – Lago Agnello station at 2304 m, and the Piamprato station at 1555 m.

We used the average of the standardized measurements over all stations in the analysis, i.e., we used

where is the value of a climatic variable (, , , or) on day *j* and for station *s*, is the average of over

$$c_j = \frac{1}{N_j}\sum_j \frac{c_{j,s}-\bar{c}_s}{\sigma_s}$$

the whole time period from 1999–2013 for the station *s*, and is the standard deviation. On each day, we performed the average on the number of stations which were active on that day.

For subsequent analyses, we aggregated meteorological variables across different critical season in the life cycle of the species.

For chamois the selected seasons were:

1. summer (June-September), both at time *t* (the year of the count) and at time *t-1* (the year before the count),
2. early winter (October-December) at time *t-1*,
3. late winter (January-March) at time *t*,
4. spring (April-May) at time *t*,
5. spring-summer (April-August) at time *t,*

For ibex the selected seasons were:

1. summer (July-September), both at time *t* and at time *t-1*,
2. early winter (October-January) between time *t-1* and *t*,
3. late winter (February-March) at time *t*,
4. spring (April-June) at time *t*,

Moreover, for both species we considered also meteorological variables aggregated over the period shortly before (August) or at the same time (first half of September) of the counts.

Count data

In the GPNP, each summer about 30 Park rangers conduct a ground count of the chamois and ibex populations by walking over established routes within assigned surveillance zones, which have an average area of about 10 km2. Wardens classify the observed individuals according to species, sex and age classes. The census of the entire park is conducted over two consecutive days within the first half of September. From 2000 to 2010 ungulate observations were drawn on a CTR (Regional Territorial Cartography) map (1:10.000) and the ID's grid cell of observation was reported on census form; from 2011 data have been recorded by a GPS. The census presence data of the ungulates were then plotted on a map with a grid of 250 x 250 m (6.25 ha). Grid unit was obtained by dividing into 16 identical parts each UTM cell (1 x 1 km) and identified by univocal ID. Each ungulate observation was assigned the average elevation of the relative grid cell, obtained from the Digital Elevation Model (DEM) TINITALY/01 (Tarquini et al. 2007; Tarquini et al. 2012) with a spatial resolution of 10 x 10 m, using the open source software QGIS 2.2.0.

Analysis methods

We investigated the effect of climatic indexes on the time-series of average altitude of Alpine ibex and Alpine chamois in GPNP through a series of Generalised Linear Models. All linear combination of variables were tested, with the limitation of using a number of independent variables that did not exceed a ratio of 1:6 to the number of available data points (that is, 2 variables at most). Models containing two variables that were significantly cross-correlated were discarded in order to reduce problems with parameter estimations (Zuur et al. 2007). Best-performing models were selected through Akaike Information Criterion. (Burnham & Anderson 2002).

Projections of average elevation

The estimation of future average elevation of the two species was obtained forcing the best-performing models with the time series of meteorological variables (temperature and precipitation) generated by the PROTHEUS regional climate model (Artale et al. 2010, Dell'Aquila et al. 2011) for the A1B scenario in the period 2014-2050. PROTHEUS is a state-of-the-art coupled ocean-atmosphere regional climate model developed by ENEA and ICTP for the Mediterranean region based on the RegCM3 atmospheric model and the MITgcm ocean model. The model configuration has a uniform grid spacing of 30 km; for the present study, we used the output of the model for the grid cell including the largest proportion of GPNP area. To standardize the model's meteorological variables for subsequent analyses, all PROTHEUS time series were scaled to have the mean and variance of the observed meteorological series in the period 1999-2013.

For each projection, 1000 runs were performed to account for uncertainty in empirical models.

Future distribution

In order to create a map of the future distribution of ungulates, we projected to a new scenario the current habitat suitability distribution obtained from September census data from 2000 to 2013. To extrapolate the future habitat suitability we used the future upward migration of the two species, resulting from GLM model, considering the 250 x 250 grid of the whole GPNP territory. However, as the future altitudinal distribution of chamois is not significantly different from the current one (see Results), we limited this operation to ibex distribution.

We used MaxEnt version 3.3.3k and accepted recommended default value of convergence threshold (10^5), and default regularisation value. We selected the value of maximum interaction (1000) and combination of feature class (quadratic, product and hinge) following the practical guide by Merow et al. (2013). We then used MaxEnt logistic output (Phillips et al. 2008) which performed species habitat suitability values, with a range from 0 (unsuitable) to 1 (optimal habitat). Considering the species attitude and range in the study area, we selected a prevalence value for ibex ($_{\text{ibex}}$=0.4) different from Maxent default value ($_{\text{default}}$=0.5), 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) (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 presence data 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 modelled the ibex current distribution (habitat suitability probability) using the topographic variables (elevation, aspect, slope and roughness), derived from the TINITALY/01 DEM and the distance to refuge zone (rock with slope >40°). Roughness is the largest inter-cell difference of a central pixel and its surrounding cell, as defined in Wilson et al (2007).

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 two different periods. 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 grid cell i:

D Schoener's Index D

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

I Index

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

We used the open source software Qgis 2.2.0 for GIS analysis and map outputs, with the plugin MOLUSCE (version 3.0) to analyse change in area and type of suitability class with transition matrix, considering the two different periods (2000-2013; 2014-2023). For the map outputs we categorised value of habitat suitability probability in four different classes (<=0.25, 0.26-050, 0.51-0.75, >0.75). We used plugin LECOs and we considered various landscape ecology indexes (the number of patches, the mean patches area, the mean patch distance and patch density) to analyse habitat fragmentation in suitability pattern during the two periods.

Results

Factors affecting average elevation of chamois

Alpine chamois in the GPNP were observed, aggregating all the data 2000-2013, at an average elevation of 2332.37 (SD 359.46) (average of mean yearly elevation: 2332.19±6.63), fairly stable over the years (no significant trend: R^2=0.15, p=0.17). Minimum elevation (2293.03±11.76 m) was observed in 2003, while maximum (2402.57±11.67 m) in 2013 (Fig. 1).

Best-performing model include the positive effect of spring-summer precipitation (April$_t$-August$_t$) and of maximum temperature in the first half of September (Tab. 1, Fig.2). The selected model explain 56% of the variance in the observed data.

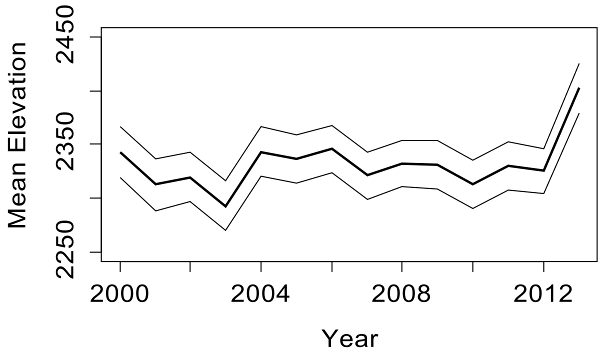

Fig. 1. Average elevation of observed chamois in GPNP during summer counts from 2000-2013. Thin lines indicate 95% confidence intervals.

Independent variable	Parameter estimate	*p*
Intercept	2272.64±18.61	<0.0001
Prec(April$_t$-August$_t$)	106.59±41.28	0.014
Tmax(1/2September$_t$)	61.66 ±21.12	0.026

Tab. 1. Selected model for the average elevation of observed chamois in GPNP during summer counts from 2000-2013.

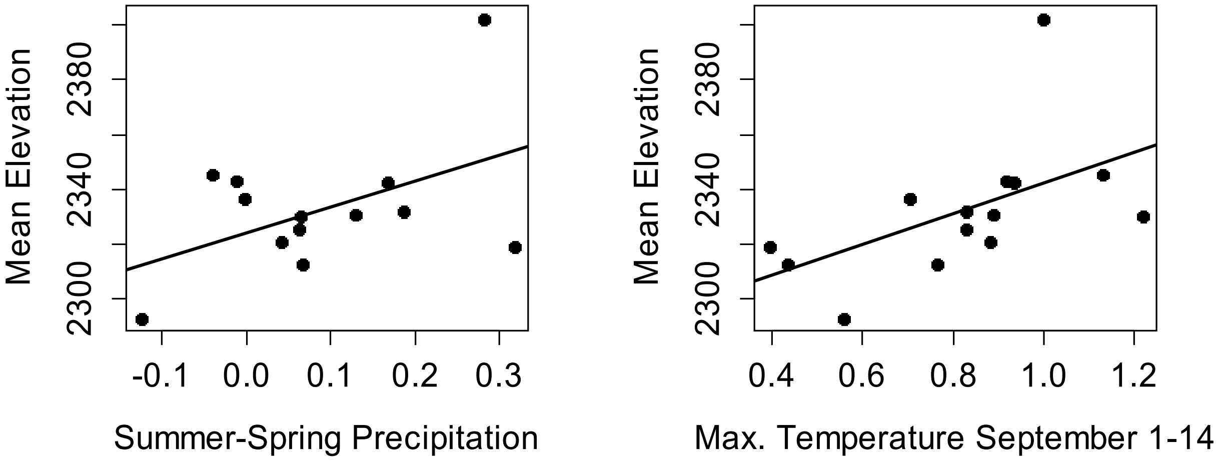

Fig. 2. Dependence of the average elevation of observed chamois in GPNP during summer counts from 2000-2013 on precipitation in April-August (left) and on the maximum temperature in the first half of September (right) at time *t*.

Factors affecting average elevation of ibex

Alpine ibexes in the GPNP were observed at an average elevation of 2611.10 (SD 282.32) during the period 2000-2013 (average of mean yearly elevation: 2612.69±12.71), showing a slightly significant increasing trend ($R^2=0.29$, $p=0.05$, +6.15±2.76 m/year). Minimum elevation (2540.61±12.02 m) was observed in 2012 (but also in 2002 the average elevation was 2542.47±12.64), while maximum (2698.51±13.16 m) in 2013 also for this species (Fig. 3).

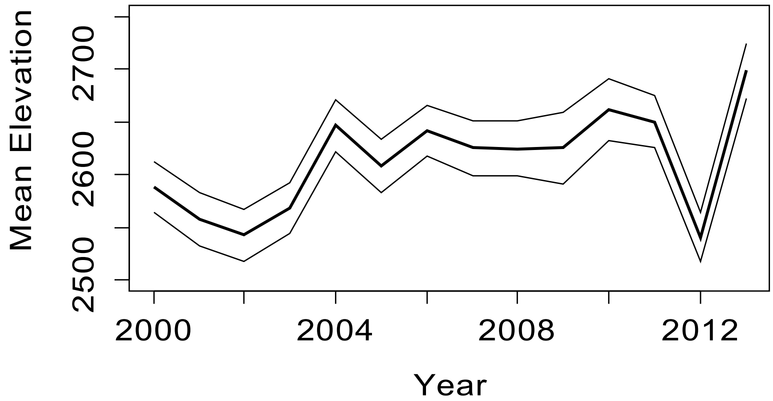

Fig. 3. Average elevation of observed ibexes in GPNP during summer counts from 2000-2013. Thin lines indicate 95% confidence intervals.

For ibex, the selected model include the negative effect of maximum temperature in late winter (February$_t$-March$_t$) and the positive effect of maximum temperature in the first half of September (Tab. 2, Fig.4), with an explained variance of 72%.

Independent variable	Parameter estimate	*p*
Intercept	2272.64±18.61	<0.0001
Prec(April$_t$-August$_t$)	106.59±41.28	0.014
Tmax(1/2September$_t$)	61.66 ±21.12	0.026

Tab. 2. Selected model for the average elevation of observed ibexes in GPNP during summer counts from 2000-2013.

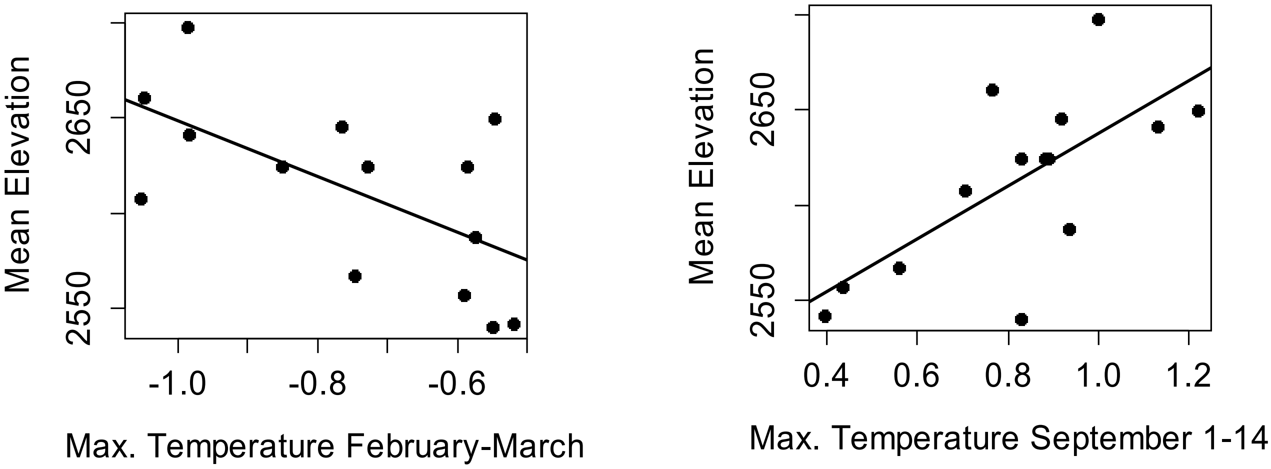

Fig. 4. Dependence of the average elevation of observed ibexes in GPNP during summer counts from 2000-2013 on maximum temperature in February-March (left) and on the maximum temperature in the first half of September (right) at time *t*.

Average elevation of chamois in response to climate change

Projections indicate that Alpine chamois in GPNP is expected to keep a stable average summer elevation in the next decades (Fig. 5). In fact in the next decade (2014-2023) the average elevation will be 2329.56±6.07 m, while in the last decade of the projection (2041-2050) it will be 2330.16±2.92 m. There is no significant difference with the current average altitude of observed chamois.

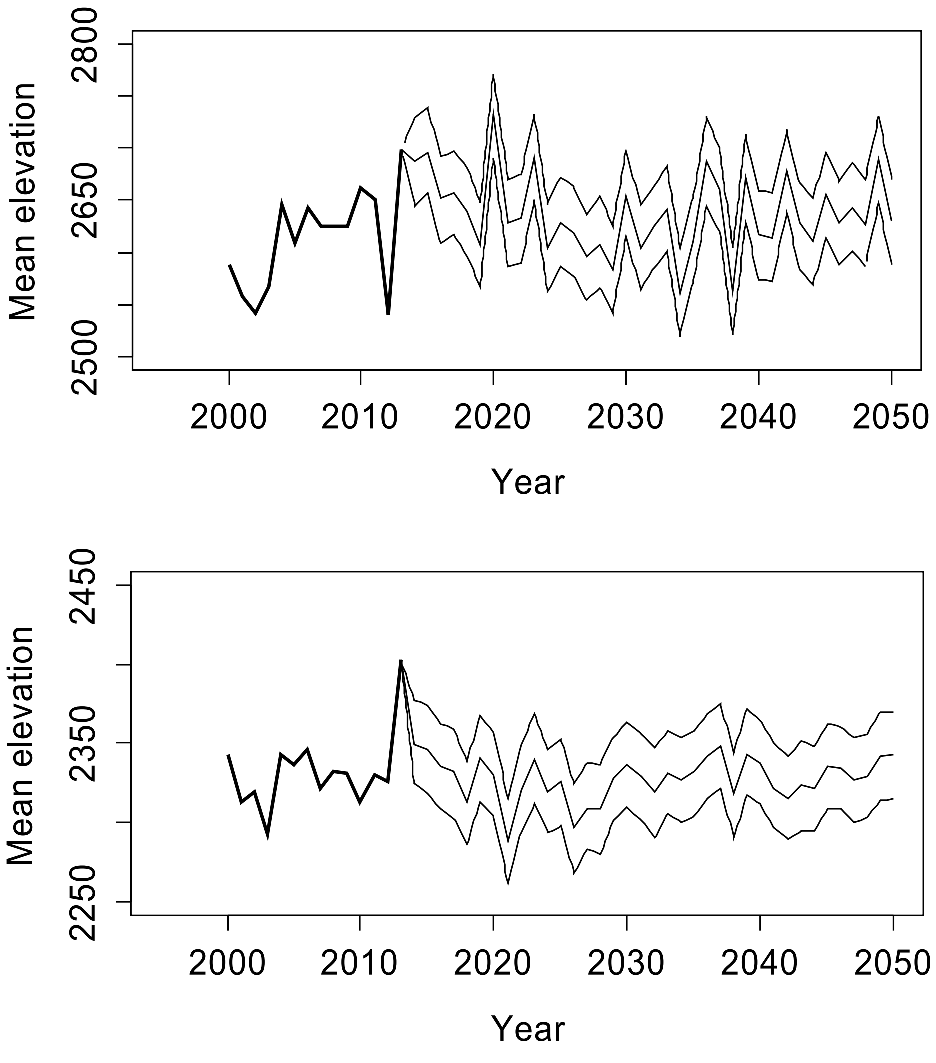

Fig. 5. Projections of average elevation of Alpine chamois in GPNP for the period 2014-2050, according to the PROTHEUS climate model for the A1B scenario. Thick line: filtered time series of chamois abundance; thin line: 50% percentile, broken lines: 5–95% percentiles of the 1000 runs.

Average elevation of ibex in response to climate change

As regards Alpine ibex, projections forecast a slight increase of average elevation in September (Fig. 6). In the next decade (2014-2023) average elevation will be 2662.27±12.11, while in the decade 2041-2050 it will be 2640.14±8.26. The difference between average yearly elevation 2000-2013 and 2014-2023 (49.58 m) is statistically significant (t-test: $t = -3.57$, $df = 15$, $p = 0.003$), while it is not significant the difference between the average elevation during 2000-2013 and the one during 2041-2050 (27.45 m; t-test: $t = -1.65$, $df = 22$, $p = 0.11$).

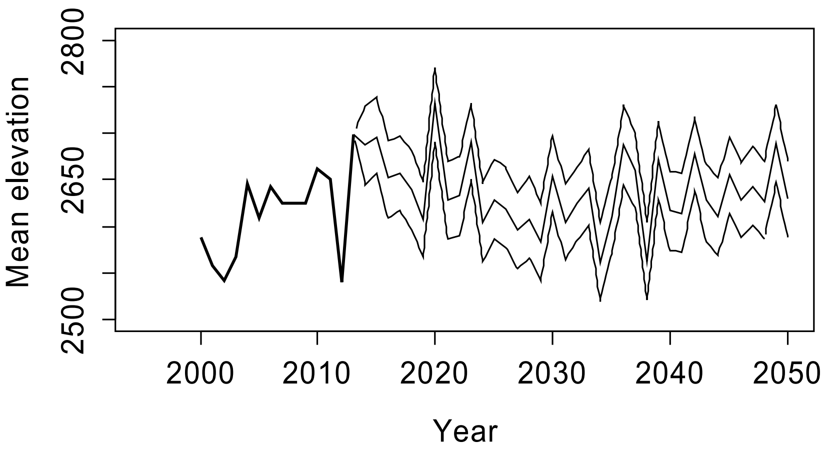

Fig. 6. Projections of average elevation of Alpine ibex in GPNP for the period 2014-2050, according to the PROTHEUS climate model for the A1B scenario. Thick line: filtered time series of chamois abundance; thin line: 50% percentile, broken lines: 5–95% percentiles of the 1000 runs.

Map of future ibex distribution

The number of ibex presence data from September census amounted to 6302 in 2000-2013 period. We randomly partitioned 50% of the annual amount for training (n=3156) and the remaining annual data for testing the model (n=3146). The ibex model had a good fit ($AUC_{train} = 0.775$; $AUC_{test} = 0.771$). According to Maxent jackknife analysis, the most important environmental variables in determining habitat suitability for model were first elevation (69.5% of contribution), then distance to refuge zone (21.2 % of contribution), aspect (5.2 % of contribution) and roughness (4.0 % of contribution).

We extrapolated the ibex habitat suitability only to future scenario 2014-2023, significantly different from 2000-2013, considering that ibex elevation distribution will be on average 49.58 m higher, according to GLM results.

The niche overlap was relevant between 2000-2013 and 2014-2023 habitat suitability maps (I=0.998; D=0.956). The area of 0.26-0.50 suitability class decreased in accord with a slightly increase of the lowest suitability class and also of 0.51-0.75 class (Tab. 3). This result was highlighted in transition matrix too (Tab. 4). The landscape measures didn't highlight relevant change in spatial suitability pattern and no evidence of increasing fragmentation under future climate scenario was suggested from the results (Tab. 5). Map of ibex current potential distribution (2000-2013) and predictive distribution (2014-2023) are represented in Fig. 6 and 7 (APPENDIX).

Class	*2000-2013 Area (ha)*	*2014-2023 Area (ha)*	*Δ Area (ha)*	*2000-2013 %*	*2014-2023 %*	*Δ %*
<=0.25	41756	42181	425	57.21	57.79	0.58
0.26-0.50	23456	22906	-550	32.13	31.38	-0.75
0.51-0.75	7781	7906	125	10.66	10.83	0.17
>0.75	-	-	-	-	-	-

Tab. 3. Changes in ibex habitat suitability classes between 2000-2013 and 2014-2023 maps.

Class	*<=0.25*	*0.26-0.50*	*0.51-0.75*	*>0.75*
<=0.25	0.96	0.04	0.000	-
0.26-0.50	0.08	0.87	0.04	-
0.51-0.75	0.00	0.12	0.88	-
>0.75	-	-	-	-

Tab. 4 . Transition matrix for ibex habitat suitability classes between 2000-2013 and 2014-2023.

Class	*Number of patches*	*Mean Patch area (ha)*	*Mean Patch distance (mt)*	*Patch density*
<=0.25	47 (48)	881.5 (871.8)	1953.6 (1957.9)	6.5E-8 (6.6E-8)
0.26-0.50	32 (34)	727.2 (668.3)	3221.5 (3191.5)	4.4E-8 (4.7E-8)
0.51-0.75	97 (86)	79.6 (91.2)	2938.1 (2958.7)	1.3E-7 (1.2E-7)
>0.75	-	-	-	-

Tab. 5. Suitability Spatial Pattern considering 2000-2013 (no bracket value) and 2014-2023 (bracket value) maps.

Discussion

Both Alpine chamois and Alpine ibex in the GPNP shifted their average elevation in September in response to climate, however the altitudinal range observed in the period 2000-2013 was more pronounced for ibex (157.90 m) than for chamois (109.54 m).

Chamois moved upward during the first days of Sempember when the temperature in the same days was higher, but not when the spring-summer season had been very dry (as it happened in 2003). This was probably due to the effect of drought on the Alpine meadows, which caused the production of low-quality forage for this ungulate. In this case, it could be more convenient for chamois to take refuge in wooden areas to avoid high summer temperatures. This result is compatible with the life-history of this species, which make much more use of forested habitat than ibex (Michallet et al. 1999).

We recorded an upward shift in response to higher temperatures in the first half of Septemper also for Alpine ibex. On the other hand, when the temperature during late winter was higher this shift was less pronounced, maybe due to an earlier snowmelt and a consequent earlier onset of vegetation in Alpine meadows or a more rapid green up, which lead to a shorter period of availability of high-quality forage for this bovid (Pettorelli et al. 2007).In according with our expectations, projections of average altitude for the two species in response to climate change indicate a significant upward shift in the summer distribution of the next decade only for ibex. However, this shift seem to be not excessive. In fact, despite maximum temperature in September is expected to rise significantly in the next decades, the predicted earlier onset of vegetation in spring could repress the altitudinal migration of ibexes.

For the same reasons, the future distribution of ibex considering habitat suitability probability, resulting from the extrapolation of current habitat suitability, didn’t change strongly, and we detected only a slightly increasing in area of lowest habitat suitability class. No evidence of a further increasing fragmentation emerged from Lanscape ecology analysis between the current and future scenario. However this Alpine ibex predictive distribution map performed with MaxEnt is only a preliminary step, and additional analysis with Species Distribution Models are suggested to better appreciate climate change effects that could directly (e.g.. temperature) or indirectly (e.g. trophic resources) influence Alpine ibex distribution.

One drawback of this study is the use of unstructured population data. It is possible, in fact, that elevational range of different age-sex classes is affected by climate in a different way. For example, adult male ibex particularly select Alpine meadows in summer as they need large amounts of food resources to accumulate as much fat as possible for the winter (Grignolio et al. 2003) using larger

areas than females (Grignolio et al. 2004). Moreover, foraging constraints caused by high temperatures affect small/younger males more than large ones (Aublet et al. 2009).
Therefore future sudies should aim at predicting altitudinal shifts of the different age-sex classes of the two species in response to climate change, as this could significant affect survival/fecundity of a single population segment, with consequences on the dynamics and the consevation of the two populations.

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APPENDIX

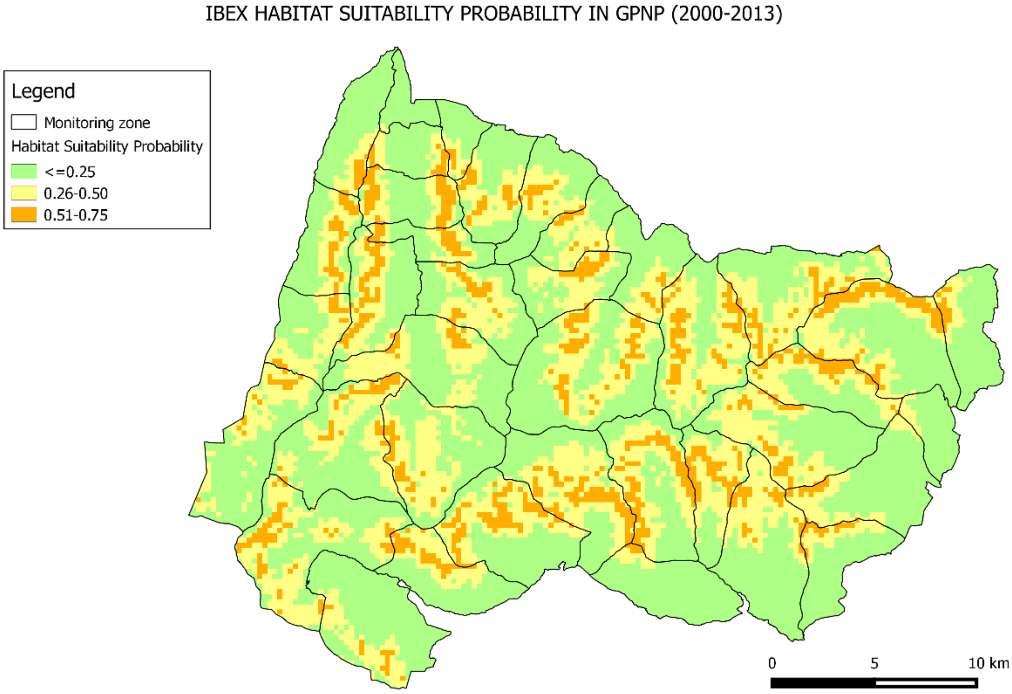

Fig.6. Current habitat suitability map of ibex in Gran Paradiso National Park (2000-2013).

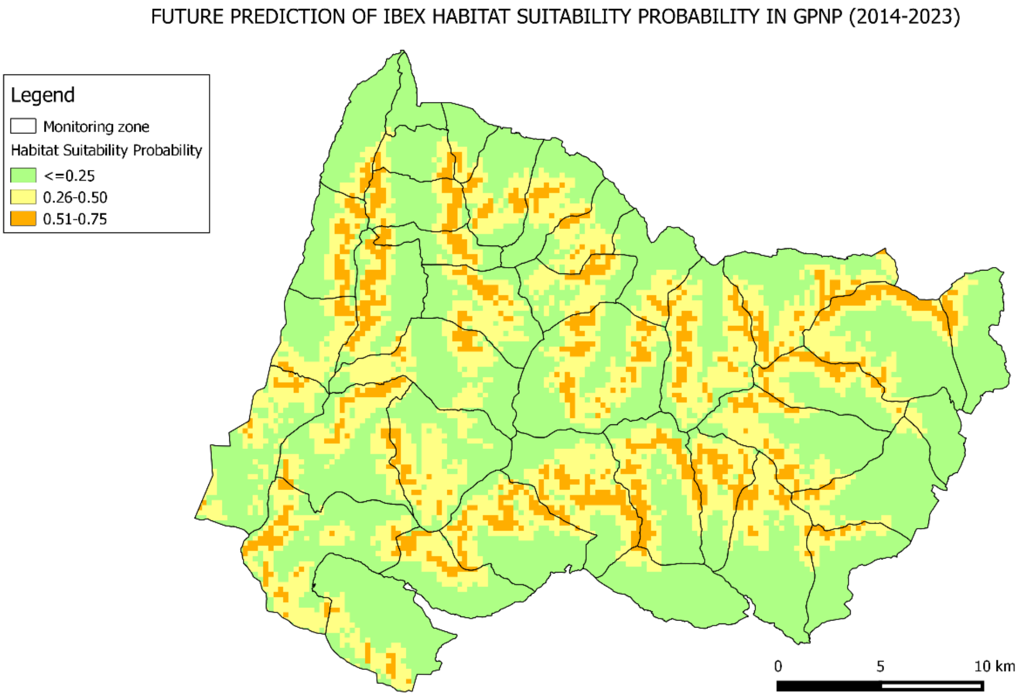

Fig. 7. Future habitat suitability map considering the effect of increasing temperature on ibex distribution in Gran Paradiso National Park (2014-2013).