Modelling the Potential Ecological Niche of *Fagus* (Beech*)* Forest in Majella National Park, Italy

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By

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Abstract

Beech forest is the dominant forest type in the Italian Apennines including in the Majella National Park. Following depopulation and improvement of social and economic conditions within the Apennine mountain communities since the middle of the last century, the forest is spontaneously expanding to claim its ecological niche that had been masked by the anthropogenic impacts. Though, the expansion has both positive and negative social and ecological significances, owing to the closed canopy and allelopathic effect of beech forest and the presence of large number of endemic taxa in the other habitat types, the adverse impact may be high on the unique floral life of the national park. Thus the main target of this paper is to investigate the underlining environmental factors that determine the ecological niche of beech forest and to predict the forthcoming areas (land cover types) to which the forest potentially spreads out. To achieve the objective, ranges of topo-climatic variables [altitude, slope angle, slope aspect, incoming solar radiation (ISR) of the hottest and coldest months] were derived from a 30 m resolution raster cells of aster DEM for the whole national park and for the areas of the park which is covered by the beech forest in the secondary vegetation map in ARC GIS 9.3. For each raster values of these variables, the ratio of pixel counts containing beech forest to total pixel counts of the national park having corresponding raster values were calculated. Kruskal-Wallis test was carried out in SPSS version 16; to check the preference of the beech forest certain ranges of ratios of the topo-climatic variables to the others. To model the ecological niche of the beech forest, maximum entropy model (Maxent 3.2) was selected and run with 1000 presence data that has been randomly generated in the beech land cover type in the secondary vegetation map using Hawth's tool in ARC GIS 9.3. All the DEM derived topo-climatic variables were used in the model along with the soil parameter as potential niche determining ecological variables of the beech forest. The model was trained with 75% of the presence data and tested with the rest, 25%. Evaluation of the model was carried out using area under the ROC curve (AUC).The model output was further classified into four probability classes of habitat suitability and overlaid with the land cover map of the study area to investigate the land cover types that share common ecological niche with the beech forest and thus under the potential threat of the forest expansion. Though, there is a tendency of the pixels containing beech forest to aggregate on the north facing slope aspects and gentle slope angles, the Kruskal-Wallis test supports only the preference of the forest to lower ISR of the hottest months and altitudinal ranges of 1000 m to 1, 800 m a. s . l. ($P < 0.05$). The heuristic estimate of the relative contributions of environmental variables in the Maxent model also shows the environmental variable with highest gain when used in isolation is altitude, which therefore appears to have the most useful information by itself followed by ISR of the hottest month with the contribution of 77.6 % and 10.1%, respectively (AUC = 0.81 for the test data). The soil variable, the slope angle, ISR of the coldest months and slope aspect hardly contributed 4.8%, 3.8%, 3.5% and 0.3% to the overall model output in their respective order. The result obtained by overlaying the model output with the secondary vegetation map shows, sparse grass/dwarf shrub, bare rock, subalpine pasture, shrub wood and abandoned crop lands have remarkable spatial extent within the high probable ecological niche of the beech forest.

Key words: Area under the ROC curve (AUC), Beech, Ecological niche, Maximum entropy model, Kruskal-Wallis test, Topo-climatic variables

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1. Introduction

1.1. Ecological niche requirements of beech

Among the European forest canopy trees, *Fagus sylvatica* L. (Beech) is known for its largest geographical distribution and widest niche breadth in substrate (Leuschner *et al.* 2006). Beech forest is remarkably tolerant against a broad range of hydrological and soil chemical factors including soil moisture and soil mineral content (Auml *et al.* 2004). Mono-specific beech forests can successfully grow on soils of wide pH ranging from highly acidic quartzitic soils to the highly basic carbonate-rich soils (Pinto and Gégout 2005). Beech forest can also occur in area of wide range of precipitation; from an area receiving less than 550 to more than 2000 mm of annual rainfall (Pinto and Gégout 2005).

Even though, European beech is a niche generalist, it shows a tendency to prefer some edaphic and climatic conditions. European beech occurrence is not constrained by soil acidity, soil nutrition (Ellenberg, 1988 ; (Leuschner *et al.* 1993) or humus type (raw humus to mull) (Leuschner *et al.* 1993). However, the highest European beech growth rates are recorded on base-rich, moderately moist but well-drained (calcareous) cambisols (Mayer, 1984 cited in (Bolte *et al.* 2007). Sites with extremely dry soils and stagnic soil types or sites with flooding and high groundwater levels are less favourable (Ellenberg, 1988). Thus, European beech reputedly does not grow on very dry sandy soils, in floodplains, in peat lands or on many gleyic soils.

The European beech also prefers a maritime, temperate climate with mild winters and moist summer conditions (Czerepko 2004). In the light of climate change, it has been suggested that the growth and competitive ability of beech will strongly be affected by a longer duration and higher frequency of summer droughts (Gessler *et al.* 2004). In climate chamber and garden experiments, and also in transect studies, it has also been found that water shortage reduces beech canopy conductance (Granier *et al.* 2000) and affects water and nitrogen balance (Gessler *et al.* 2004).

The European beech expansion and colonization of the Central Europe was also after a climate change around 6200 BC, when the climate became increasingly colder and more humid (Tinner and Lotter, 2001).The drought sensitivity is also assumed to be a key factor limiting the range of beech in Southern and South-eastern Europe (Backes and Leuschner 2000) and other area of Europe (Granier *et al.* 2000; Bornkamm 2006; Tinner and Lotter 2006).

Generally, the beech forest avoids the pronounced continental climate, long, severe winters and summer drought (Czerepko 2004) regardless of its ability to dominate all other tree species under the moderate site conditions widespread throughout Central Europe (Tinner and Lotter 2006). Some of the minimum climatic factors for occurrence of European beech are summarized and presented in appendix 5.

1.2. Distribution of beech in Europe

Because of its relative wide niche, European beech covers a wide range of habitat and large geographic area which is far exceeding 300 000 km^2 in Central Europe (Leuschner *et al.* 2006). Its natural range, extends from southern Sweden (with some isolated locations in southern Norway) to central Italy, west to France, southern England, northern Portugal, and central Spain, and east to northwest Turkey (Tröltzsch *et al.* 2009).

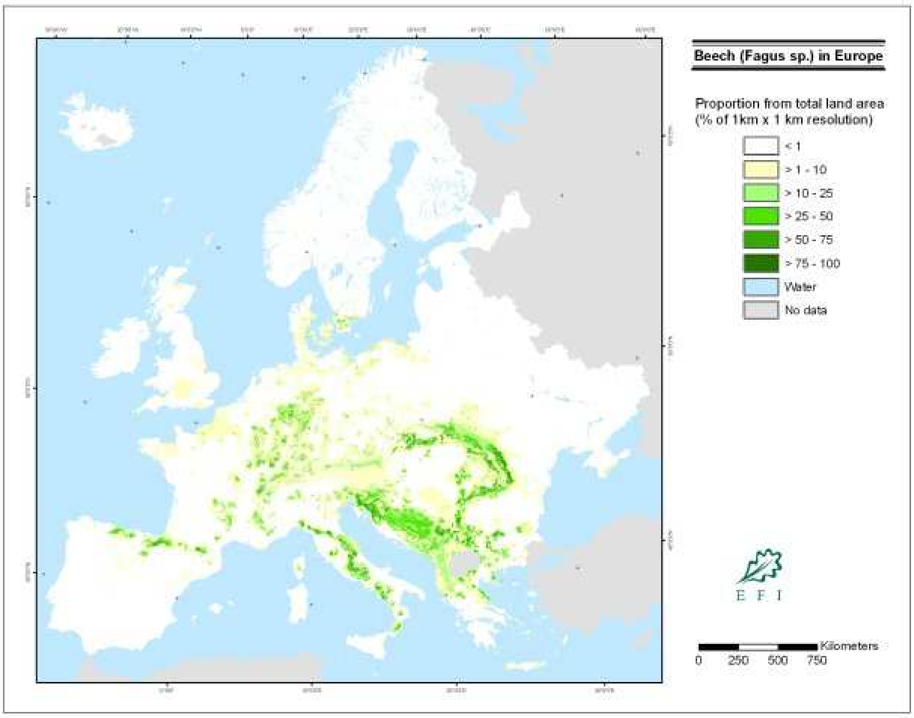

Figure 1 Distribution of beech in Europe; Source (Tröltzsch *et al.* 2009)

Paleobotanical and genetic data show that European beech began colonizing Central Europe from its northerly glacial refugia in southern France, in Slovenia and Istria and possibly even in southern Moravia and Bohemia; Mediterranean refugia did not contribute (Magri *et al.* 2006). The spreads to the Central Europe was taken place after a climate change around 8200 cal. yr ago during the second half of the Holocene (Tinner and Lotter 2006). The climate change was characterized by changes towards wetter and cooler conditions and corresponded to previously recognized Holocene cold phases in Central Europe as well as in the North Atlantic realm (Tinner and Lotter 2006). The forest expansion reached the southern Baltic shores of Poland and northern Germany between 1500 and 1000 BC; European beech then became abundant and dominant on almost all suitable sites between 500 and 1000 AC, when it reached its current range (Thomas Giesecke *et al.* 2007).

1.3. Distribution of beech in Italy

Like the other parts of Europe, Beech is the dominant forest types in Italy. Specially, many mountain areas in Italy, from the Alps down to the southern regions of Campania, Basilicata, Calabria and Sicily in the Mediterranean area are characterized by Beech forests (Nocentini 2009).The Italian National Forest Inventory of 1985, cited in (Coppini and Hermanin 2007), report shows that the beech woods covers an area of about 700,000 ha. In Italian mountain areas including in Majella national park, on the other hand, the 2005 National Forest Inventory report cited in (Nocentini 2009), shows the total area of beech wood has increased to 1 042 129 hectares, which corresponds to 9.4% of the country's total forest area. Moreover, in Majella national park beech is the most dominant forest type and almost 70% of the forest in the national park belongs to beech (Majella, 2007).

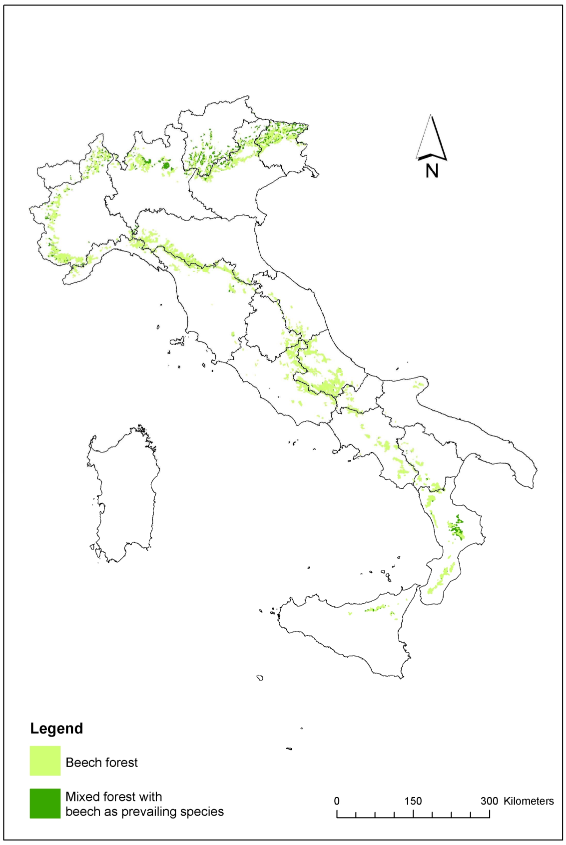

Figure 2 : Distribution of beech in Italy; Source, (Nocentini 2009)

The beech forest exists throughout all regions of Italy except in Sardinia and it dominates the other forest types almost in all of the regions. As compared to other regions, almost 50% of all beech high forests in Italy are in the southern regions of Abruzzo (the region where the current study area is situated), Molise, Puglia, Campania, Basilicata and Calabria. The spatial extent of beech forest in the different regions of Italy is presented in appendix 6.

1.4. Problem statement and Justification

Since the medieval epoch, many forests with European beech were converted into agricultural land in central Europe (Ellenberg, 1988). Similar scenario is there in the current study area, in the Italian Apennines. Especially coppicing high beech forests stand, small size timbering, firewood collection and charcoal making were common practices in the hilly and mountainous Mediterranean areas (Coppini and Hermanin 2007). However, in the upper mountain belt of the Apennine ranges, where beech coppices with standards are mainly located, depopulation and changes in the socio-economical conditions over the last 60 years led to a pronounced drop in the local demand for the aforementioned forest resources (Ciancio *et al.* 2006). Over the same period, mountain forests were considered increasingly important as a defence against natural hazards, for biodiversity conservation, for the development of recreational and tourist activities, for the protection of water resources and so on (Ciancio *et al.* 2006; Coppini and Hermanin 2007). Such a scenario mitigated the primary environmental factors determining the occurrence and competitiveness of European beech that had been masked by anthropogenic activities. As a result, the forest started expanding over time ((Baur *et al.* 2006; Van Gils *et al.* 2008). This might also be the reason why the spatial area extent of beech forest reported by the Italian National Forest Inventory of 2005 cited in (Nocentini 2009) is by far excel that of the 1985 report cited in (Coppini and Hermanin 2007).

The expansion and the change in spatial extent of beech forest over time have got several positive and negative social and environmental significances. It has a positive impact on carbon sequestration (Giupponi *et al.* 2006) and reduces soil erosion and the risk of flooding and avalanche formation (Tasser *et al.* 2003). It also has negative impacts which includes the expansion of beech into Alpine pasture (Van Gils *et al.* 2008) which resulted in loss of grass lands and mountain pasture (Baur *et al.* 2006), out competing shade intolerant endemic herbs (Reidsma *et al.* 2006) and resulting in the long term loss of species rich habitats and causing the declining of landscape diversity (Anthelme *et al.* 2001).

Majella national park, on the other hand, belongs to one of the Mediterranean biodiversity hot spots. Globally, hot spot biodiversity areas are branded by high species richness, high proportion of unique and endemic taxa, and by presence of large number of threatened species. Most of the endemic species of the Mediterranean region are mainly out of the forest in grass lands and open lands (Stanisci *et al.* 2005). Moreover, beech inhibits the establishment of shade-intolerant tree species and underneath growth primarily because of its closed canopy and secondly because of its allelopathic effect (Hane *et al.* 2003). This magnifies the adverse effect of the beech forest expansion to the species rich habitats.

Because of these remarkable significances of the beech forest expansion, there is a need to investigate the underling environmental factors which govern the expansion of the forest and model the suitable habitat for forthcoming beech forest. Assessing the land cover types that share common ecological niche with beech forest and potentially affected by the forest expansion is unquestionably important for park management to make decision on how to enhance the positive impacts and mitigate the negative ecological and social problems that might be resulted as a consequence of the forest expansion on the long term. Expansion of forest is also acquiring new relevance by the UN

Framework Convention on Climate Change for calculating carbon budgets, understanding the missing mid-latitudinal carbon sink and negotiations on carbon credits for reforestation.

1.5. Research Gaps

In the current study area, in Majella national park, (Van Gils *et al.* 2008) reported that the European beech forest is advancing into abandoned farmland and subalpine pastures from the contagious, mid-altitudinal beech forest and from beech tree outliers, at a rate of 1.2 % per year in the years from 1975 to 2003. Besides of the expansion rate, (Van Gils *et al.* 2008) also carried out a spatial environmental prediction model for beech forest expansion. They have taken into consideration factors such as DEM derived topo-climatic variables, sheep grazing intensity, proximity of seed source and neighbourhood effect in their model. In their research report, they have revealed how distance from *Fagus* tree affects the expansion. The report also shows heterogeneity in substrate and sheep grazing do not remarkably predict the expansion of the forest. Other authors also repeatedly reported and appreciated the widest niche in substrate of beech forest (Auml *et al.* 2004; Pinto and Gégout 2005; Leuschner *et al.* 2006).

However the impact of topo-climate (aspect, altitude and incoming solar radiation) is not well studied. Though, (Van Gils *et al.* 2008) revealed heterogeneity in these factors have less impact and do not significantly predict the expansion of beech forest, their study was confined to the central part the park, Orta valley (figure 3), 78 Km^2. This spatial extent is nearly 10% of the area of the national park. Therefore, the result that has been obtained from this part of the park may not represent the whole scenario for the entire beech forest in the national park. Specially, the area does not also seem representative from topo-climate point of view. Places like Morrone (North West) and the North Eastern Majella Mountain ridges seem to have different altitudinal, slope and aspect gradients (figure 3). For this reason and because of the absence of other detailed research reports elsewhere; there is a need of caring out further studies considering the whole national park to see the impact of environmental factors giving more focus on topo-climatic variables, to predict the ecological niche and forthcoming areas for beech forest expansion. Carrying out such an investigation for the whole national park also offers the park management an opportunity to have overall images of the scenario to verify the comparative advantage and disadvantage of the forest expansion to take mitigatory actions. So, this research paper will be an extension of the research work by (Van Gils *et al.* 2008).

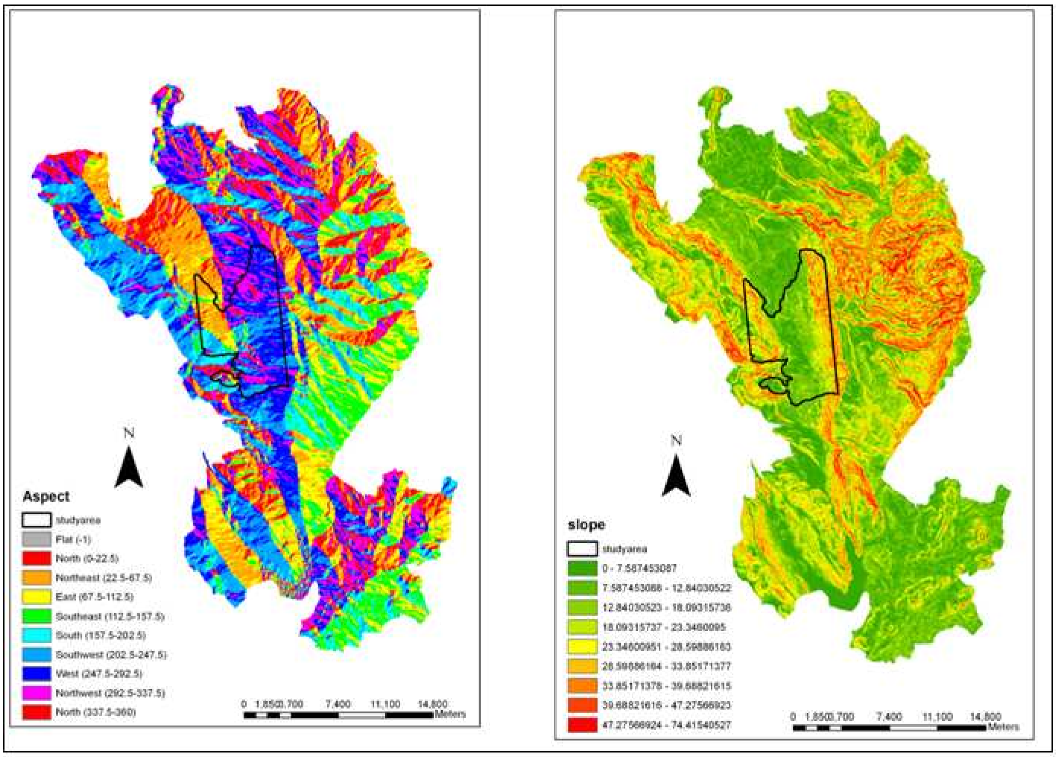

Figure 3: Aspect and slope map of the study area, and the study area considered by (Van Gils *et al.* 2008)

2. Objectives

2.1. General objective

- To investigate the underlining environmental factors that determine the ecological niche of beech forest and to predict the forth coming areas (the land cover types) that may be affected by beech forest expansion.

2.2. Specific objectives

- To investigate the values of ranges of topo-climatic and soil variables that are preferred by beech forest
- To determine the explanatory DEM derived topo-climatic variables that determines the habitat suitability of beech and
- To predict the potential ecological niche for forthcoming beech forest

3. Research questions and research hypothesis

3.1. Research questations

- Which range of DEM derived topo-climatic variables are more preferred by beech forest?
  - Which altitudinal, slope, and aspect ranges are more preferred by beech forest?
  - Does the incoming solar radiation have a significant impact on the habitat suitability of beech forest?
- Is it possible to accurately model the potential ecological niche of beech forest with Dem-derived topo-climatic and soil variables?
- Which land cover types share more ecological niche with beech forest and serve as a potential area for beech forest expansions?
- Does the beech forest expansion has a threat to the species rich grass land mosaic and the alpine pasture?

3.2. Research hypothesis

Ho: Topo-climatic variables cannot predict the potential ecological niche for beech forest expansion
H1: Top climatic variables can predict the limit of beech forest expansion and ecological niche

4. Materials and methods

4.1. Study area description

The study was undertaken in Majella National Park ("Parco Nazionale della Majella"). Majella national park is located in the region of Abruzzo, central eastern Italy, within the coordinates of 42^0 51' N to 42^o 15' N latitude and 13^0 15' 21.209'' E to 14^0 14' 46.21'' E longitude (figure 4). The national park is 740 km^2 of unique wilderness area and is home to an amazingly rich floral and faunal life. At floristic level, the Park is the most southern branch of the European Alpine Area and an authentic crossroad of genetic flows, with classes of high ecological and phytogeographic recognition: with more than 2,000 floristic species the Park hosts the 65% of Abruzzi flora, the 37% of the Italian ones and the 22% of European plant species (Majella national park, 2007).

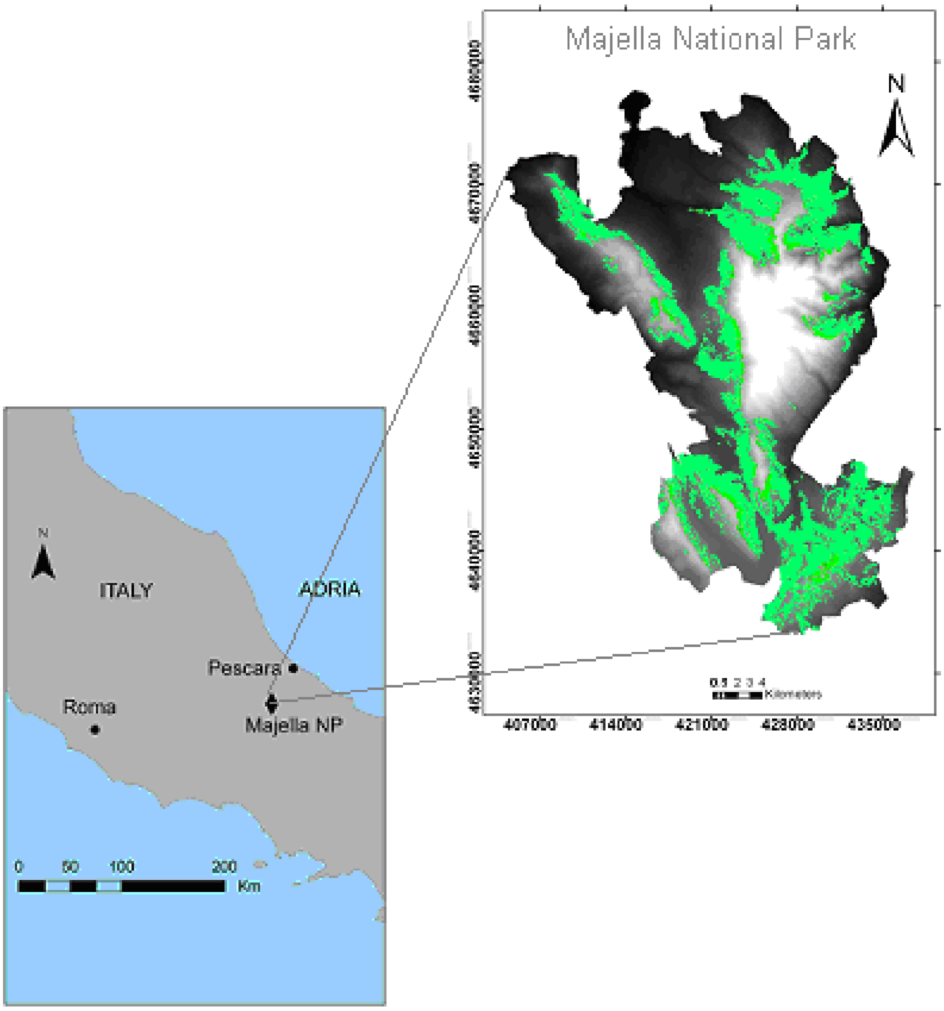

Figure 4: Study area

Topographically, the park is one of the most impressive and extensive mountain ranges of the Italian Apennines, containing more than 30 peaks higher than 2000 m. More than 55% of the park area is located at altitude higher than 2000 m above sea level. The highest peak, mount Amaro, is 2797 m high and it is the second highest peak of the Apennines.

The diverse habitat in the park can be divided into four major vegetation belts by overlay of DEM – derived contour-lines and the vegetation map (Table 1). These are:

- **Sub-Mediterranean**; this region is found within the altitudinal ranges below 900 m. a. s .l. The belt characterized by Downy oak; deciduous, thermophilic forest which includes *Quercus pubescens*; and by large number of farmlands.
- **Temperate montane**: This vegetation belt is mainly found within the altitudinal range of 900 – 1800 m a. s. l. altitudinal range. In the belt, the beech wood is typical of the forest landscape, often associated with deciduous mesophilic forest which includes Yews, Hollies, mountain Ashes, Maples and several fruit-bearing species. The European beech is contagious and a monospecific stand on the upper belt. Beech is also the major forest type in the national park comprising 70% of the forest types. Moreover, beech forest is expanding down the altitudinal gradient to abandoned farms and grass lands, and to alpine pasture in the upper altitudinal ascent ((Van Gils *et al.* 2008).
- **Subalpine belt**: This belt is a belt which is found above the beech forest timberline. Its altitudinal belt ranges from 1700-1800 to 2000 m a. s. l. Shrubby pine, Dwarf juniper; coniferous shrub land; *Pinus mugo*, *Juniper nana* dominates this vegetation belt.
- **Alpine belt**: Alpine belt is a belt without trees or shrubs. It is characterized by grassland, open herbaceous and dwarf shrub vegetation and by bare land which is lacking any vegetation types. This belt includes the area of the park which has an average altitude of above 2200 m a. s. l.

4.2. Materials used

Some of the materials used for the study purpose are summarized in table as follows:

Table 1: Materials used

Materials	Resolution	Source
DEM	30 m	Aster DEM
Land cover map	1:25,000	Anonymous, 1999
Soil map	1: 50, 000	Anonymous, 1999

4.3. Methods

4.3.1. Exploration of ranges of DEM derived variables for the whole national park versus for the areas of the park occupied by Beech forest

From the DEM model of the study area, the map of DEM derived topo-climatic variables (slope map, aspect map and incoming solar radiation map of the hottest months, July and August) of the national park were made (appendix 1). The incoming solar radiation values were calculated for every 30 minutes and summed up per the two hottest months (Kumar *et al.* 1997). Using extract values to points in ARC GIS, raster values of these topo-climatic variables were derived from each of the 30 m by 30 m raster cells. Pixels containing beech forest were derived from the land cover map of the study area (anonymous, 1999). After rasterizing, the beech forest map is multiplied by the maps of the DEM derived topo-climatic variable using raster calculator in ARC GIS to obtain pixel count to each of the raster values of the variables. For each raster values of these variable (altitude, incoming solar radiation, slope and aspect), the ratio of pixel counts containing beech forest to total pixel counts of the national park having corresponding raster values were calculated. Histograms showing ratio of the pixel counts of the actual area occupied by beech forest to the whole national park for each of corresponding raster values of the topo-climatic variables were made for comparison purpose. These ratios were further classified in to logical groups and Kruskal-Wallis test was carried out in SPSS Version 16 environment to check whether the beech forest prefers certain ranges of the topo-climatic variables to the others. Slope aspect was grouped into eight groups of equal interval of azimuthal angles (45^{o}). On the other hand, slope and ISR were also classified into four groups of equal intervals. Beech forest locally goes to an altitude lower than 1,000 m and above 1, 800 m a. s. l. Hence the raster values of altitude below 1,000 m, from 1000 m to 1, 800 m and above 1, 800 m a. s. l. were considered as three logically groups to carry out the statistical test. In all cases ratios of the pixel counts containing beech to total pixel counts in the entire park with corresponding values were considered.

4.3.2. Modelling the ecological niche

4.3.2.1. Model used

The model selected to determine the beech niche is Maxent 3.2 (maximum entropy model). Maxent use only presence data in combination with environmental data for the whole study area to derive a model and predict suitable conditions or ecological niche. Based on the presence data and the relation of the presence data with the environmental variables, Maxent assigns a non-negative probability to all pixels in the study area (Phillips, 2004).

4.3.2.2. Environmental variables

All the aforementioned raster layers used for suitability map were used in the model. Some additional environmental variables that most likely influence the beech niche such as (soil type, incoming solar radiation for the hottest months (July and August) and incoming solar radiation for the coldest months (January to December) were also used as additional input (Table 2). Extreme cold and snow in the winter and drought in the summer affects beech growth and establishment (Czerepko 2004).

Table 2: Environmental Variables used as input

predictor variables	Data type Attribute	Spatial	Format	Resolution	Ranges
Altitude	Continuous	Raster	ASC	30 m	1 – 2797 m
Slope angle	Continuous	Raster	ASC	30 m	0 – 73 ^{o}
Slope aspect	Continuous	Raster	ASC	30 m	-1 – 359 ^{o}
Radiation of the hottest months	Continuous	Raster	ASC	30 m	36.6 – 437.56 KWH/m2
Radiation of the coldest months	Continuous	Raster	ASC	30 m	10.13 – 156.92 KWH/m2
Soil type	Categorical	Raster	ASC	30 m	0 – 16 (codes)

4.3.2.3. Data source

In the areas covered by beech forest in the secondary vegetation map of the study area, 1000 random points were generated using ‘Hawth’s tool’ in arc GIS. These random points were used in Maxent (maximum entropy model) as a presence data for beech forest. 75% points were used to run the model while the other 25% random points were used to test and validate the model.

4.3.2.4. Validation of the model

The accuracy of the predictive model was measured by the Receiver Operating characteristic (ROC) curve. The Receiver operating characteristic (ROC) is a widely used statistical technique for accuracy assessment (Hanley and McNeil 1982). The plot is obtained by plotting a fraction of correctly classified cases on the y axis (sensitivity) against the fraction of wrongly classified cases (specifity) for all possible thresholds on the x axis at different threshold. The ROC curve is summarized by the area under the ROC (AUC) as a measure of overall accuracy that is not dependent on a particular threshold (Hosmer and Lemeshow 2000). The value of AUC varies from 0.5 to 1. Values close to 0.5 indicate a fit no better than that expected by random while values close to 1 indicate more accuracy and a perfect fit. In the current study AUC was graded based on (Hosmer and Lemeshow 2000). (Hosmer and Lemeshow 2000) graded the area under the ROC (AUC) as: AUC = 0.5 as “no discrimination”, 0.7 < AUC < 0.8 as acceptable range, 0.8 < AUC < 0.9 is excellent range and AUC > 0.9 is outstanding range. This range was also used to measure the performance of the model in the current study.

4.3.2.5. Data analysis

The output raster layer of Maxent was imported to ARC GIS and the whole study area is reclassified into habitat suitability classes. These probability (suitability) classes were overlaid with the actual beech forest in the secondary vegetation map in ARC GIS. The actual land cover class in the areas that were predicted as potential niche for beech forest with the probability 50% and above were identified and their spatial area was quantified to see the niche overlap of beech forest with other land cover classes.

5. Results

5.1. Ranges of DEM derived topo-climatic variables preferred by Beech forest

No pixels below 480 m and above 2073 m a.s. l. Contains beech forest. The Pixels containing the beech forest are exclusively and almost normally distributed within the altitudinal ranges from 480 to 2073 m a. s. l. However, most of the pixels containing beech are found within the altitudinal ranges of 1000 to 1800 m a. s. l (figure 5).

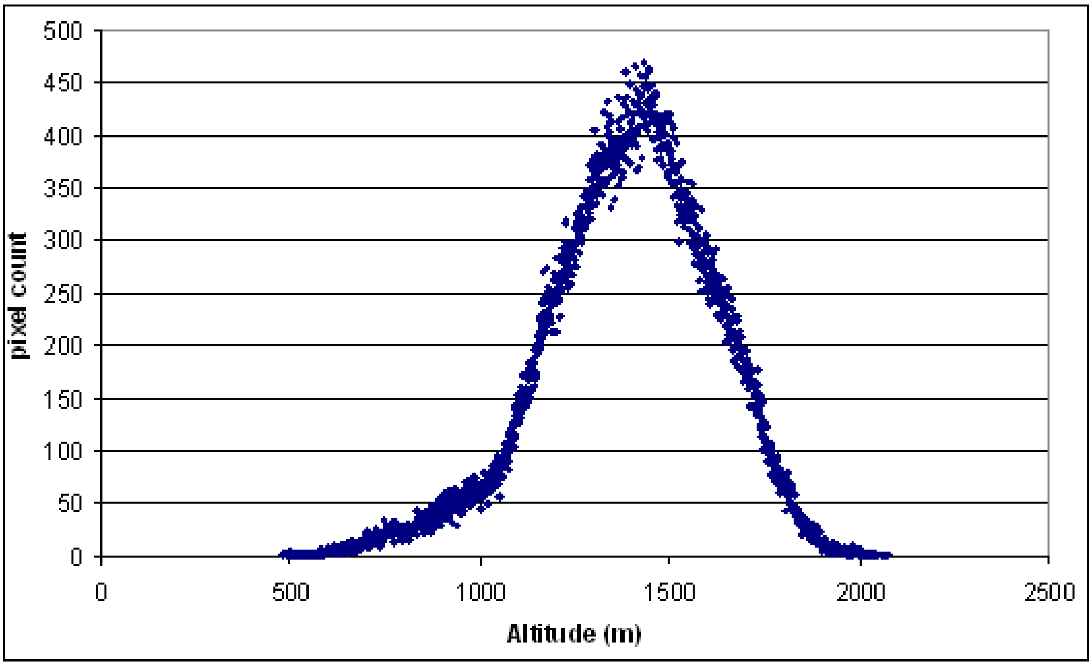

Figure 5: Altitudinal ranges of beech

Nevertheless, in some areas of the park the forest goes to the extreme lower and upper altitudes. But, these areas are localized into certain parts of the national park (figure 6, 7 and 8). The analysis of the Kruskal-Wallis Test also confirms the preference of the beech to the altitudinal ranges from 1000 to 1, 800 m above sea level in statistically significant way ($p < 0.05$).

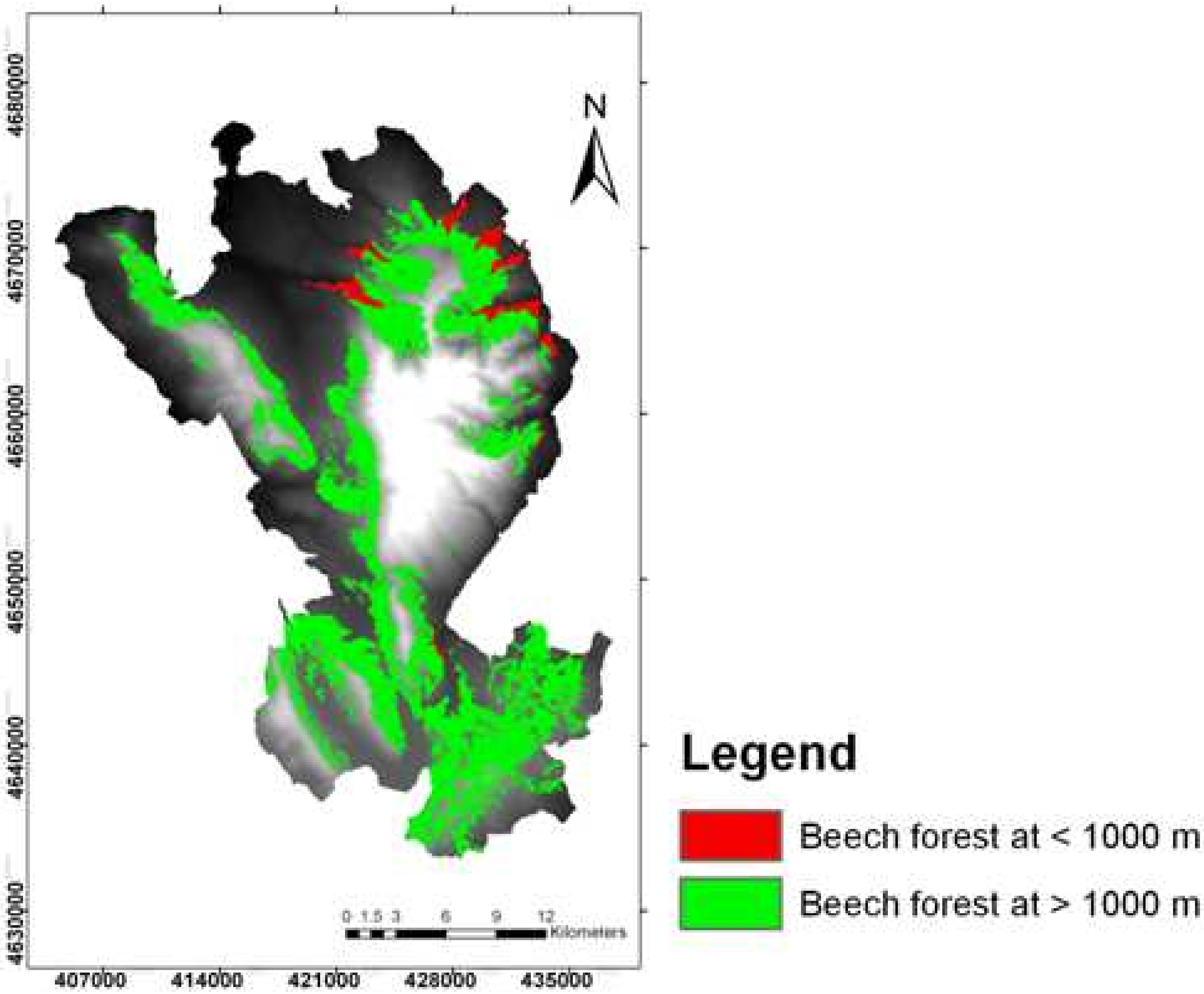

Figure 6: Areas of the park where the beech forest goes below 1000 m altitude

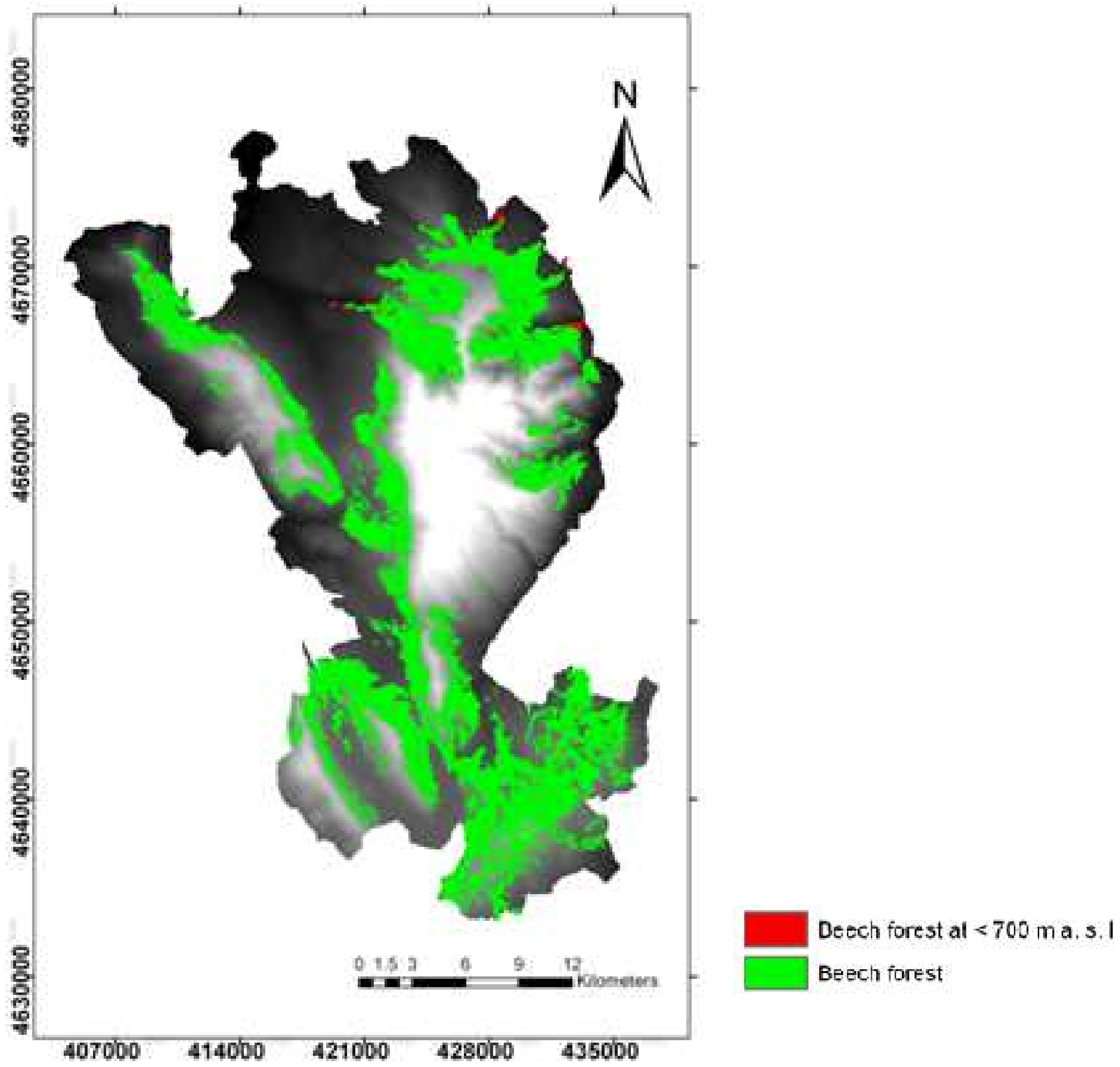

Figure 7: Areas of the park where beech goes down the extreme lower altitude, below 700 m a. s. l

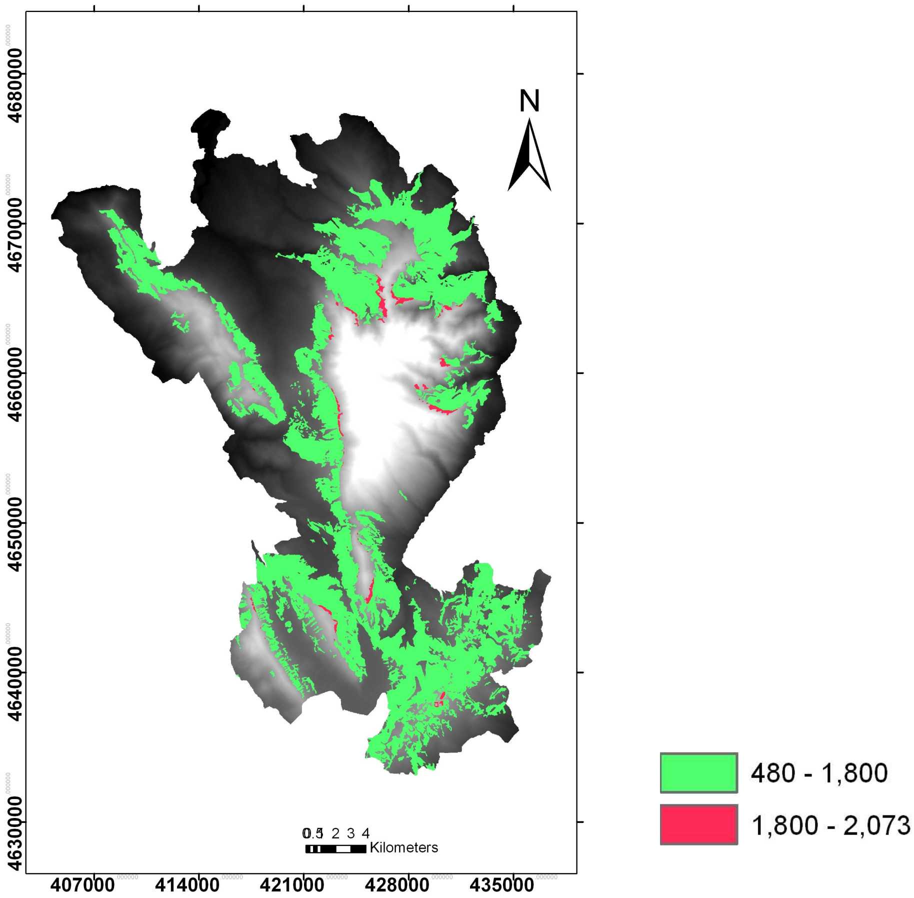

Figure 8: Areas where the beech forest goes beyond 1, 800 m a. s. l

Areas where the beech forest goes below 1000 m a. S. l. is exclusively found in the northern and north east part of the national park (figure 6 and 7). On the other hand, the beech forest goes to the higher altitude, above 1,800 m a. s. l. almost exclusively in south facing slopes (figure 8). These areas are areas which are receiving higher incoming solar radiation while areas where the beech forest goes below 1000 m a. s. l, is the areas of the park which are receiving lower incoming solar radiation (figure 9).

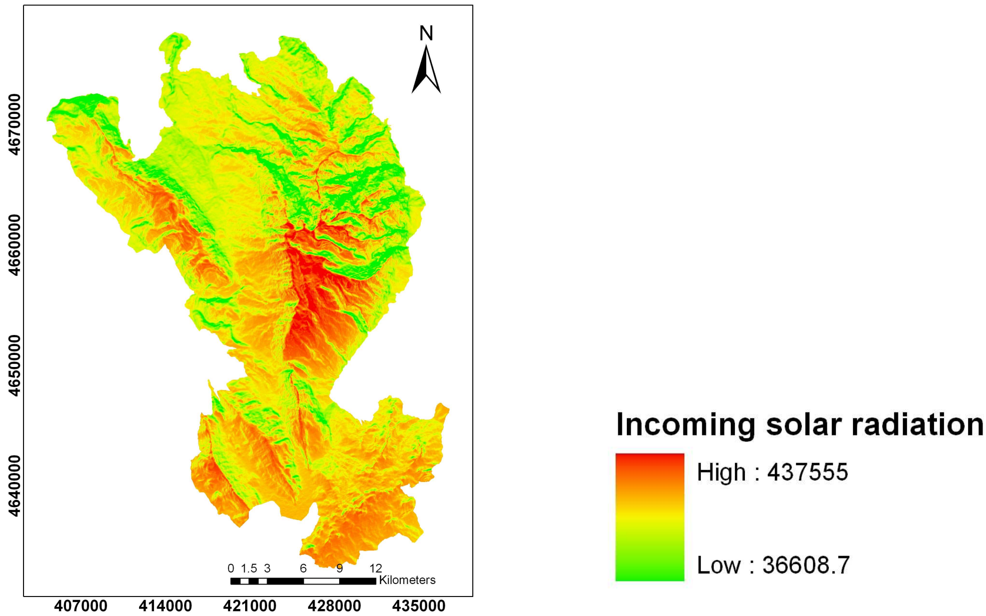

Figure 9: Incoming solar radiations (WH/m2) of the two hottest months, July and August

The beech forests also tend to prefer areas that are receiving lower incoming solar radiation. However, there are no remarkable variations across the different aspect ranges. The ratio of pixel counts for beech forest to the pixel count of the whole national park at each of the raster values of aspect are almost the same throughout the whole ranges of aspect. Similar is true in case of slope. However, the beech forest tends to avoid the extreme lower and upper slopes. Kruskal-Wallis test also shows the lack of beech forest to significantly prefer one slope and aspect range to the others ($P < 0.05$). On the other hand, the ratio of beech containing pixels to the total pixels in entire national park seems higher in the areas of the park that are receiving less incoming solar radiation of the hottest months, July and August. The preference of the beech forest to lower ISR is also supported by Kruskal-Wallis test. The histograms showing the ISR, aspect and slope preference of beech forest are presented in histograms (figure 10, 11 and 12).

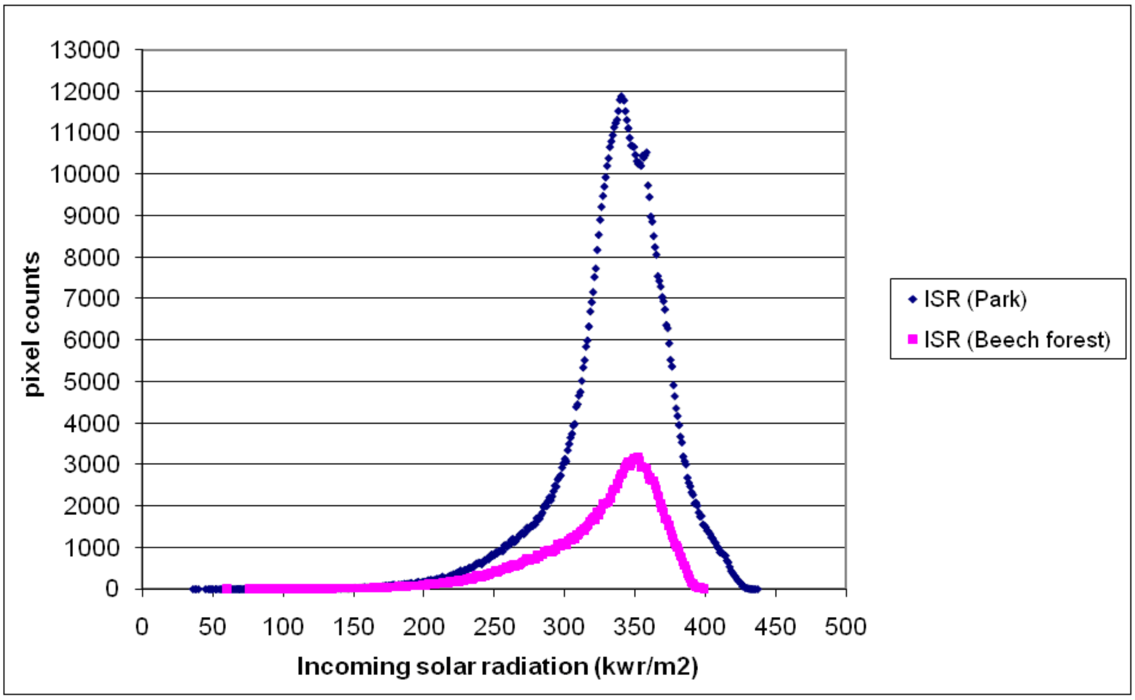

Figure 10: Distribution of pixels across the raster values of ISR during the summer hottest months, July to August; Pixels throughout the national park in blue and pixels containing beech forest in red.

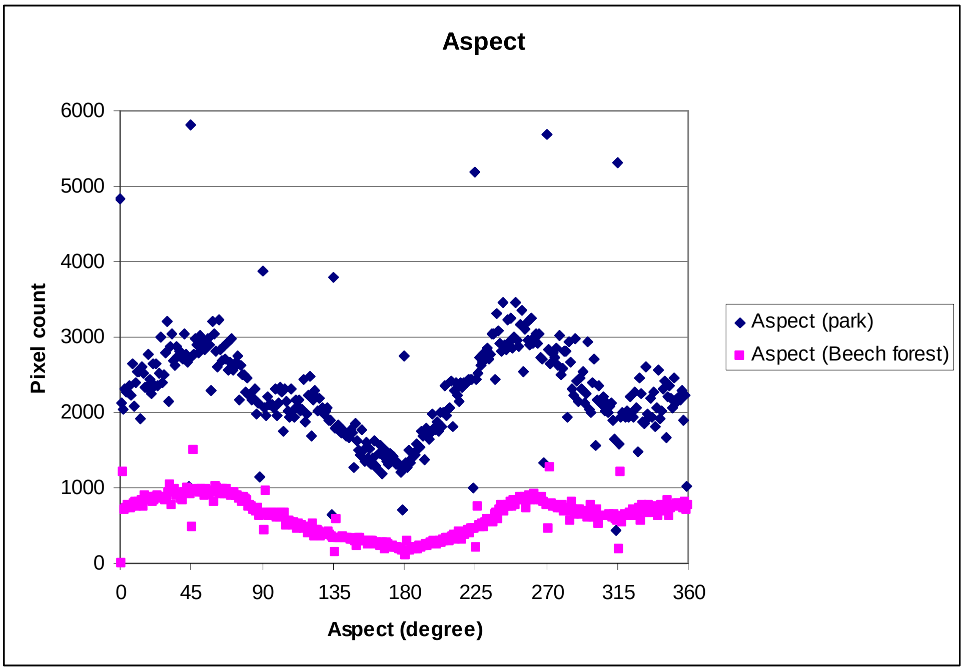

Figure 11: Distribution of pixels across the raster values of aspect ranges; Pixels throughout the national park in blue and pixels containing beech forest in red

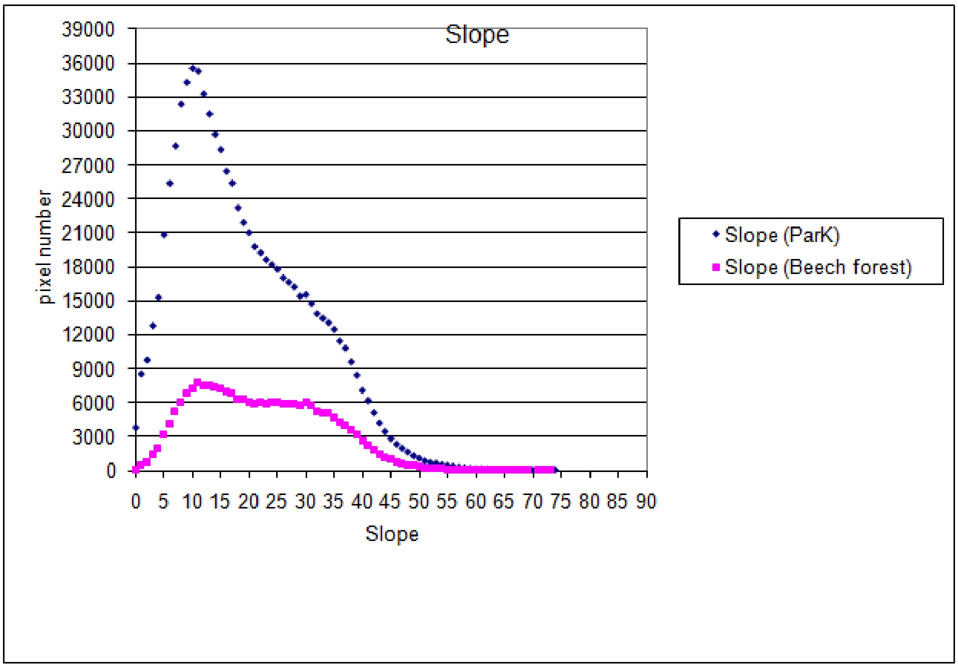

Figure 12: Distribution of pixels across the raster values of slope ranges; Pixels throughout the national park in blue and pixels containing beech forest in red

5.2. Model outputs

The model calculated the omission rate for both the training and test data. The omission rate and predicted area as a function of the cumulative threshold are presented in figure 13.

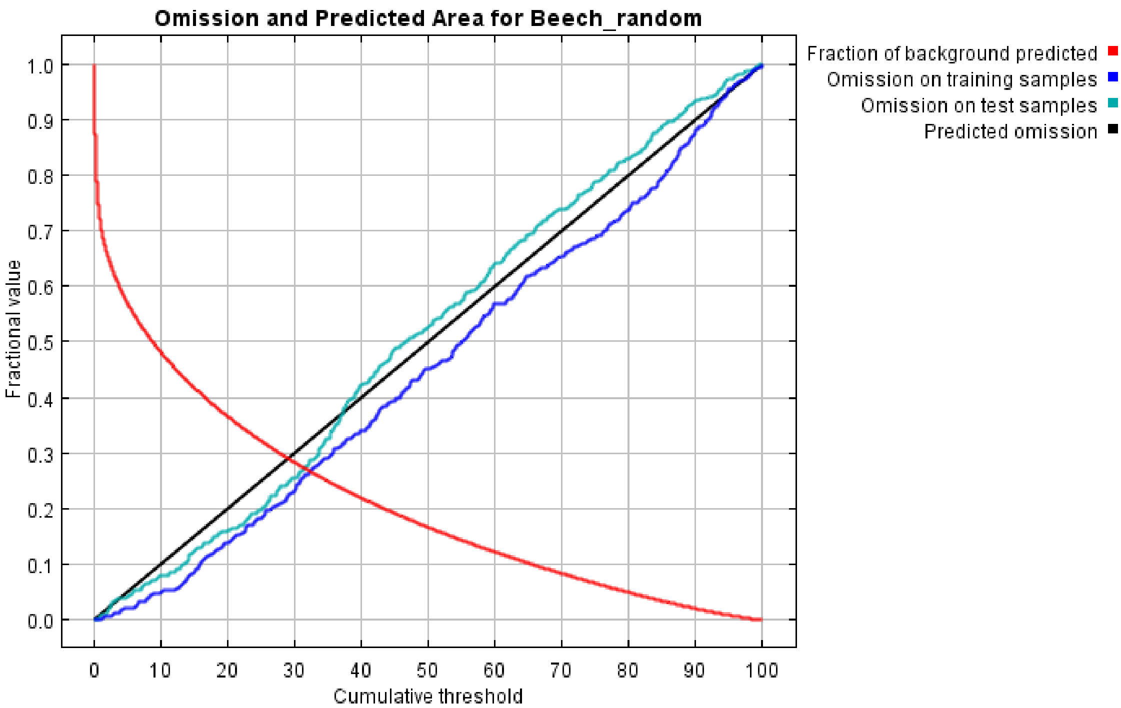

Figure 13: Omission rate for both the training and test data

In the following picture the receiver operating curve for both training and test data, are also shown. The red (training) line shows the “fit” of the model to the training data. The blue (testing) line indicates the fit of the model to the testing data**,** and is the real test of the models predictive power (Fielding and Bell 1997). So the area under the ROC (AUC) is 0.817 which indicates the model is 81.7% valid.

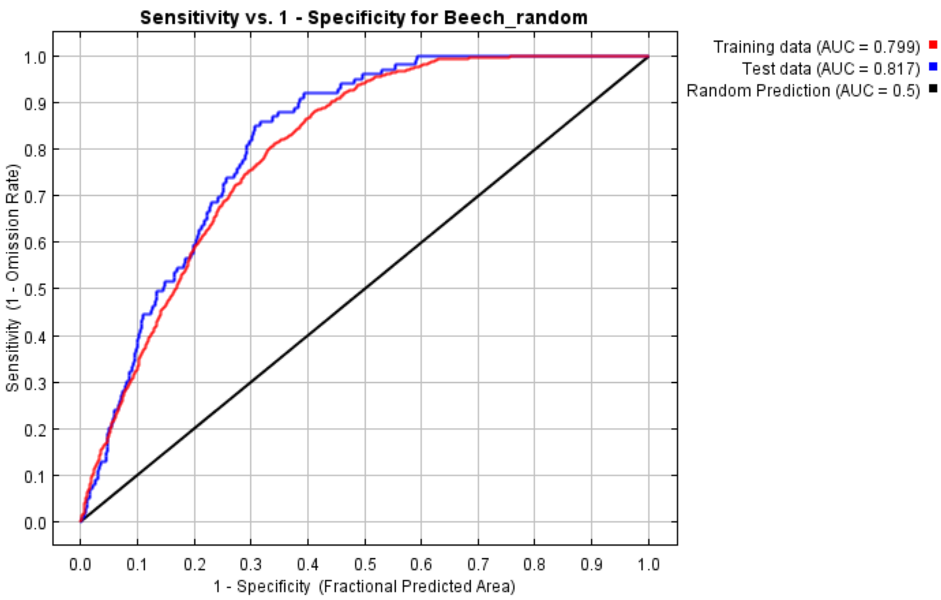

Figure 14: Receiver operating curve for both training and test data

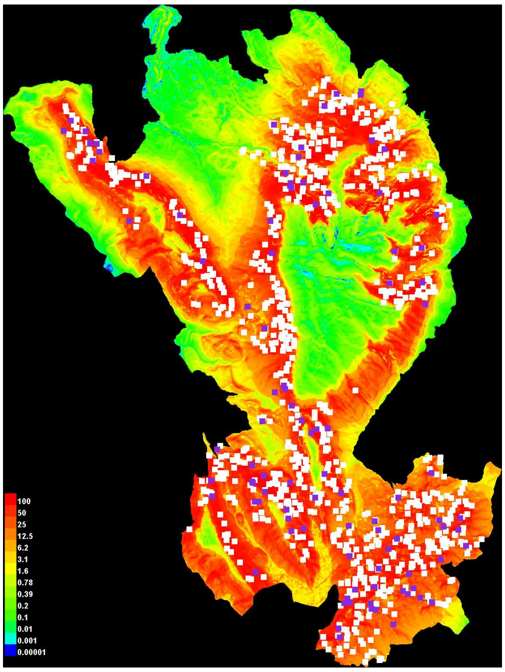

Figure 15: Picture of the model output

The picture of the model output shows the probability ranges for beech niche throughout the national park. In the picture, the red colour indicate high probability of suitable conditions for the beech forest while lighter shades of blue indicating low predicted probability of suitable conditions. The white dots show the presence locations used for training, while violet dots show the test locations.

The model output is further classified into four probability classes (picture 16). From the secondary vegetation map of the study area, in the east flank of the Majella massif and the west flank of the Morrone massif, the beech forest is conspicuously absent currently. However, the model output shows the presence of habitat suitability of beech forest in these areas. This indicates the presence of a chance for beech forest to expand from south and north east of the Majella massif to fill the gap between them. Similar scenario may also work for gap which is found between the beech forest which is found on the South and North West side of the Morrone massif.

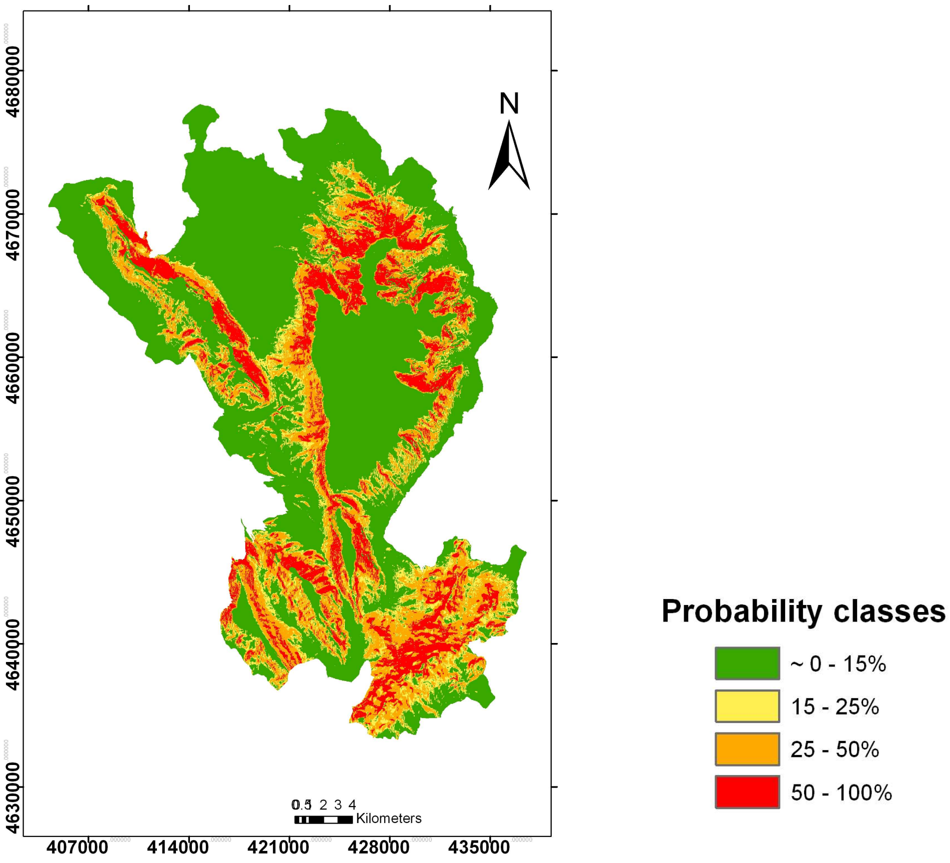

Figure 16: Probability classes for beech forest expansion

5.3. Responses curve and analysis of variable contributions

The Maxent model shows the response of beech forest to certain range of altitudes, aspect slope, and incoming solar radiation and soil types. As it can be seen from the response curve, the beech forest best suits to the mid altitudes of the park, not the extreme high and low altitude ranges. Even though aspect has less contribution for beech forest habitat suitability, the response of the forest to the variable has an ecological implication. From the curves, it is also possible to say that the beech forest excludes the extreme low and high slope ranges. As compared to other variables, altitude plays the major role in determining habitat suitability of beech forest. However, these plots also consider the dependence of predicted suitability induced by correlations between them and other variables. Thus, they are best interpreted in the presence of highly correlated variables.

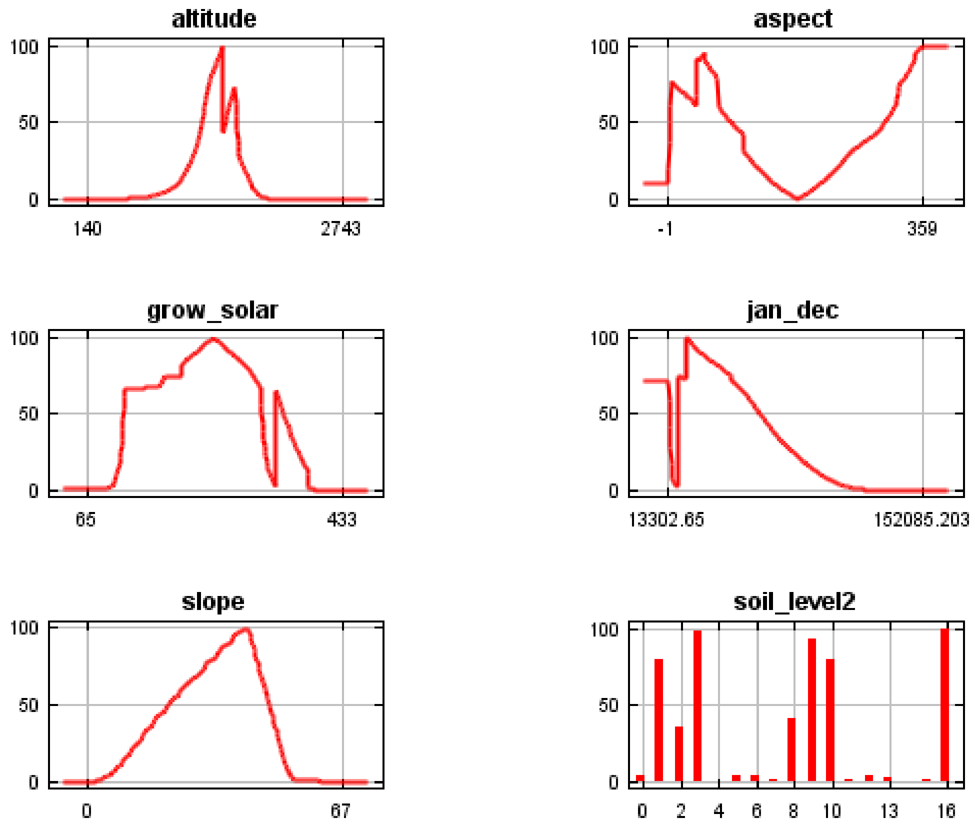

Figure 17: Response curves of the environmental variables.

Altitude (m) and slope (degree) are standing to the whole altitudinal and slope ranges throughout the ISRnational park. Grow solar (KWH/m^2) refers to the ISR of the two hottest months of the growing season, July and August while Jan_Dec (WH/m^2) stands for the ISR during the two coldest months of the year, January and December. Soil-level2, on the other hand is the soil types in the national park (appendix 3).

Table 3: Heuristic estimate of the relative contributions of environmental variables to Maxent model

Variable	Percent contribution
altitude	77.6
ISR of the hottest months	10.1
Soil_level2	4.8
Slope	3.8
ISR of the coldest months	3.5
Aspect	0.3

As it can be seen in heuristic estimate of the tabulated relative contribution of variables, altitude plays the major role in determining habitat suitability of beech forest. The jackknife test of variable importance also shows the environmental variable with highest gain when used in isolation is altitude, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is altitude, which therefore appears to have the most information that isn't present in the other variables. The jackknife plot of the model out is presented in figure 18.

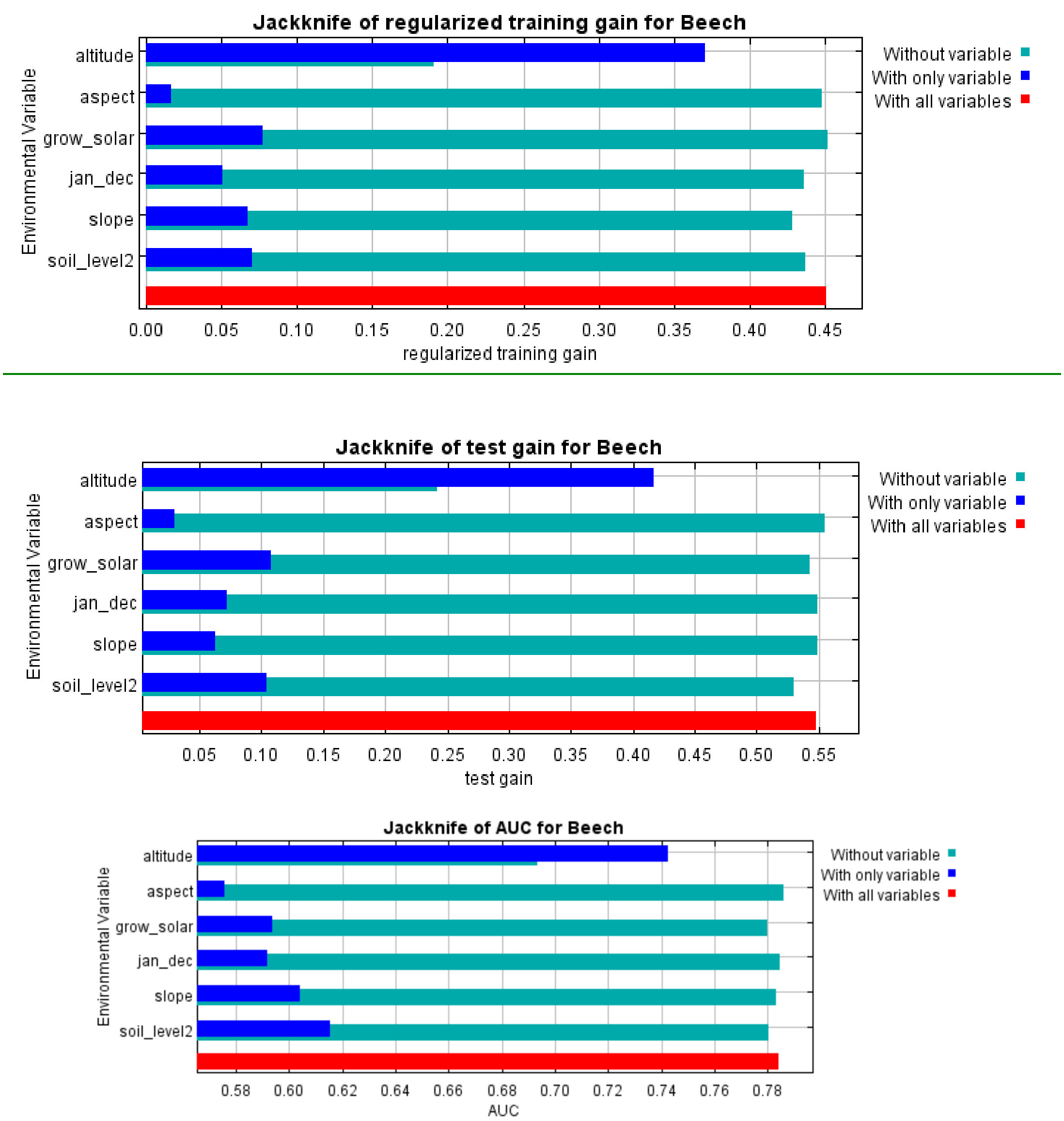

Figure 18: Jackknife plots of variable test. Meanings of each of the codes are mentioned in the caption of figure 17.

In the jackknife plots, the red bar indicates the overall performance of the model while the blue bar shows the performance of the model with the only underlining environmental variable. The light blue bars on the other hand, indicate the performance of the model without the corresponding variables. Thus, from the plots, it can be further noticed that if Maxent uses only slope or aspect or incoming solar radiations of the two hottest and coldest months, it achieves almost no gain. Omitting of these variables one after the other, does not also affect the overall performance of the model. So, they contribute more in group set than in separate.

5.4. Potential forthcoming ecological niche for beech forest

The result obtained by overlaying the probability classes of beech suitability map with the secondary vegetation map of the study area shows, the beech forest less likely exist in the gully/ravine habitat. This habitat type is exclusively situated within the area that less likely suits to beech forest, the ~ 0 – 15% probability classes (table 4). Similarly *Quercus ilex*, *Sali*x/*Populus/Alnus*, *Quercus pubescens* and *Quercus cerris* also have less niche overlap with beech forest (Figure 20and Table 5). Even though, *Quercus pubescens* and *Quercus cerris* have remarkable area in the other beech probable niche ranges, the other land cover types (gully/ravine, *Quercus ilex* and *Sali*x/*Populus/Alnus*) are exclusively fall in the lowest probable niche range (~0 – 15%) of the beech forest.

Table 4: Spatial extent (ha) of the different land cover types that are situated in different probability classes of the beech niche

Land cover types	***suitability ranges***			
	~0 - 15%	**15 - 25%**	**25 - 505**	**> 50 %**
(sub) Mediterranean shrub	1590.88	41.30	60.51	10.37
bare rock	6757.66	243.93	789.18	387.80
Betula	0.00	0.00	0.00	5.20
Built-up	218.42	24.74	18.31	4.40
crop field	8998.20	1045.15	1036.83	106.48
gully/ravine	45.76	0.00	0.00	0.00
montane shrub	1761.42	286.51	357.56	91.55
Ostrya carpinifolia	805.32	101.41	94.54	24.87
Pine plantation	1928.99	268.19	403.41	89.95
Pinus mugo	750.27	6.81	52.28	71.30
Pinus nigra natural	20.41	7.74	23.87	6.63
Quercus cerris	290.53	75.57	37.19	0.62
Quercus ilex	41.07	0.00	0.00	0.00
Quercus pubescens	3322.26	106.51	96.13	4.43
Salix/Populus/Alnus	35.41	0.00	0.00	0.00
shrub wood	2062.94	293.53	416.21	146.10
sparse grass/dwarf shrub	6765.99	1682.19	3101.21	1137.09
subalpine pasture	2323.96	169.35	442.28	214.15
subalpine shrub	1388.75	43.39	169.16	91.77

Nomenclature of the taxa is following (Conti 1998)

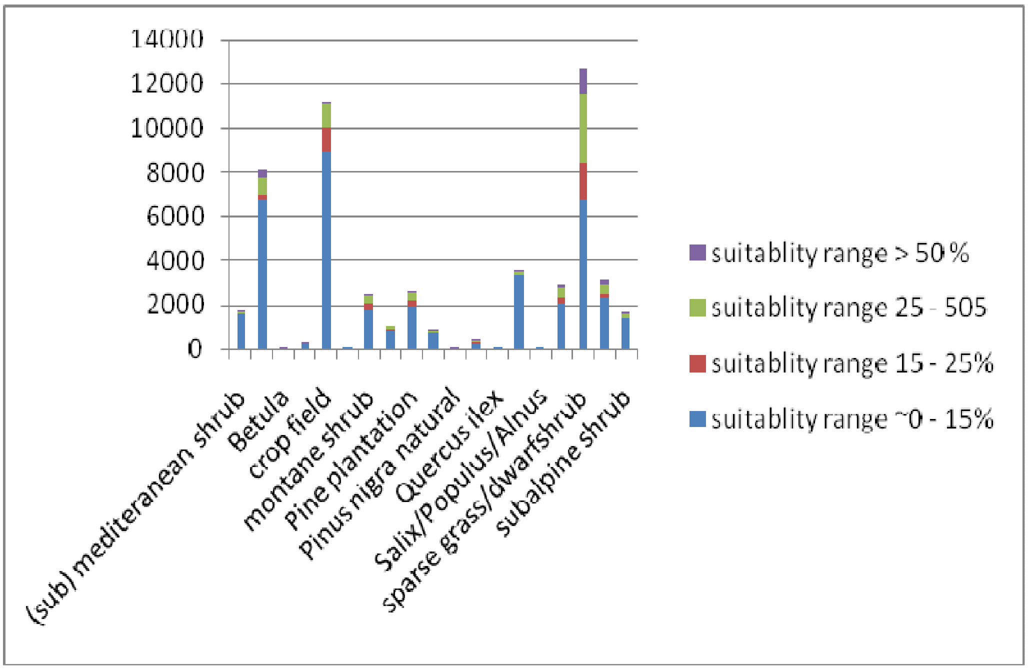

Figure 19: The spatial area (ha) of each land cover types within the different habitat suitability ranges of beech forest

Sparse grass/dwarf shrub has the highest spatial extent within the high ecological niche of beech forest followed by bare rock, subalpine pasture, shrub wood and abandoned crop lands (table 4 and figure 19). When it comes to the proportion, *Betula pendula* is totally found within the high probability range of beech ecological niche (50 % and above suitability range) regardless of its confinement to small area extent. Almost similar scenario also works for the natural *Pinus nigra* (table 5 and figure 20).

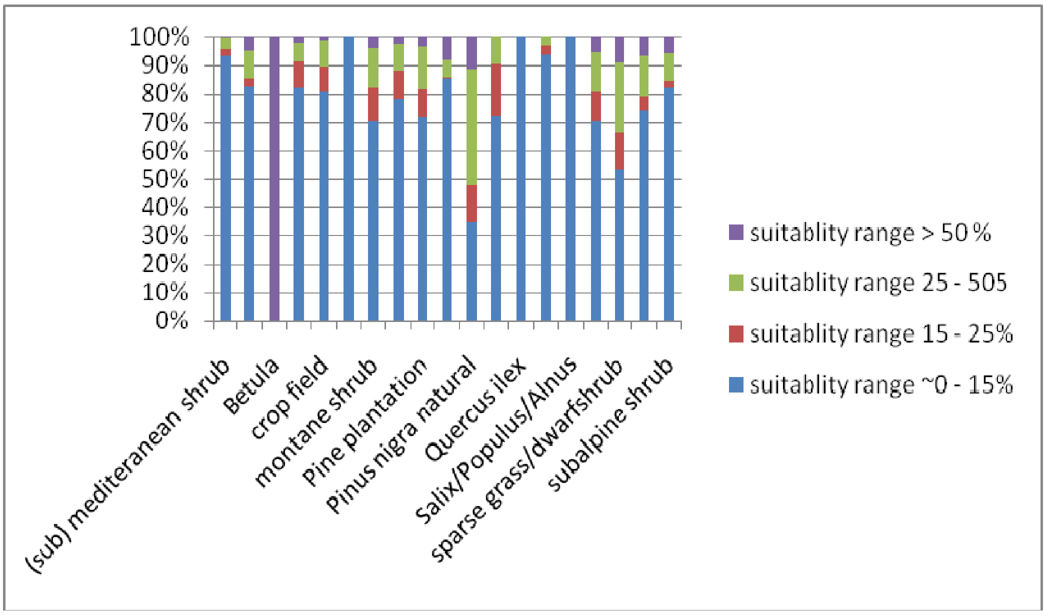

Figure 20: Proportion of the land covers in the different habitat suitability range of beech forest

Table 5: Proportion of the land cover types that commonly shares more than 50% probability range of the beech ecological niche

Land cover types	**Ratio (%)**
gully/ravine	0.00
Quercus ilex	0.00
Salix/Populus/Alnus	0.00
Quercus pubescence	0.13
Quercus cerris	0.15
(sub) Mediterranean shrub	0.61
crop field	0.95
Built-up	1.66
Ostrya carpinifolia	2.42
Pine plantation	3.34
montane shrub	3.67
bare rock	4.74
shrub wood	5.01
subalpine shrub	5.42
subalpine pasture	6.80
Pinus mugo	8.10
sparse grass/dwarfshrub	8.96
Pinus nigra natural	11.30
Betula	100.00

Nomenclature of the taxa is following (Conti 1998)

6. Discussion

6.1. Response of beech forest to DEM-derived topo-climatic variables

Pixels containing the beech forest exclusively occur within the altitudinal range from 480 to 2073 m a. S. l. However, Kruskal-Wallis test shows the preference of beech forest to the altitudinal ranges from 1000 to 1, 800 m a. S. l. Areas where the beech grows out of this altitudinal range are also very local. The area where it goes to the lower altitudes, below 1000 m, is almost exclusively confined in the north and north east part of the national park while areas where it goes beyond 1, 800 m is localized to the south facing slopes.

The north and north eastern part of the park, where the beech goes to the lower altitude, is characterized by the relatively lower incoming solar radiation of the hottest months (figure 9). It is also part of the national park which is receiving high precipitation and more humid as compared to the other parts. The low incoming solar radiation along with the high precipitation amplifies the moisture availability. The presence of moisture during the hot summer season in turn must have played a great role for the presence of beech on such lower altitudes. The fact beech is drought sensitive and its growth and expansion is favoured by wetter and cooler climatic conditions is well known and documented in so many literatures (Granier *et al.* 2000; Gessler *et al.* 2004; Tinner and Lotter 2006; Lendzion and Leuschner 2008). Our field observation also clearly shows, seedling of the beech tree are exclusively found from north west to north east aspects from their seed source (mother trees) where these trees and tree patches cast shadow. The topographic shadow effect of the Majella massive in the north east part of the park also seems to serve as an analogue of the local trees and tree patches.

As a general truth, though, the beech (*F. sylvatica*) require cooler and moist climate in the summer (Backes and Leuschner 2000; Gessler *et al.* 2004), it also requires a mild winter with relatively higher temperature (Bolte *et al.* 2007). That might be the reason why, in the current finding of ours, the beech forest goes to extern higher altitude, beyond 1800 m a. S. l., mainly in south facing slopes where the incoming solar radiation is high (figure 8 and 9). High ISR has an impact on the snow prevalence on the higher altitudes during the cold winter while low ISR has less impact on soil moisture content during the hot summer on the lower altitudes.

For the matter fact north facing slopes receives lower ISR and south facing slopes receive higher ISR, there are pixels that are found at lower extreme altitude (480 m a. s. l.) and still contain beech forest in the northern slopes of the Majella national park and there are also pixels which are found on extremely high altitude (2073 m) and contain beech on the slopes facing south. This finding of ours is in line with (Nocentini 2009). On the sunnier and warmer southern slopes, the lower vegetation limit for beech tends to move higher while the northern slopes and where there is more rain and fog maintain moist air conditions, it goes lower (Nocentini 2009). (Nocentini 2009) also mentioned that in the southern regions, in areas with high air moisture conditions, beech can descend to an altitude of 400-500 m, where it comes into contact with evergreen oak (*Quercus ilex* L.) and in the Gargano peninsula (Puglia) it even descends to an altitude of 200-300 m a.s.l. resulting in an inversion of the vegetation planes, with beech occurring at lower elevations compared to evergreen oak.

In Majella national park the upper limit of the pixel containing the beech forest is found at 2073 m a. S. l. In the Northern Italian Apennines (latitude 44° N), the timber line reaches an elevation of 1,825 m a. s. l. with the highest range at 1,525 to 1,725 m a. s. l. with 13% of the peak at 1,600 to 1, 625 m ranges (Pezzi *et al.* 2008). On the other hand, (Daubenmire 1954) shown that tree timberline shows a decrease of 110 m in its elevation for every degree of the northern altitude in the Pacific coast mountains and Appalachian mountains of America. The latitudinal difference between our study area and the study area of (Pezzi et al., 2008) is about 2 - 3 degree toward the south in which case the timber line elevation difference of about 250 m is reasonable and thus this result is inline the report of (Daubenmire 1954). In the Mount Etna in Sicily, south of our study area, the beech reaches an altitude of 2000 m (Hofmann, 1996 and Del Favero, 2008, cited in Nocentini 2009**)**. This might also serve as an add to see the general truth of how the beech tree timberline generally increases as we are going down across the latitude.

Even though, the beech forest requires different ranges of incoming solar radiation in different slope aspects, pixel containg beech forest are almost null in the reas of the park which are recieving higher ISR (figure 9). The computed Kruskal-Wallis test also shows the preference of beech forest to the lower ISR. On the other hand, though, the preference of the beech forest differs from one slope and aspect ranges to the other, no slope and aspect ranges totally excluded the presence of pixels containing the beech forest. The computed Kruskal-Wallis test also does not show the preference beech forest one slope and aspect range to the other ranges. Altitude and ISR are the only topo-climatic variables that have totally excluded pixels contain beech forest in certain ranges of their raster values. No beech containing pixels found on the lower and upper extreme of altitudinal and ISR ranges.

The heuristic estimate of relative contribution of environmental variables of the Maxent model also shows ISR of these hottest months has the second highest contribution in determining beech habitat suitability while slope and aspect have less contribution. In broad terms 77.6% of the habitat suitability is explained by altitude and 10.1% by ISR of the hottest months. The environmental variable that decreases the gain of the Maxent model the most when it is omitted is altitude, which therefore appears to have the most information that is not present in the other variables. Altitude is a proxy to many environmental variables and thus most environmental factors that determine floral life change with the change in altitudinal gradients. Nevertheless, the response curve of each factor makes ecological sense, even the aspect curve that has hardly any contribution to the overall result.

6.2. Potential forthcoming areas for beech forest expansion

Among the vegetation types in Majella, *Betula pendula* and the natural *Pinus nigra*, sparse grass (dwarf shrub), subalpine pasture and subalpine shrub and subalpine shrub woods shares a relatively high proportion of their ecological niche with beech forest. Among these, *Betula* is confined to very small area and exclusively found in the relatively high potential area of beech niche.

When we compare the spatial extent of each land cover types, most of the spaces for potential beech expansion (km square) are grassland (abandoned farm lands), bare rock (artefact, land slide, quarries, eroded), subalpine pasture, shrub wood and crop field (Table 4). The sparse grass/montane bush, shrub wood, subalpine pasture and pine plantation are probably abandoned farmland where historically beech was removed for crops, pasture or a combination. On the latter category (pine plantation); abandoned farmland was reforested with pine and in the pine plantation the spontaneous succession moves towards a mixed beech (pine) forest (Van Gils *et al.* 2010). This can also be considered as an evidence for the fact the beech forest is reclaiming its ecological niche that had been masked by the anthropogenic impacts.

The expansion of the beech forest into the subalpine pasture and grass land habitat is already reported from Majella national park (Van Gils *et al.* 2008). From similar study area, there is a report about presence of high floral diversity including the remarkable number of endemic plant taxa in the subalpine pasture, subalpine shrubs and grass land habitats (Nanyomo 2010). Majella national park comprises more than 144 endemic taxa which are almost exclusively found out of the beech forest and most of these taxa are herbaceous in their life forms (Nanyomo 2010). On the other hand, there are reports on the impact of forest expansion on shade intolerant endemic herbs (Reidsma *et al.* 2006), on the loss of landscape diversity, grass land mosaics and montane pasture (Baur *et al.* 2006) and on the long term loss of species rich habitat (Anthelme *et al.* 2001). When it comes to beech forest, the scenario would even be worse for the reason beech forest is not species rich and it is usually occurs in monospecific stand. Likewise its closed canopy and allelopathic effect (Hanley and McNeil 1982) does not allow the establishment of shade-intolerant herbs and tree species.

The secondary vegetation map of the study area shows that, pixels containing *Q. ilex* are found within the altitudinal range of 510 to 843 m mainly concentrating in 600 m a. s. l. (figure 21). However, beech goes below 1000 m a .s. l. only in the northern and north east part of the national park. *Q. ilex* on the other hand, is found in small patches that are exclusively found on the north western par of the Morrone flank. The area also receives high ISR as compared most of the areas which are covered by beech forest and exists on similar altitudinal range (figure 22). Hence the lack of the niche overlap between *Q. ilex* and beech seems reasonable.

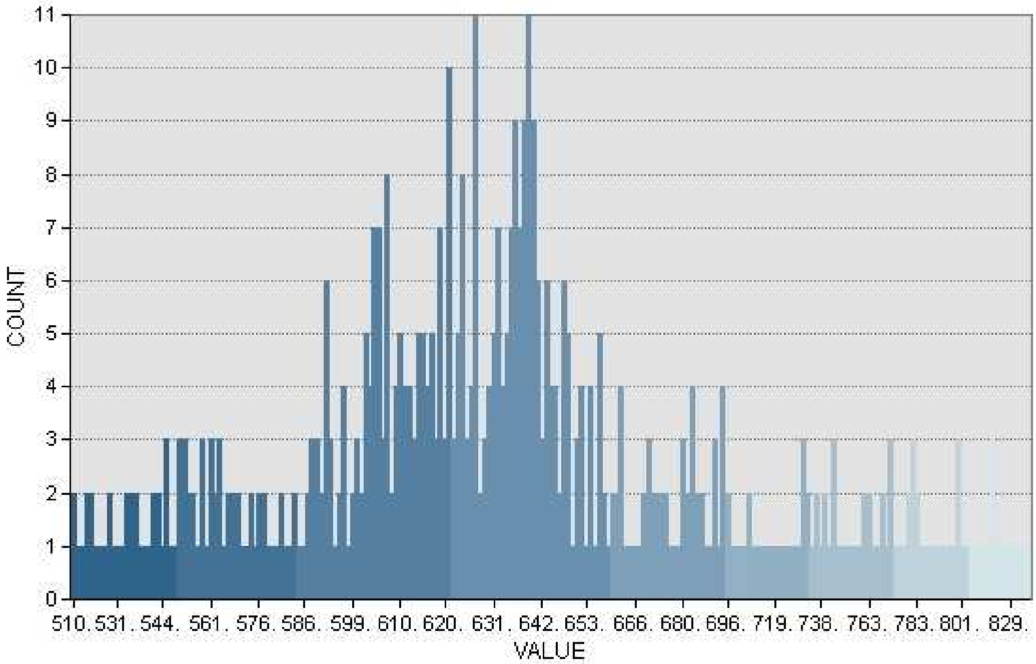

Figure 21: Altitudinal ranges of Q. ilex in Majella

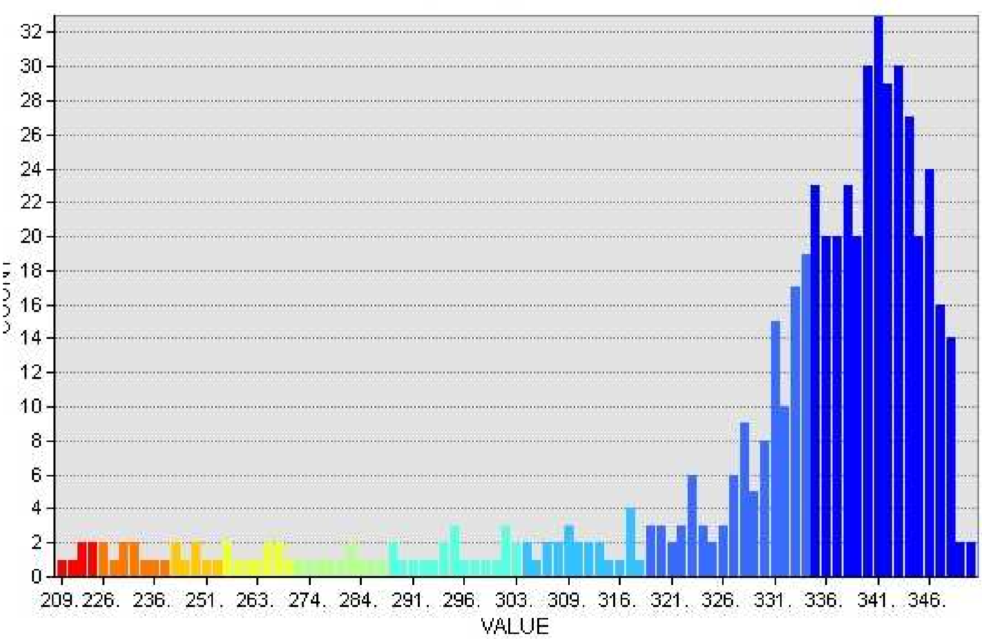

Figure 22: ISR of the hottest months in the areas covered Q. ilex in Majella

On the other hand, the competition among beech and *Q. cerris* is universal in the Eurasian mountains from the Atlantic to the Himalayas and even in North Africa. In our study are, there is a similar scenario. The secondary vegetation map shows that pixel containing *Q. cerris* almost makes a normal curve from 900 to around 1350 m a. s. l. The pixel number reaches peak at an altitude of 1130 m. a s. l. (figure 23). This altitude is the altitudinal range in which the ratio of pixels containing the beech forest to pixels in the national park on a similar altitude is high (figure 5). The incoming solar radiation in the area that's covered by *Q. cerris* is also reasonably tolerable by beech forest.

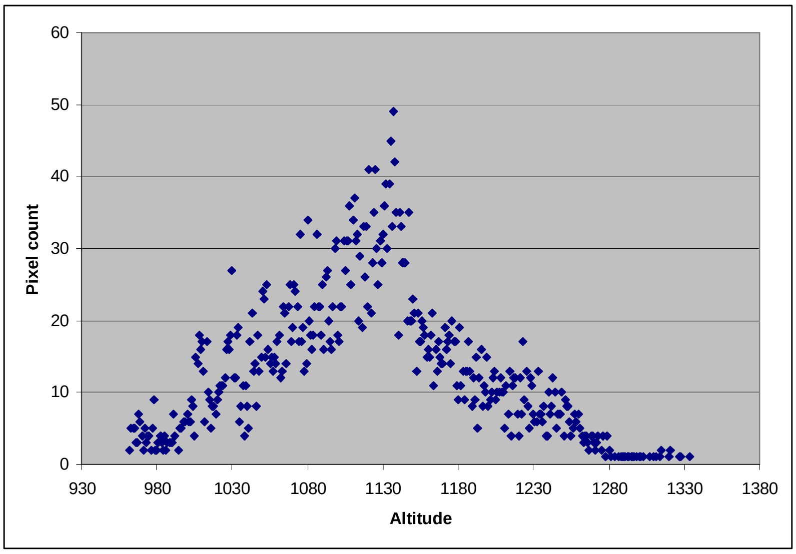

Figure 23: Altitudinal ranges for *Q. cerris* in Majella national park

Another land cover type that appeared not suitable to the beech forest is gully/ravine. Ravines are generally characterized by slope landform of relatively steep (cross-sectional) sides. The beech forest on the other hand, less likely grows on steeper slopes (figure 24) and also less likely expands to such slopes (Van Gils *et al.* 2008). Moreover, they may also have active streams and water logged clay soil at the lower slopes. Beech requires both moist and well drained soil, not wet feet (Mayer, 1984 cited in (Bolte *et al.* 2007)). The topographical position index which is produced from DEM model of the study area also shows the beech forest mainly prefers the middle slope, not the lowest and the upper ridges (figure 24).

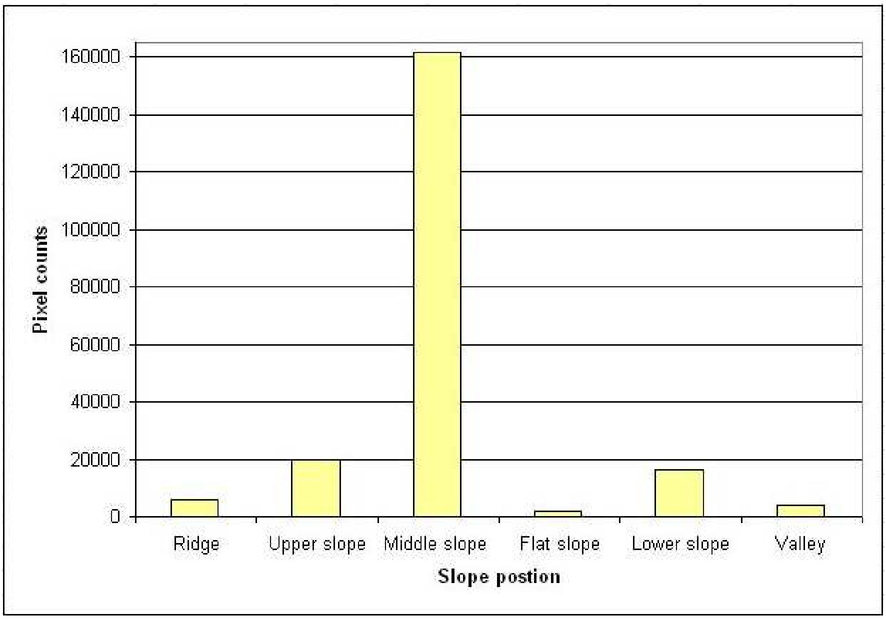

Figure 24: Beech forest distribution across slope positions

The maxent model output response curve of the beech forest to soil types also shows the preference of beech to soil types such as loose calcareous soils, loose moraine residues, Calcareous marl and Current debris and alluvial cone and moraine deposit. On other hand, the beech forest did not show a positive response to Landslides/ice induced cryoclastic surface, locally active karst processes on high altitudes, Clay Marl and Sandy levels on hilly areas and Irregular slopes and cliffs with rock outcrops.

7. Conclusions and recommendations

The beech forest exists within wide ranges of topo-climatic variables. Beech is found almost in all slope aspect and slope angle ranges. Though, the distribution of pixels containing beech varies from one slope angle and slope aspect range to the others, the variation is not supported by Kruskal-Wallis test ($P < 0.05$). However, the preference of beech forest to lower incoming solar radiation of the hottest months of the year and to the altitudinal ranges from 1000 to 1, 800 m a. s. l. is statistically significant ($P < 0.\ 05$). Unlike the case of slope and aspect, altitude and incoming solar radiation of the hottest months have excluded raster cells that are not containing beech forest on both their lower and upper raster values. From the heuristic estimate of relative contribution of environmental variables of the Maxent model, it is also possible to conclude that altitude has the highest gain when used in isolation, which therefore appears to have the most useful information by itself followed by ISR of the hottest months. Though, the soil variable, the slope angle, ISR of the coldest months and slope aspect hardly contributed to the overall model, their response curve also gave a sensible ecological scene.

The impact of incoming solar radiation in determining the upper and lower limit of beech belt varies from one slope aspect to the other. It looks there was a possibility to enhance the contribution of ISR by dividing the park into slope aspects portions and separately carrying out modelling to each of the portions. Thus, to make bold and objective claim about the degree of the impact of ISR on determining beech altitudinal belts further research is recommendable. For altitude is proxy to many other factors, determining the belts across the different slope aspect by itself can provide adequate information about the beech ecological niche.

From the Maxent model output, it can be concluded that, the beech forest has a large spatial extent of a highly probable ecological niche in the sparse grass/dwarf shrub, bare rock, subalpine pasture, shrub wood and abandoned crop land habitats. Most of these habitat types are known for comprising a highly diverse flora and large number of shade intolerant endemic plant taxa. Owing to beech forest occurrence in mono-stand, possession of a closed canopy and allelopathic effect, its expansion to these habitat types will have an adverse effect from biodiversity conservation point view. The objective of the park management is also to preserve the open spaces for scenic and grassland biodiversity values.

Carrying out detailed floristic composition studies, mapping and documenting the locations of species rich habitats firstly help the park management to conserve the diverse flora and endemic taxa and secondly, to foster the forest expansion in certain selected habitat types to increase the carbon sequestration, to minimize avalanche formation and soil erosion, and to foster connectivity among fragmented forest patches which might also help to create an ecological corridor for wild life and thus mitigate the genetic drift that might arise because of the lack of gene flow.

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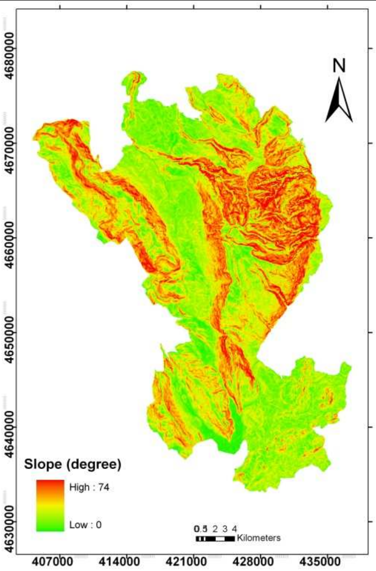
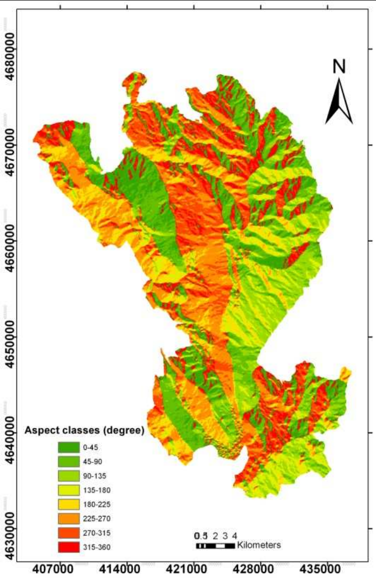
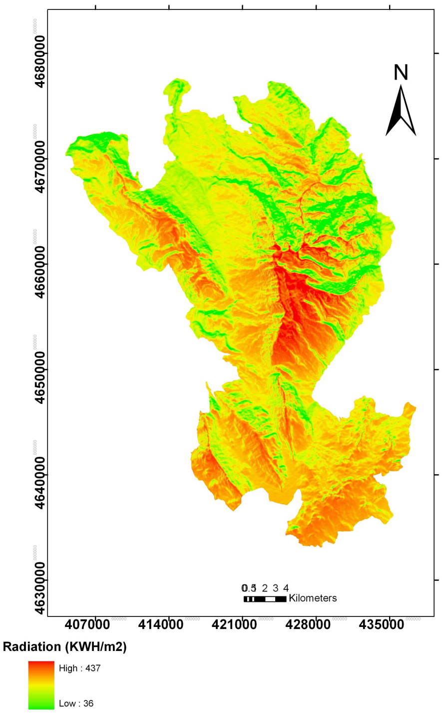
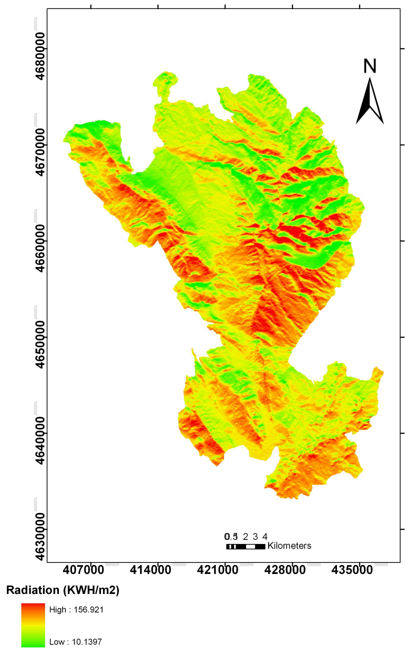
Appendices

Appendix 1 Map of Slope angle, Slope aspect, ISR of the hottest months (July and August) and coldest months (January and December) of the year









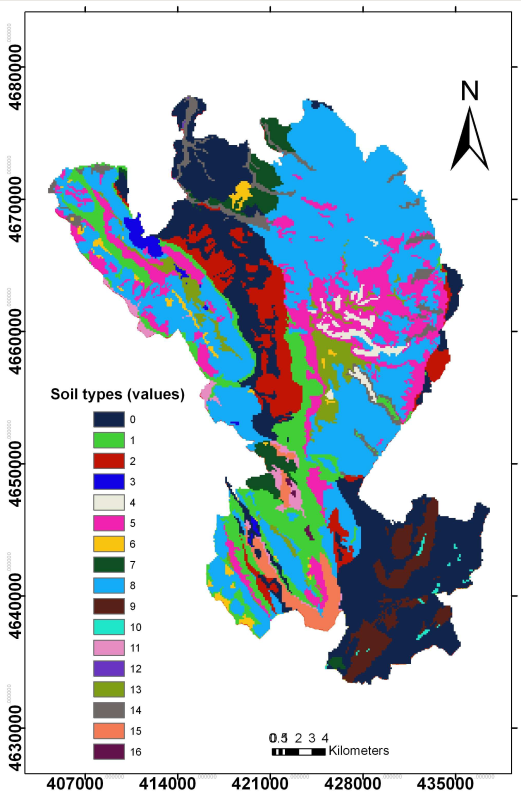
Appendix 2 : Average values of the forest parameters at each sample plots

Coordinates		Forest parameters							Distance
X	Y	DBH (cm)	Height (m)	Canopy cover	Crown diameter	Number of seedlings	Number of Saplings	Number of saplings	(from contagious forest

							(seed)	(stool)	edge) (m)
417718	4662412	23	47	40		40	3	14	137.7
430774	4659147	20	12	45		3	7	22	218.0
430917	4659448	26	13	70		56	3	18	421.2
421776	4661446	19	15	35		23	3	5	0.0
421776	4661446	20	16	15		4	0	3	0.0
421733	4661085	23	22	55		47	0	0	0.0
420997	4662327	22	11			12	0	3	597.9
421495	4661680	23	21	60		200	7	32	103.2
421495	4662618	16	11	40		25	8	35	168.1
421635	4663533	16	15	80		8	8	10	0.0
421635	4663533	19	16	40		11	7	7	0.0
431457	4659133	20	57	70		12	4	7	138.3
431301	4658899	17	27	30		4	1	2	32.3
424938	4672154	13	13	40		12	5	12	487.5
421856	4660559	19	22			70	0	0	141.3
421856	4660559	19	16	40	13	210	0	0	141.3
424331	4670072	17	18	60		160	0	0	115.3
424338	4670079	23	25	25	8	93	0	0	117.9
424137	4669850	16	23	60		220	3	6	71.4
424119	4669068	14	9	25	5	20	6	7	0.0
424113	4669885	16	28	60		254	2	7	111.2
424328	4669943	14	17	25	9	32	3	15	27.7
424207	4669994	21	15	30	13	35	11	29	157.6
424190	4670025	22	17	70		80	14	17	188.2
418163	4660870	13	13	25	5	0	5	8	189.7
418192	4660853	16	15	25	8.5	35	4	2	212.9
418248	4660821	19	14	20	8	25	0	0	264.1
418471	4660074	22	28	75		24	6	9	59.8
418483	4660111	21	18	70		21	0	0	93.2
419003	4659360	18	14	65		15	5	3	146.1
419050	4659423	21	14	40	12	6	2	6	224.3
425317	4669872	20	9	30	9.6	18	11	21	205.5
425295	4669883	16	7	25	7	0	0	0	209.4
425279	4669904	16	10	35	10	4	17	35	226.7
425240	4669953	14	8	20	7	0	10	27	256.9
425131	4669746	23	13	35	9	6	12	29	53.9
425095	4669793	17	9	40	9	0	6	37	100.4
424061	4669882	14	12	30	7	0	12	0	128.4
424670	4669707	16	17	30	7	5	0	0	69.5
421933	4650029	18	17	25	7	4	3	2	49.4
421963	4650045	20	11	45	11	2	5	0	55.9
421985	4650046	25	17		12	8	8	3	57.7
422056	4650045	21	14	55	15	5	3	2	73.8
424113	4650056	15	11	25	10	20	7	13	103.6
422153	4650137	19	13	30	15	16	4	6	193.5
422858	4649103	11	7		4	0	0	0	52.5
422861	4649046	19	11	55		5	15	8	99.7
422866	4649033	16	9		4.5	0	0	0	108.3
422871	4649014	18	11		6	0	0	0	122.3
422756	4650739	22	16	55	16	25	3	2	31.7
422756	4650720	22	19	50	25	0	3	10	45.8
422680	4650731	22	16	35	17	5	4	9	99.8
422442	4651205	18	14		16	11	14	12	254.3

422429	4651200	21	16	60	18	0	3	7	267.5
422336	4651202	17	6		6	0	2	3	271.0
422264	4651202	20	30		20	0	15	9	287.8
422137	4651711	17	10	55	17	0	14	17	35.2
422107	4651694	21	9	50	16	0	3	8	68.9
422095	4651611	28	12	60	18	8	5	7	125.3
422077	4651554	14	13	0	5	0	0	0	180.2
426470	4647852	14	11	30	6	0	6	18	60.0
426565	4647879	7	9		3	0	3	0	140.5
426476	4648481	19	8	35	10	11	5	2	263.1
426482	4648475	14	7	40	7	15	13	12	268.8
426514	4648437	18	10	70		21	7	53	302.3
426565	4648424	18	9	25	11	0	0	0	354.5
426648	4648366	16	16	25	7	0	8	25	445.1
426681	4648356	17	10	15	10	5	0	40	479.4
426738	4648337	26	12		6	0	0	60	504.9
435322	4641946	42	17	65		22	27	58	193.1
435399	4641897	13	6	50		0	0	0	239.9
434044	4664192	16	19	50		25	17	6	29.3
434059	4664235	19	18	40		29	7	4	50.4
434080	4664243	23	17	45		15	7	0	72.6
433749	4664332	16	15	40		15	15	10	0.0
433748	4664348	14	12	35		25	16	22	0.0
433770	4664362	14	13	25		7	8	22	0.0
433524	4664596	18	18	55		20	4	11	0.0
433497	4664644	18	11	40		13	4	3	0.0
433468	4664673	23	15	30		7	0	0	18.4
420603	4655653	17	15	40	9	68	3	4	0.0
420497	4658718	18	12	40	18	120	3	5	1109.3
420450	4658745	18	15	45	14	57	3	6	1085.6
420221	4658769	27	14	25	12	15	5	2	884.1
421137	4659021	23	10	25	11	12	0	2	479.6
421043	4658993	23	17	35	14	30	3	4	574.8
421013	4658977	20	17	37	14	23	1	0	608.8
420386	4659510	20	19	20	13	110	3	4	632.0
420361	4659524	17	14	25	15	105	3	1	635.4
420333	4659546	17	26	65		85	23	12	636.0
420001	4659409	32	33	70		93	10	9	969.9
419945	4659472	34	34	20	9	47	0	0	967.2
419945	4659472	29	19	15	6	9	0	0	967.2
419886	4659508	34	12	15	11	5	0	0	931.3
420328	4660014	26	19	60	12	32	0	0	368.3
420304	4660049	16	17	50	11	35	17	4	366.6
420285	4660524	21	15	65	20	31	7	4	239.6
420235	4660501	17	11	20	12	38	0	13	294.3

Appendix 3 Soil map of the study area



Value	*Area by pixel count (3 0m by 30 m)*	*LIV_2*	*Soil type*
0	178923	3.1	Clay_Marl and Sandy levels on hilly areas
1	74037	1.2	Current debris and alluvial cone and/or morane deposit
2	49066	1.3	Colluvial deposits mixed with debris /moraines
3	6124	2.1	Degraded patches on irregular steep slopes
4	10013	1.1	Moraine with debris deposition on lower slope to g
5	90901	4.2	Irregular slopes and cliffs with rock outcrops wit
6	8276	1.7	Residual deposition of rerra rossa on small plain
7	22259	4.4	Lower slope to very steep (no soil type indicated
8	281618	4.3	Irregular steep slopes (No soil type given)
9	27613	3.3	Calcareous marl on hilly to steep slopes
10	1612	3.2	Loose calcareous soils on steep slopes
11	9040	1.4	Debris on subplain to stepp slope or cone areas b
12	185	1.8	Alluvial bed area with sandy to gravely soil
13	25702	4.1	Locally active karst processes on high altitudes
14	23122	4.5	Landslides/ice induced cryoclastic surface on very
15	15462	1.6	River and lake/swamp residues of volcanic deposit
16	765	1.5	Loose moraine residues on undulating areas/moderate

Appendix 4 Description of the soil types

From book of the Park (Ente Parco Nazionale della Majella): aspetti pedologici

Translated by Laura Dente & Anton Vrieling, the English transilation is put in bracket

1. SISTEMA DI PAESAGGIO DELLE UNITÀ CONTINENTALI PLIO-QUATERNARIE. DETRITO DI FALDA, CONOIDI, DEPOSITI ELUVIO-COLLUVIALI, DEPOSITI MORENICI, DEPOSITI RESIDUALI (TERRE ROSSE) E DEPOSITI FLUVIALI

Aree di deposizione morenica e detritica di falda di “alta quota” situate nella parte basse dei circhi e delle valli glaciali. La morfologia della superficie è irregolare e la pendenza varia da dolcemente inclinata a moderatamente ripida.

English: (Areas of moraine and scree deposits of high altitude situated in the lower parts of the c and glacial valleys. The surface morphology is irregular with slopes varying from gentle to moderately steep.)

Aree di versante ricoperte da detrito di falda e di conoide recente o attuale e/o da depositi morenici. La morfologia si presenta prevalentemente regolare e la pendenza è da molto inclinata a ripida.

(Slope areas covered by scree and detritus of recent or present …. and/or by moraine deposits.

The morphology is mainly regular and the slope is from very inclined to steep.)

Aree di versante con copertura colluviale mista a detrito di falda e/o depositi morenici, che si appoggiano sul substrato terrigeno. La morfologia della superficie è irrregolare e la pendenza prevalentemente ripida. Prevalgono fenomeni gravitative superficiali e profondi.

English: (Slope areas with mixed colluvial cover with scree and/or moraine deposits, which leans over the soil sub-layer. The morphology of the surface is irregular and the slope is mainly steep. The superficial and deep gravitational phenomena are predominant.)

Aree delle falde detritiche e delle conoidi, da subpianeggiantie a molto inclinate, che bordano le conche intramontane.

English: (Areas of scree and of ... , from sublevel to very inclined, which border the intra-mountain basins.)

Rilievi collinari delle conche intramontane costituiti da morene residuali a morfologia regolare, e pendenza dei versanti da molto inclinata a moderatamente ripida.

English: (Hilly reliefs of the intra-mountain basins consisting of moraine remainders with regular morphology and side slope from very inclined to moderately steep.)

Aree pianeggianti delle grandi conche intramontane (Campo di Giove, Quarto Grande e Quarto Santa Chiara) con depositi fluviolacustri e/o palustri, depositi vulcanici o residuali (terre rosse).

English: (Level areas of the large intra-mountain basins (Campo di Giove, Quarto Grande e Quarto Santa Chiara) with fluviolacustrine and/or marshy deposits, volcanic or residual deposits (red soils).)

Aree di piccolo ripiani o depression morfologiche con depositi residuali (terre rosse), con pendenza da pianeggiante a dolcemente inclinata.

English: (Areas of little terraces or morphologic depressions with residual (red soils) deposits, with a slope from level to gentle.)

Aree di alveo fluviale con depositi prevalentemente ghiaioso-sabbiosi.

English: (Areas of fluvial beds with mainly gravel-sand deposits)

2. SISTEMA DI PAESAGGIO DELLE UNITÀ MARINE PLIO-QUATERNARIE. (CONGLOMERATI CALCAREI PASSANTI VERSO L'ALTO AD UN'ALTERNANZA PELITICO-CALCARENITICO-ARENACEA).

Versanti a morfologia spesso irregolare, da molto inclinati a molto ripidi, talvolta interessati da fenomeni di dissesto superficiale.

English: (Slope areas with often irregular morphology, from very inclined to very steep, sometimes with superficial landslide phenomena.)

3. SISTEMA DELLE UNITÀ TERRIGENE. ALTERNANZE ARENACEO-PELITICHE, ARGILLITI VARICOLORI E CALCARENITI

Rilievi collinari ad energia media e medio-elevata, con morfologia dolcemente ondulata ed ondulata, con versanti prevalentemente da molto inclinati a molto ripidi e fenomeni franosi (superficiali e profondi molto diffuse, localmente è presente erosion di tipo calanchivo.

English: (Hilly reliefs with average to average-high energy, with gently undulating to undulating morphology, with slopes mainly from very inclined to very steep with common occurrence of superficial and deep landslide phenomena, locally gully erosion is present.)

Versanti calcarei a bassa energia del rilievo, con pendenza ripida o molto ripida.

English: (Calcareous side slopes with low relief energy, with steep or very steep slopes.)

Rilievi collinari prevalentemente calcareo marnosi. Versanti prevalentemente da moderatamente a molto ripidi.

English: (Hilly relief mainly calcareous .... Slopes are mainly moderate to very steep.)

4. UNITÀ CARBONATICH DI PIATTAFORMA E RAMPA E CALCAREE O CALCAREO-MARNOSE DI TRANSIZIONE

Aree sommitali (creste, vette e parti alte dei versanti) dei rilievi, con pendenza da dolcemente inclinata a moderatamente ripida; localmente è presente erosione carsica.

English: (High areas (crests, summits and high parts of the side slopes) of reliefs, with slopes from gently inclined to moderately steep: locally carsic erosion is present.)

Versanti a morfologia irregolare e pendenza molto ripida. Prevalgono fenomeni di crioclastismo e di crollo.

English: (Side slopes with irregular morphology and very steep. Phenomena of …. and collapse are predominant.)

Versanti a morfologia e profile prevalentemente regolare e pendenza da ripida a molto ripida.

English: (Side slopes mainly regular morphology and profiles from steep to very steep.)

Versanti a bassa energia del rilievo con pendenza da molto inclinata a ripida, raramente molto ripida.

English: (Side slopes with low relief energy, from very inclined to steep, rarely very steep.)

Versanti molto ripidi o pareti verticali delle incisioni fluvial o torrentizie profonde (fore e gole del F.Orfernto, del F.Orta, vallone della Grotta del Cavallone ecc.). Dominano I fenomeni di crioclastismo e di crollo.

English: (Very steep side slopes or vertical face of deep fluvial or torrential incisions (fore e gole del F.Orfernto, del F.Orta, vallone della Grotta del Cavallone ecc.). Phenomena of .... and collapse are predominant.)

Appendix 5 Summary of the minimum climatic requirement by European beech forest

Author	***Precipitation***	***Temperature***	***Other factors***
De Candolle (1855)	≥ 7 rainy days per month	Mean winter temperature > − 6.25°C	–
Grisebach (1872)	–	–	Length of vegetation period (≥ 150 days)
Willkomm (1887)	–	Mean winter temperature – 6.25 to − 5°C	–
Hempel and Wilhelm (1889)	–	–	Length of vegetation period (≥ 150 days) maritime climate
Köppen (1889)	–	January temperature > − 3°C; February temperature > − 2°C	Length of vegetation period ≥ 8 months with temperature more than 10°C; winter ≤ 3 months
Mayr (1925)	≥ 250 mm during the vegetation period	Annual mean temperature 7 – 12°C, May to August 16 – 18°C	Air humidity May to August: ≥ 70%
Pax (1918)	≥ 660 mm per year	–	Elevation about sea level
Jedliński (1922)	-	≤ 3 months with temperature <0°C; May temperature >8°C, May temperature amplitude <10°C	Late frost (topography and site conditions may lesson frost impact)

Lämmermayr (1923)	Climate continentality (summer drought, duration of winter: ≤ 4 months)	-	-
Hueck according to Lämmermayr (1923)	–	January isotherm – 2.5°C	-
Enquist (1929)	Climate continentality (summer drought and winter frost), January temperature ≥ 4 months	≥ 217 days with temperature ≥ 7°C or 245 days with temperature ≥ 5°C	-
Steffen (1931)	≥ 500 – 750 mm per year	-	Length of vegetation period
Goetz (1935)	≥ 500 – 750 mm per year		Late frost, topography, site conditions
Hueck (1936)	Summer drought, precipitation: evapotranspiration ~ 100 – 120%	January temperature ≥ − 3°C	-
Hjelmqvist (1940)	≥ 550 mm per year	≥ 213 days with temperature ≥ 7°C or 216 days with temperature ≥ 6.5°C	Topography and no stagnic moisture
Tarasiuk (1999)	≥ 320 mm May to October	≤ 141 days with temperature <0°C	–
Hofmann (2001)	≥ 550 – 580 mm per year (European beech dominance)	July temperature <18 – 19°C (European beech dominance)	Mild winter, high air humidity

Appendix 6 Spatial extent of the distribution of beech forest in different regions of Italy

Region	Beech forests area (ha)	Other wooded land area (ha)
Piedmont	115501	404
Valle d'Aosta	1156	0
Lombardy	65681	441
Alto Adige	3781	0
Trentino	62247	360
Veneto	67196	374
Friuli V.G.	88812	1115
Liguria	37004	733
Emilia Romagna	100863	368
Tuscany	72260	361
Umbria	15115	0
Marche	17837	0
Lazio	71710	0
Abruzzo	122402	1731
Molise	14836	390
Campania	55197	0
Apulia	4661	0
Basilicata	26448	373
Calabria	77237	373
Sicily	15162	0
Sardinia	0	0
Italy	1035103	7023

Appendix 7 some of the remarks that had been made at some of the sample points

Plot s	Remark
1	Four patches, three of them on stone heaps, on gravel road side
2	Two patches, both on stone heaps
3	Three patches, all of them are stone heaps
4	On stone traces
5	one patch of trees on stone heaps
6	Trees are all exclusively on stone tracings, 10% canopy cover is by maple
7	All trees are exclusively on stone heaps
8	Two parches of trees on the edge of valley, seedlings facing valley (northern slope)
9	Trees along the valley, all seedling facing valley (northern slopes)
10	Tree patches on stone tracings
11	Trees on abandoned crop field
12	Trees on abandoned crop field (Stone tracings)
13	huge trees on stone tracing
14	patches of trees on abandoned farmland (surrounded by oak tree)
15	Beech trees in mixed forest patches in abandoned farm land
16	Beech trees within mixed forest
17	On stone heaps, all seedlings facing northern slopes
18	The ground is almost totally covered by seedlings, all seedlings facing northern slope
19	Three patches of trees all on stone heaps
20	single patch, on a stone trace, seedlings facing northern slope
21	single patch on stone heaps, seedlings northern slope
22	all seedlings N/west, single patch
23	Three patches, all seedlings in northern slope
24	single patch, on stone heaps, most saplings are from seedlings northern slope
25	all seedlings northern slope, all sapling not branch, on stone heaps, grazing land
26	single patch, on stone heaps
27	Stony habitat (rocky)
28	Two patches
29	Two patches trees
30	Two patches of trees
31	Single patch, on stone heaps, on stream side
32	All seedling on the northern slope
33	single patch
34	No seedling, all are saplings
35	Three patches, all on stone heaps
36	single patch, grazing land, on stone heaps, all sapling, maple on lower end
37	single patch, on stone heaps, all sapling, grazing land
38	on grazed grass land, scattered stones, dense patch
39	Dense patch on grazed grass land
40	Single patch of trees
41	Dense sapling in under grazed grassland, on road side
42	grass land habitat, all are at sapling stage
43	Single patch, under grazed grass land, all seedlings on the northern aspect
44	on stone heaps, no seedling, single patch

45	two patches making common canopy
46	Two close patches, seedlings under the canopy
47	two patches on stone terraces
48	single patch, on the edge of rail way
49	two patches, on gravel road side
50	single tree, on stone heaps, seedling under canopy
51	Only two trees
52	single patch, all sapling, grazing land
53	grazing land, trees on road side
54	Three patches, two trees
55	Single patch
56	single patch
57	Two patches, on stone heaps
58	single patch on grazing land
59	single patch
60	on stone heaps
61	single tree
62	looks in plantation
63	all sapling , looks in plantation
64	all coppice origin
65	5 close patches, all under canopy
66	Most saplings are saplings are from coppiced ruminants, along water path
67	along stream line, under grazed grass land
68	along stream line, saplings from coppiced ruminant
69	on stream side and mainly from coppice ruminant
70	on terraced heap of stones
71	Coppiced single patch
72	on stone heaps
73	Two patches on stone heaps
74	Seedling exclusively on northern slopes
75	seedlings in all direction except in south
76	seedlings in all direction, saplings northern slopes
77	on stone terraces
78	30% maple by composition

Appendix 8 Average annual rainfall and temperature in different stations of Majella (1960-1994)

STATION	*ALTITUDE (M)*	*AVERAGE TEMPERATURE (^{O}C))*	*AVERAGE PRECIPITATION(MM)*
SULMONA	420	1 3.81	624. 77
GUARDIAGERELE	577	13. 67	840. 31
S. EUFEMIA	870	10. 73	1456. 45
PESOCOSTANZO	13,95	8.11	919. 15
PASSOLANCIANO	14, 70	8.69	1431. 67
PALENA	767	11. 94	964. 86
POPOLI	260	13.45	685.32
CAPRACOTTA	1400	8.68	1079.86
LANCIANO	283	14. 62	788. 0