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# Vegetation and Glacier Trends in the Area of the Maritime Alps Natural Park (Italy): MaxEnt Application to Predict Habitat Development

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**Abstract:** Climate change is significantly affecting ecosystem services and leading to strong impacts on the extent and distribution of glaciers and vegetation. In this context, species distribution models represent a suitable instrument for studying ecosystem development and response to climate warming. This study applies the maximum entropy model, MaxEnt, to evaluate trends and effects of climate change for three environmental indicators in the area of the Alpi Marittime Natural Park under the Municipality of Entracque (Italy). Specifically, this study focuses on the magnitude of the retreat of six glaciers and on the distribution of two different plant communities, *Alnus viridis* scrub and *Fagus sylvatica* forest associated with *Acer pseudoplatanus* and tall herbs (*megaforbie*), in relation to predicted increases in mean temperatures. MaxEnt software was used to model and observe changes over a thirty-year period, developing three scenarios: a present (2019), a past (1980) and a future (2050) using 24 "environmental layers". This study showed the delicate climate balances of these six small glaciers that, in the next 30 years, are likely to undergo an important retreat (≈−33%) despite the high altitude and important snowfall that still characterize the area. At the same time, it is predicted that the two plant communities will invade those higher altitude territories that, not so long ago, were inhospitable, expanding their habitat by 50%. The MaxEnt application to glaciers has shown to be an effective tool that offers a new perspective in the climate change field as well as in biodiversity conservation planning.

**Keywords:** climate change; *Alnus viridis*; *Fagus sylvatica*; altimontane beech forest



**Citation:** Comino, E.; Fiorucci, A.; Rosso, M.; Terenziani, A.; Treves, A. Vegetation and Glacier Trends in the Area of the Maritime Alps Natural Park (Italy): MaxEnt Application to Predict Habitat Development. *Climate* **2021**, *9*, 54. https://doi.org/10.3390/cli9040054

Academic Editor: Steven McNulty

Received: 11 March 2021
Accepted: 25 March 2021
Published: 31 March 2021



## 1. Introduction

Global climate change has an impact on indicator species and ecosystem dynamics [1] and significantly affects the services provided by ecosystems in any geographical area [2–5]. According to recent studies, global warming effects could be severe, and the temperature will continue to rise over the 21st century by minimum 0.3–1.7 °C to maximum 2.6–4.8 °C [6] with dramatic consequences for glacier reduction and vegetation distribution. In this perspective of change, the ecological indicators traditionally used to assess the state of the ecosystem may become increasingly unreliable [7]. Moreover, the multiple drivers of global change may shift baselines and emergent novel properties of ecosystems. In this context, the study of the evolution of ecosystems is a suitable instrument that makes it possible to predict habitat development as well as to estimate geographic distribution [8].

The geographic distribution of species is influenced by multiple aspects, including interactions with biotic and abiotic factors that define their habitat [9–11], and could be evaluated through a valid numerical tool: the species distribution models (SDMs). SDMs relate species distribution data with environmental and/or spatial characteristics [8]. They are commonly used in ecology, biogeography and conservation biology studies [12], and they allow the study of the impact of climate warming and land use change on disease vectors, bacterial infection, animals and plant reintroduction or preservation [13]. There are several SDMs working with different statistical algorithms and input parameters [14,15]. To predict the effects of climate change, the most implemented methods are: climatic envelope models such as BIOCLIM [16], genetic algorithms such as GARP [17], ecological niche factor analysis (ENFA) [18], generalized additive models (GAM) [19], generalized linear models (GLM) [20] and maximum entropy models such as MaxEnt [21].

Among these various methods for species distribution modeling, MaxEnt was chosen for the present investigation. MaxEnt is a popular modeling software developed by Steven Phillips that relates landscape-scale presence-only data to landscape variables. Moreover, it offers simple operation and high accuracy even with small sample sizes and scant data [14,22]. It also tests the forecast precision, directly produces a spatially open habitat suitability map and evaluates the significance level of individual environmental variables [23].

To track ecosystem status, trends and effects of climate change, this research proposes the application of the maximum entropy model MaxEnt for three environmental indicators in the area of the Alpi Marittime Natural Park under the Municipality of Entracque. Specifically, this SDM was used to measure and predict: (1) the magnitude of the retreat of six glaciers and (2) the ecological niche evolution and habitat distribution of two different species of woody vegetation, *Alnus viridis* and *Fagus sylvatica*, in response to the environmental condition changes over the next 30 years.

## 2. Study Area

The study area is located inside the Alpi Marittime Natural Park (AMNP) between latitudes of 44°08′ N to 44°06′ N and longitudes of 7°21′ E to 7°26′ E in the northwest of Italy (Piedmont Region) (Figure 1). It is a small area called Gesso valley under the municipality of Entracque (CN). The area covers almost 15.6 km$^2$, with an altitude ranging from 1560 m to 3087 m a.s.l.

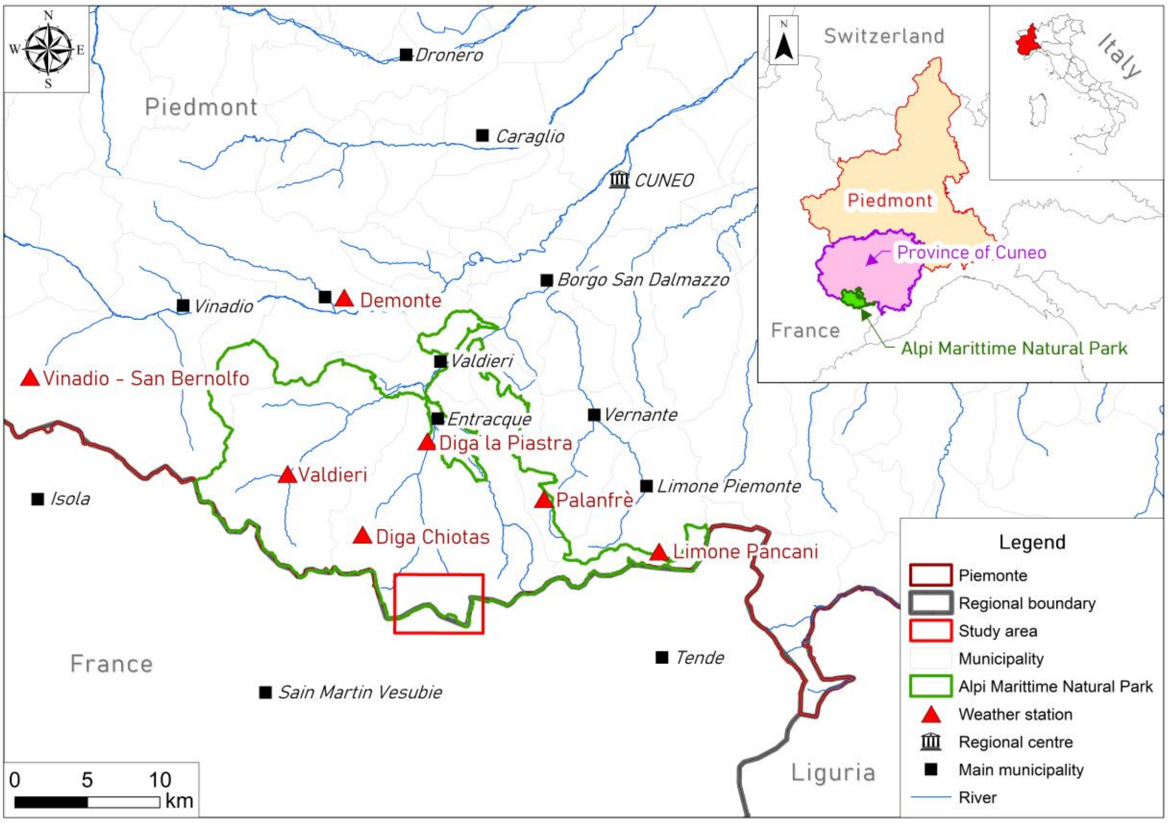


**Figure 1.** Location of the study area (red box) in the Natural Park of Alpi Marittime (Province of Cuneo, Italy). The seven weather stations considered for the analysis are represented with red triangles.

It is an alpine area characterized until 2300 m by the presence of *Alnus viridis* and altimontane beech forest, with a strong prevalence of the former over the latter, and at the highest altitudes with sparse or absent vegetation, small lakes and glaciers. Lithology mainly consists of gneiss and granite. Bedrock is covered by limestone, anhydrite and dolomite.

### 2.1. Climatology

The study area is characterized by very snowy winters and annual rainfall above the average of the region. According to CCimaTT [24], precipitation is snowy in the winter months throughout the park area and the snow accumulation ranges with altitude. Specifically, this accumulation varies from 300–400 cm per year around 1000 m a.s.l, up to 700–800 cm per year above 2000 m a.s.l. Moreover, a stationary trend has been observed in the annual average cumulative snow while a non-negligible progressive reduction of the resident time of snow has been recorded. In the last twenty years (2000–2018), this decrease is approximately 20 days compared to the previous two decades (1980–2000). At present, the snow cover is present for about 170/200 days in areas above 2000 m a.s.l., almost 130 days for areas between 1500 and 2000 m a.s.l. and almost 50 days in areas at altitudes below 1500 m a.s.l.

The decrease of snow residence time and the consequent reduction of the areas covered by ice are due to the increase of global temperature [6]. In the study area, at altitudes above 700 m a.s.l., there has been an increase in the average annual maximum temperature and in the average annual temperature with values respectively of 12 °C and 8.5 °C in the last decade [24]. The minimum temperature, however, is almost unchanged at 4.5 °C.

Precipitation does not show great variation over the years, ranging from 960 mm per years in the lowland territories to over 1500 mm per year recorded at the Limone Pancani station [25]. This strong variation in the range of precipitation values is due to proximity to the Mediterranean Sea, which is only 50 km from the highest peaks of the Maritime Alps. Specifically, the depressions created on the Ligurian Gulf are the cause of the heavy rainfall on the area of the Alpi Marittime Natural Park.

### 2.2. Glaciers

Several small glaciers are present in the Maritime Alps, but the most important structures are in the Clapier-Maledia-Gelas mountain group. Specifically, Smiraglia and Diolaiuti [26] identify five cirque glaciers in the Gesso Valley (Figure 2). These five glaciers extend, on average, above 2700 m a.s.l., and they are the southernmost in the Alps. Moreover, they are north-facing and protected by the high walls to which they are attached. The altitude, the northern exposure and the protected location promote the permanence of snow of avalanche origin, even in the warmer months. Until the 1930s, in this area, there was another glacier, the Muraion, and the surface covered by ice was much higher. However, nowadays there is an overall regression of glaciers. Based on the last survey (2010), the Muraion has disappeared, and the surfaces of the other five glaciers range from 0.05 $km^2$ of Gelas to 0.3 $km^2$ of Clapier.

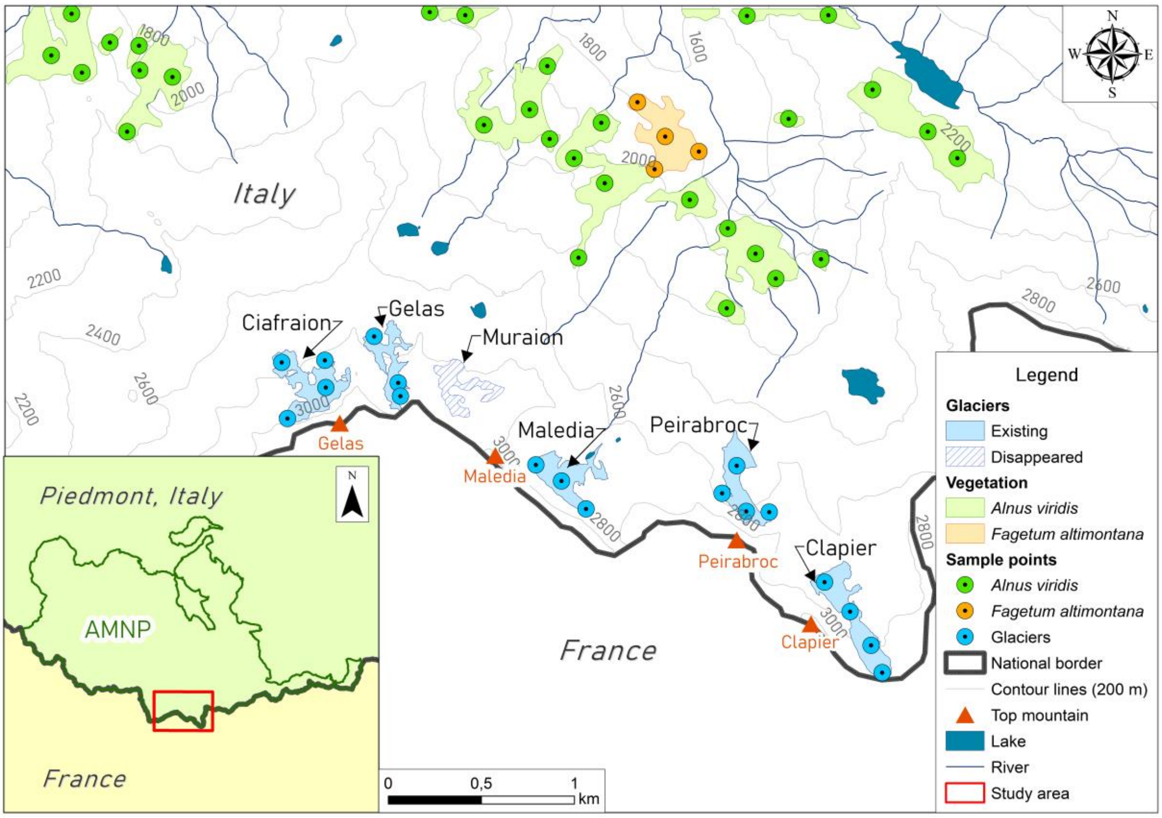


**Figure 2.** Geographical location of the sample points of the three environmental indicators, i.e., *Alnus viridis*, altimontane beech forest (*Fagetum altimontana*) and glaciers and their current areas of distribution. The areas are adapted from Smiraglia and Diolaiuti [26] for glaciers and from the map of woodlands (2016).

Detailed information about glaciers and their surface characteristics is reported in Table 1.

**Table 1.** Information regarding glaciers and their surface characteristics. The glaciers are listed from west to east. The information shown is adapted from Mercalli and Cat Berro [27] and from the Nimbus website (http://www.nimbus.it/ accessed on 1 March 2021), except those with an asterisk.

| Name | Surface ($km^2$) | | Collector Basin (m a.s.l.) | Front (m a.s.l.) | Mount | Reduction | State |
|---|---|---|---|---|---|---|---|
| | 1930 | 2010 | | | | | |
| **Ciafraion** | **0.12** | **0.11** | **3007** | **2650** | Gelas (3143 m a.s.l.) | 69% from 1896 to 2010 | Regression |
| Gelas | 0.11 | 0.05 | ≈3007 | 2720 | Gelas (3143 m a.s.l.) | 62% from 1896 to 2010 | Regression |
| Muraion | 0.14 | Extinct | - | - | Caire Muraion (2985 m a.s.l.) | - | Disappeared |
| Maledia | 0.31 | 0.06 | ≈2800 | 2640 | Maledia (3061 m a.s.l.) | 91% from 1896 to 1992 * | Regression |
| Peirabroc | 0.15 | 0.07 | 2440 * | ≈2375 * | Peirabroc (2940 m a.s.l.) | 87% from 1896 to 1992 * | Regression |
| Clapier | 0.4 | 0.3 | 2850 * | 2615 * | Clapier (3045 m a.s.l.) | 83% from 1896 to 1992 * | Regression |

* Federici and Pappalardo [28].

## 2.3. Vegetation

The area has an international floristic importance thanks to a strong geopedological and climatic variety. A very important role is played by two tree species: *Alnus viridis* and *Fagus sylvatica*. These species have different growth rates that could influence the species' response to environmental changes. The first, *Alnus viridis* or green alder, is a light-demanding, fast-growing, small deciduous tree [29], while the second, *Fagus sylvatica* or beech, is a large deciduous tree, extremely hardy, that can maintain its growth rate until late maturity [30].

Generally, these species occupy different habitats. The *Alnus viridis* habitat (EUNIS code F2.311) is largely monospecific and characterized by moist soil and open areas such as screes and shallow stony slopes, avalanche tracks, edges of wet meadows and stream-banks [29]. Conversely, *Fagus sylvatica* is in the less favorable or transitional areas that largely characterize the mountain context of the Piedmont Region that is associated with other broad-leaved and coniferous species, giving rise to multi-specific stands with a more diversified structure [31]. Specifically, in this study area, *Fagus Sylvatica* is associated with *Acer pseudoplatanus* and tall herbs (*megaforbie*) and constitutes the altimontane beech forests. The habitat occupied by this plant community is identified with Natura 2000 code 9140, and it is rare, given its little wide spreading at a regional level (0.3% of the surface) and the low levels of growth of *Fagus sylvatica* [31].

## 3. Materials and Methods

### 3.1. MaxEnt Development

MaxEnt is a modeling software based on the maximization of entropy that is mainly used for the estimation of the potential spatial distribution of environmental indicators [14,22]. It requires two types of information: sample data and background samples. The former corresponds to the presence locations of indicators, while the latter represent the predictive variables of the study area. The linearity of the environmental variables must be tested to obtain reliable and easily interpretable results.

After the input data has been prepared, the model is set up. If the study concerns a few species or one at a time, as in this case, it is necessary to change the default settings depending on the indicators considered. Two modifiable parameters are the "regularization multiplier" and the "default prevalence". These parameters permit smoothing the model, loosening or tightening the constraints and defining how common a species is within a certain reference site.

A fundamental step of MaxEnt development is the validation of the predictive distribution model. The standard method to assess accuracy is the under curve area (AUC), and it was applied in the present study. A model with AUC $\approx$ 1 has an excellent predictive capacity and consequently, a high-level accuracy of prediction, while a model with AUC $\leq$ 0.5 is affected by randomness. The data preparation, the modeling procedure and the validation of the models are described in the following paragraphs.

### 3.2. Presence Records of Glaciers, Alnus Viridis and Altimontane Beech Forest

In the study area domain, 52 sample points of environmental indicator presence were considered: 18 points for glaciers, 30 points for *Alnus viridis* and 4 points for altimontane beech forest. The sample points were randomly selected from the areas of certified presence using ArcMap 10.6.1 software and expressed according to the coordinate system WGS84/UTM 32N. The areas of certified presence were derived for glaciers from Smiraglia and Diolaiuti [26] and for the two plants communities from the map of woodlands (Geoportal of Piedmont Region; shapefile, 2016; scale 1:10,000). The sample points and the corresponding areas of certified presence are shown in Figure 2.

### 3.3. Environmental Variables

To implement the MaxEnt model, the variables that most influenced the presence of glaciers and vegetation were evaluated. Specifically, 24 environmental variables referring to climate, topography and land use were selected and generated with a resolution of 10 m. Table 2 describes the set of environmental layers, reporting the units of measure and the source maps used.

**Table 2.** List of environmental variables considered for the implementation of the MaxEnt model. For each variable, the unit of measure, the source data and scale.

| Environmental Layer | Unit of Measure | Source Map |
|---|---|---|
| Altitude | m | DTM, Geoportal of Piedmont Region (Raster 10 m, 2008—from CTR 1:10,000) |
| Exposure | ° | |
| Curvature | - | |
| Slope | % | |
| Hillshade of summer and winter solstice and of spring and autumn equinox | - | DTM, Geoportal of Piedmont Region (Raster 10 m, 2008—from CTR 1:10,000). The azimuth and altitude values of the sun derived from http://www.marcomenichelli.it/sole.asp (accessed on 1 March 2021) |
| Corine Land Cover | DN | Corine Land Cover map, SINAnet (shapefile, 2018; scale 1:100,000) |
| Average temperature | °C | Meteorological database of ARPA Piedmont (reference period 2007-2018) |
| Minimum temperature | °C | |
| Maximum temperature | °C | |
| Maximum temperature average quarter hottest | °C | |
| Minimum temperature average quarter coldest | °C | |
| Minimum temperature coldest month | °C | |
| Maximum temperature warmest month | °C | |
| Absolute maximum temperature | °C | |
| Absolute minimum temperature | °C | |
| Average precipitation | mm | |
| Precipitation of the hottest quarter | mm | |
| Cumulative snow annual average | cm | |
| Fresh snow accumulated annual average | cm | |
| Snow accumulated on the ground | cm | |
| Snow accumulated annually | cm | |

The temperature and precipitation layers were generated considering meteorological data over the period 2007–2018 and referred to seven stations: Entracque-la Piastra dam, Entracque-Chiotas dam, Demonte, Valdieri, Palanfrè, Limone Pancani and Vinadio-San Bernolfo. Specifically, these 15 environmental layers were calculated using a linear regression with the altitude. The geographic location of the seven stations is shown in Figure 1.

In order to evaluate the trends of glacier extension and *Alnus viridis* and altimontane beech forest distribution, a past (1980), a present (2020) and a future scenario (2050) have been developed. The choice of the year for the past and future scenarios was guided by two considerations. First, the datasets before 1980 lack detail. Second, a longer-term forecast would lead to a lower significance of the model for the future. The current forecast of climatic conditions for the next 30 years should remain almost accurate, while it might not be for longer times.

In this context, the projection layers relating to the past and future scenarios were generated considering the increase of temperatures per decade documented by CCimaTT [24]. In fact, starting from the 1950s, this document reports an increase per decade equal to +0.35 °C for the maximum temperature values, to +0.26 °C for the average values and to +0.18 °C for the minimum values. In the last decade, a further increase was recorded for maximum and average temperatures, and it was, respectively, equal to +0.64 °C and +0.34 °C. Specifically, the further increase in the maximum values of temperatures was recorded in the territories above 700 m a.s.l.

The past and future projection layers were generated through the ArcMap Raster Calculator tool by subtracting (past scenario) or adding (future scenario) the temperature increase values to the raster layers of the present scenario and multiplying everything by the number of decades. Moreover, the values obtained were linearly interpolated with the altitude. The increase in temperature referring to the entire registered period was used for the past scenario, while that related to the last decade was used for the future scenario. Precipitation was excluded from the predictive analysis of these two scenarios as was the geomorphology, even though they represent an important aspect of glaciers and plant communities. This is due to the absence of significant variations in annual accumulation. The distribution of precipitation varies only during the year.

To assess the linearity of variables and avoid their cross-correlation, the Pearson test was conducted. Overall, the less significant and excessively correlated variables were excluded and specifically, the layers of the absolute minimum temperature, of the absolute maximum temperature and of the Corine Land Cover layers were excluded from the analysis.

### *3.4. Modeling Procedure*

To create the present, past and future scenarios of environmental indicators, the MaxEnt software was used in version 3.4.0, December 2016. First, the sample data points (18 for the glaciers, 30 for the *Alnus viridis* and 4 for the altimontane beech forest) and the environmental variables (raster layers) were included in the software. Second, the "logistic output" option was chosen. This option permits obtaining models with a probability value between 0 (zero probability) and 1 (certainty). Third, the settings were modified according to the scenario and to the environmental indicator considered. Specifically, the "regularization multiplier" and the "default prevalence" were modified as appropriate. Finally, the three environmental indicators, i.e., glaciers, *Alnus viridis* and altimontane beech forest, were performed one at a time.

The present scenario was the first scenario developed. It was performed for the glaciers using the subsample option and setting a single cycle that used 50% of the data for training and 50% for the test. To ensure a significant approximation, the regularization number and the default prevalence were set to 0.2 and to 0.8. The processing of the two plant communities was carried out using different options due to the different number of sample points. The cross-validate option was applied for *Alnus viridis*, while the subsample option was used for the altimontane beech forest. Moreover, the subsample option was performed with 4 replicas and a random test percentage value equal to 25. Despite the limited number of sample points, the use of this option simulates an execution similar to the cross-validated option but with a standard deviation highlighted. The regularization multiplier and the default prevalence were set for both the plant communities, respectively, equal to 0.1 and 0.8.

The past and future scenarios were performed through the projection layers, and the same training and test options of the present scenario were applied. However, a different number of repetitions was set for the glaciers: A cycle of 10 repetitions at the voice "replicate" and a cycle of 50 at a random test percentage were set up.

After the predictive maps were obtained (ranges from 0 to 1), they were exported to ArcMap 10.6.1 for further analysis. These results will be discussed in the following section.

## 4. Results

The results related to the three scenarios are based on the statistical analysis and the predictive maps. The statistical analysis, i.e., the graph of the receiver operating characteristic ROC, indicates the accuracy of the model, whereas the predictive maps identify the probability that the three environmental indicators (i.e., glaciers, *Alnus viridis* and altimontane beech forest) are present in the study area. Compared with the current map of woodlands and of glaciers [26], the predictive maps provide the identification of trends, evaluating the expansion and reduction of the distribution areas. To clearly highlight the areas suitable for the three environmental indicators, only the two classes of probability (0.8–0.9 and 0.9–1) are reported in Figure 3. These classes represent the highest probability ranges.

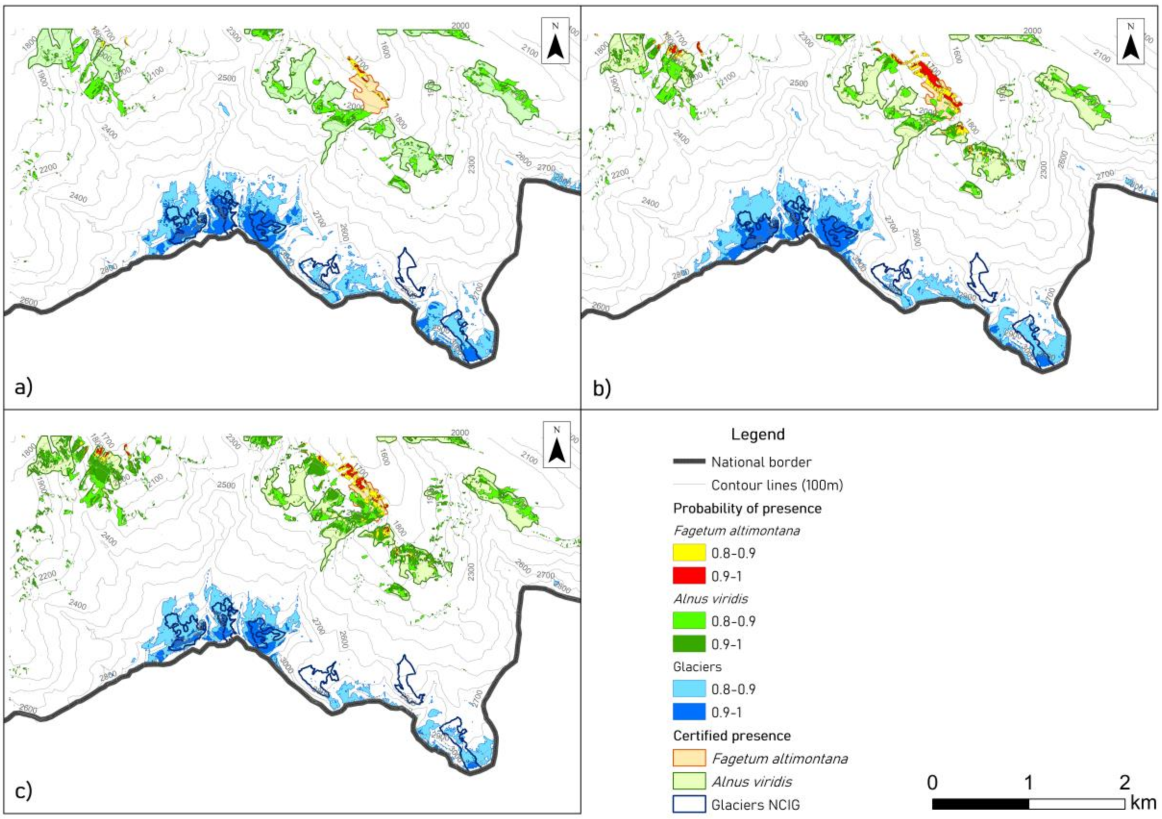


**Figure 3.** Maps of the three scenarios carried out from MaxEnt application of glacier, *Alnus viridis* and altimontane beech forest distribution (*Fagetum altimontana*). (**a**) Past scenario (1980), (**b**) Present scenario (2020), (**c**) Future scenario (2050).

The results are reported in detail according to the present, past and future scenarios in the follow paragraphs.

### 4.1. Present Scenario

The statistical analysis showed that the area under the receiver operating curve (AUC) had values of 0.903 (±0.038) for glaciers, of 0.972 for *Alnus viridis* and of 0.966 (±0.044) for altimontane beech forest (Figure 4). These AUC scores indicated a high-level accuracy in the model prediction.

The predictive map of the present scenario (Figure 3b) identified the presence of 5 glacier areas. From the comparison with Smiraglia and Diolaiuti [26] (Figure 3), these areas probably corresponded to the Ciafraion, Gelas, Muraion, Maledia and Clapier glaciers, with an overestimation of the Muraion glacier, currently classified as disappearing. The Peirabroc glacier was not shown. The distribution areas of *Alnus viridis* and of the altimontane beech forests approximated when compared with those of the current (2016) woodlands map.

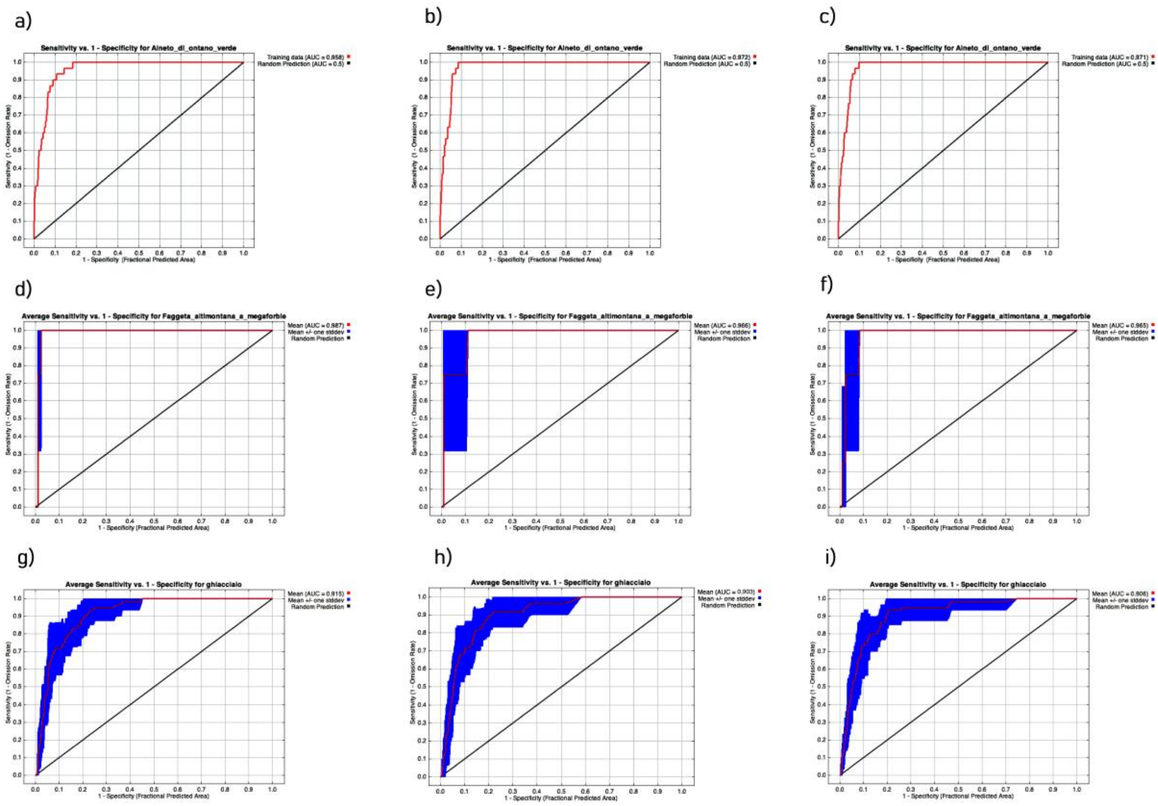


**Figure 4.** Receiver operating characteristic (ROC) curve of the three scenarios and environmental indicators. (**a**) ROC curve of past, (**b**) present and (**c**) future scenarios for *Alnus viridis*; (**d**) ROC curve of past, (**e**) present and (**f**) future scenarios for altimontane beech forest; (**g**) ROC curve of past, (**h**) present and (**i**) future scenarios for glaciers.

### *4.2. Past Scenario*

The statistical analysis showed for the past scenario an AUC value of 0.915 (±0.031) for glaciers, of 0.958 for *Alnus viridis* and of 0.988 (±0.005) for the altimontane beech forests, indicating a high-level accuracy of the model prediction (Figure 4).

Regarding the distribution, in the past scenario, an increase was observed in the dimension of the areas suitable for Maledia and Clapier glaciers. The others remained substantially unchanged (Figure 3a). As for the present scenario, the Peirabroc glacier was not shown and the Muraion glacier was further overestimated. A lower dimension, distribution and probability of presence of the habitats of the two plant communities than today was observed.

### *4.3. Future Scenario*

The statistical analysis of the future scenario showed, as the previous ones, a high-level accuracy of the model prediction, reporting AUC values of 0.906 (±0,039) for glaciers, of 0.971 for *Alnus viridis* and of 0.965 (±0.028) for the altimontane beech forests (Figure 4).

The predictive map of the future scenario presents a decrease of ice presence, mostly observed for the Maledia, Ciafraion and Clapier glaciers (Figure 3c).

Regarding the vegetation, an increase of extension and probability of areas yet occupied by these two species was observed. Moreover, new territories, even at higher altitudes, provided results suitable for the colonization of *Alnus viridis* and altimontane beech forest.

Overall, the three scenarios, i.e., past, present and future, show a reduction of glaciers and an expansion of *Alnus viridis* and altimontane beech forests over time. The percentage change of the areas was calculated over the periods 1980–2020 and 2020–2050 (Table 3).

**Table 3.** Expansion and Reduction of the three environmental indicators, expressed in percentages.

| Environmental Indicator | Expansion/Reduction 1980—2020 | Expansion/Reduction 2020—2050 |
|---|---|---|
| Glaciers | ≈−19% | ≈−33% |
| *Alnus viridis* | ≈+39% | ≈+50% |
| *Altimontane beech forest* | ≈+73% | ≈+54% |

## 5. Discussion

The past, present and future scenarios, obtained by implementing the model for the three environmental indicators, revealed a high-level accuracy of prediction: AUC scores were always higher than 0.9. However, some issues were encountered. In the predictive maps, the Ciafraion, Gelas and Clapier glaciers, characterized by similar climatic conditions (such as exposure, temperature, altitude, permanence of snow on the ground), were faithfully reported, while the Muraion, Maledia and Peirabroc glaciers were over or underestimated respective to the reference map. In line with the MaxEnt model purpose, these estimations identified the areas that presented suitable characteristics for the natural settlement and spread of a species/indicator without guaranteed presence. This behavior is evident when looking at the Muraion glacier that was once imposing, as can be seen from some historical photos [32], and has currently almost disappeared. This glacier is overestimated in the predictive maps of the present and future scenarios. This estimation reveals the persistence of the environmental conditions suitable for its presence, although the Muraion glacier has disappeared. Indeed, this overestimated prediction could be due to the permanence of snow in the area for more than six months a year (from November to June). This hypothesis is supported by the strong contribution of four variables: cumulative snow annual average, fresh snow accumulated annual average, snow accumulated on the ground and snow accumulated annually. These findings suggest that the presence of this glacier is conditioned by other key variables linked to the dynamics of the glacier itself and not considered in this study. Unlike the Muraion, the Peirabroc and Maledia glaciers are underestimated by the MaxEnt model. However, this result is again probably linked to special conditions. The Peirabroc glacier is set between high rocky walls. These rocky walls allow the ice to survive in completely different environmental conditions compared to the other glacial systems, such as lower altitude, greater shading and predisposition to avalanche accumulation. On the contrary, the Maledia glacier is covered by a thick layer of rock collapsed from the walls above. This rocky layer isolates the glacier from external agents such as solar radiation and allows it to survive. These estimations also remain the same, forcing the model to use sample points belonging to these glaciers for training and test.

Seasonal changes in temperature, rainfall, snowfall and permanence of snow on the ground can significantly influence the development of plant species: With mild winters, there is a greater expansion of vegetation, while with colder and snowy winters, the chances of survival in some extreme areas can be compromised [15]. In the past, the altimontane beech forest lived in areas further downstream that were more temperate and less subject to avalanche events, and the scenarios obtained confirmed the habitat distribution of this species until 1800 m a.s.l.. Moreover, it can be observed that over the past thirty years, there was a considerable development of the altimontane beech forest near the lower limit of the *Alnus viridis*, and that further development may be possible in the next thirty years.

The predictive maps of the two plant communities show an important territorial supremacy of *Alnus viridis* over the altimontane beech forest, in full agreement with the map of woodlands and the habitat and ecological characteristics of the species, such as rapid growth even after avalanches and preference for open areas as avalanche tracks [15]. The *Alnus viridis* previously distributed approximately around 2200 m a.s.l. could spread also at higher altitudes in the next thirty years. These findings are supported by the encroaching characteristics of *Alnus viridis*, and they highlight the ability of this species to settle first on recently formed soils as a pioneer species and to occupy the areas of higher altitude after the retreat of glaciers and permanent snow due to the temperature increase. On the other hand, beech communities do not have this "invasive" tendency. However, even if not comparable to that of the *Alnus viridis* maps (30 samples points used), the predictive maps obtained for this environmental indicator are exhaustive and present a good resolution despite the small areas and consequently, the small number (4) of sample points used.

## 6. Conclusions

A snapshot of the effects of climate change has been obtained combining three environmental indicators (glaciers, *Alnus viridis* and altimontane beech forest) for past, present and future scenarios in a small area of the Alpi Marittime Natural Park. Specifically, the results show an important retreat of the glaciers in the next thirty years despite the high altitude and a strong expansion of the two plant communities that will invade high altitudes that until recently were hostile to these communities.

Some direct consequences of these changes are the zero-thermal increase, the reduction of snow permanence on the ground and finally, a substantial reduction in the feeding of the glaciers. These reductions may impact not only the dimensions of the glaciers but also many alpine springs directly fed by glaciers and on their closely related habitats. At the same time, the rise in temperatures plays an important role in the development of other habitats such as those occupied by *Alnus viridis* and *Fagus sylvatica* associated with *Acer pseudoplatanus* and tall herbs (altimontane beech forest). Because of climate change, these species would seem to expand their original range and also to colonize new areas. Moreover, such rapid climatic changes may lead to changes in tree species richness and the composition of forest species [33].

Overall, the results obtained both for glaciers and vegetation were significant and in agreement with expectations. The combined application of the MaxEnt model to glaciers and vegetation made it possible to study climate change effects not only on a habitat scale but also a local and regional scale.

This study contributes to the evaluation of glacier retreat, proposing a new approach. The MaxEnt model applied revealed a high-level accuracy. Although validation statistics indicated a very good model quality, results should be interpreted with care because the present study did not evaluate the use of multiple criteria to enhance its robustness [34]. Further species distribution models could be implemented in order to compare different results, or both true skill statistics (TSS) and areas under the receiver operating characteristic curves (AUC) could be used [35]. Future research should monitor the three environmental indicators across the area to experimentally assess habitat suitability and to understand how they respond at different environmental gradients.

In conclusion, the present study contributes to the current literature for several reasons. First, the application of MaxEnt on glaciers is a novelty. Only one application is known in the field of glaciers [36]. Second, the study area is located in the Alpi Marittime Natural Park, the largest protected area in the Piedmont region. This park hosts an exceptional variety of flora and fauna species and in particular, a rare plant community, i.e., altimontane beech forest (*megaforbie*). Therefore, it is important to understand the effects of climate change on ecosystems, evaluating the loss or degradation of habitats and microhabitats, in order to implement a strategic management plan [37].

**Author Contributions:** Conceptualization E.C.; methodology E.C., formal analysis A.F. and M.R., data curation A.T. (Andrea Terenziani) and A.T. (Anna Treves); validation A.T. (Andrea Terenziani) and A.T. (Anna Treves); writing—original draft preparation E.C. and A.T. (Anna Treves); review E.C., A.T. (Anna Treves), A.T. (Andrea Terenziani), A.F. and M.R.; supervision, E.C. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** The authors would like to thank the Alpi Marittime Natural Park: the director Giuseppe Canavese, Gianluca Giordano, Laura Martinelli, Gianni Oppi and all the park rangers. Thank to Anna Reyneri for the comments during the paper writing.

**Conflicts of Interest:** The authors declare no conflict of interest.

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