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PHYTOGEOGRAPHY OF *QUERCUS SUBER* L. IN LAZIO (CENTRAL ITALY): A CAUSALISTIC APPROACH

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Abstract
A descriptive statistical approach to the causalistic distribution of *Quercus suber* in Lazio (Central Italy), based on presence/absence data and mean values of an array of environmental variables standardized on a geographical 6,9 x 5,5 Km grid, shows that only temperature, precipitation, elevation and slope are significant. At this scale, soil conditions and aspect are apparently no limiting factors to the colonization ability of the species. A simulated potential range, based on this parameterization, identifies a larger area than the one occupied by the species today. It suggests that competition and human disturbance might account for the large gaps and discontinuities in the real range. Since inland disjunct outposts still lie either outside or at the boundary of this simulated range, their establishment is likely to have originated under macroclimatic conditions different from the present day ones.

Key Words - *Quercus suber L., quantitative phytogeography, potential range*

INTRODUCTION

In middle Italy, *Q.suber* (nomenclature and authorities to scientific names follow Pignatti, 1982) is a widespread tree in the districts of the region Lazio between 42°48' and 41°12' North, on the western side of the Apennine ridge, facing the coast of the Tyrrhenian Sea. The species is scattered in stands and isolated populations within a coastal belt, at lower elevations, mostly in areas on leached, acidic soils of any type of bedrock, where Mediterranean climatic conditions rule.

Common associates (cfr. Pignatti, 1998) are the species of the Mediterranean, seasonally dry, sclerophyllous oak forests and maquis, especially woody *Ericaceae* (*Erica arborea, Arbutus unedo*) and *Myrtus communis*. Disturbed or destroyed stands are usually detected by populations of *Daphne gnidium*. It extends also further inland into the domain of the deciduous forest dominated by *Q. cerris,* reaching sites where *Castanea sativa* and *Erica sp.pl* or *Arbutus* occur, as extreme outposts of a meso-thermophilic vegetation and flora. In these cases sub-Mediterranean *Genisteae* take over in the structure of the understorey. Its coenological behaviour in the region is unclear. *Q suber* does not seem to be a late successional species in any local climatogenic vegetation types (cfr. Pignatti, 1998, De Lillis *et al*., 1986), suggesting a successful competitive ability only in permanent woodland communities of lower-com

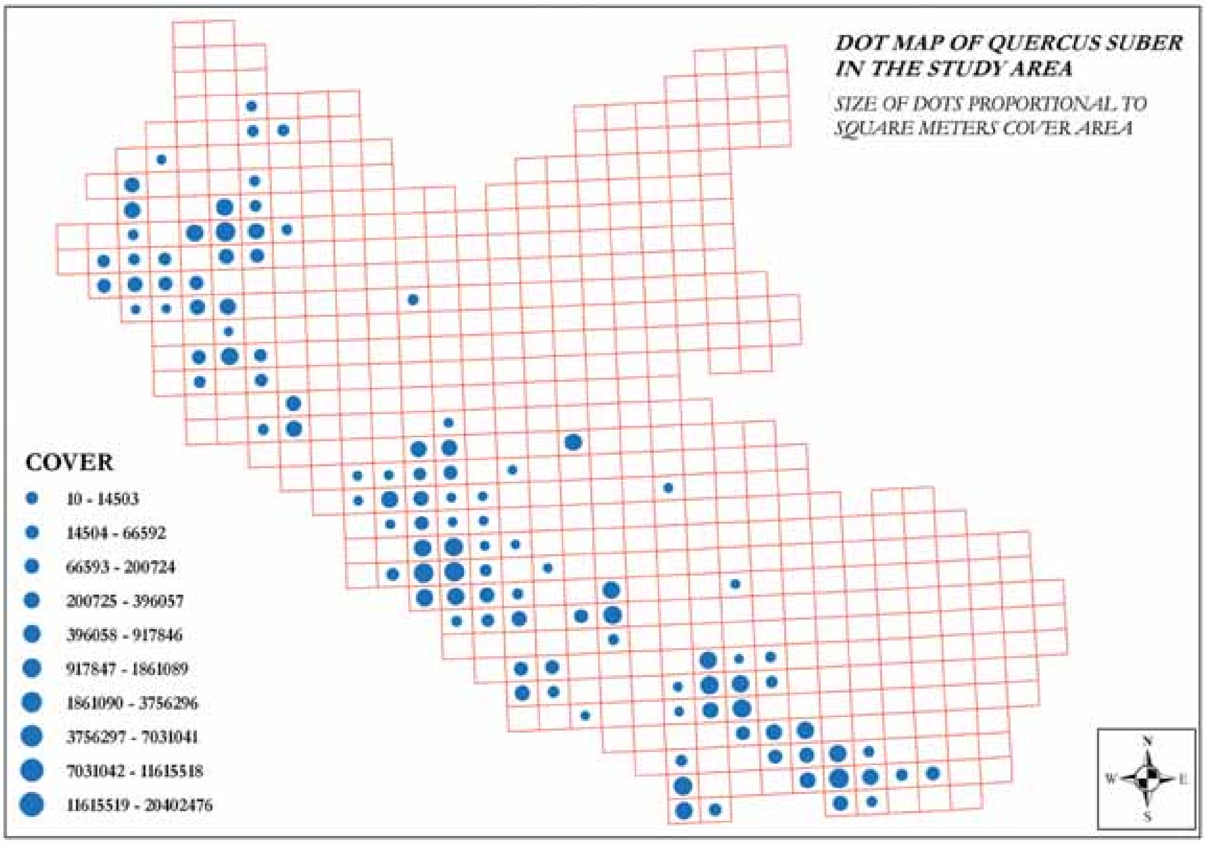


Fig 1 - Dot map of the range of *Q. suber* in the study area

petition sites, along with an enhanced resilience to fire disturbance.

Q suber hybridizes with *Q. cerris*, giving origin to a cline of transitional, morphologically heterogeneous, phenotypes *(Q. crenata)*. This happens wherever both species meet, a common pattern in Lazio, where disjunct enclaves of either evergreen or deciduous broadleaved trees are scattered throughout the altitudinal gradient. *Q. crenata* grows also further inland, where populations of the "pure" parent *Q.suber* do not reach. (cfr. Spada *et al.*, 2006).

Human exploitation of the cork has a long history. In some areas of the Roman Campagna, pastured savanna-like stands in an agrosilvopastoral landscape, similar to the Iberian *dehesas*, have therefore developed. Nevertheless, there is no evidence for an active human propagation of the species in order to supply the cork-trade. Assumed "cultivation" in the past rather suggests a type of management solely aimed to prevent competition from other coexisting, late successional trees, using selective cutting at the expense of the evergreen *Q. ilex*, of deciduous oaks and, sometimes, chestnut.

Though widespread throughout the coastal districts of Lazio, *Q. suber* exhibits an uncommonly discontinuous range in this region.

Particularly crucial are the disjunct stands on leached soils on limestone, aligned, further inland, along the ancient coastal *falesias* of the Pliocene transgression. These are located at the inland edge of the zonal belt of Mediterranean ecosystems and the belt of the deciduous forests or are embedded in the latter (Fig. 1), suggesting the importance of range fluctuations in time.

mean annual Temperature	°C
mean annual Precipitations	mm
Lang´s pluviofactor	P(mm)/T(°C)
mean Slope	degrees (angle of inclination)
mean Aspect	compass degrees
mean Elevation	m a.s.l.
nutrient availability	adimensional semiquantitative scale
mean permeability	adimensional semiquantitative scale

Tab. 1 - Variables

Since its ecological demands are traditionally inferred from inspection of the total range, with focus on a silicicolous behaviour (cfr. Pignatti, 2005), it is still controversial whether the local gaps are dependent on natural habitat discontinuities or biotical factors, as competition and human impact. To address this question, a parameterization of the species is here attempted in order to detect elements useful to the interpretation of the developmental history of its range.

MATERIAL AND METHODS

The study area is limited by the administrative boundaries of the region Lazio (Central Italy). The range of *Q. suber* in the area has been represented on the 533 cells (each 37,95 km^2) of a geographical 6,9 x 5,5 Km grid according to the Lazio Regional Grid, as a dot map of abundance (Fig. 1), the dot size is indicative for the relative cover area in the cell, each square corresponding to one sheet of the Carte Tecniche Regionali (CTR at 1:10.000 scale). These squares are the Operational Geographic Units (O.G.U.s) *sensu* Crovello (Crovello, 1981) used in Quantitative Phytogeography. Dot maps are a useful way of conveying the distribution pattern of a species across a geographical unit and its relationships with environmental factors

The distribution map is original. Sources are the existing botanical literature on the region Lazio and own records from field inventories, carried out during the period 2004-2006. Ancillary sources have been found in the *Herbaria* at the Dipartimento di Biologia Vegetale in the University of Roma "La Sapienza" (*Herbarium Generale, Herbarium Romanum, Herbarium Anzalone et Herbarium Beguinot*).

The parameterization of *Q. suber* uses descriptive statistics applied to a data set based on a selection of climatic, geo-lithological and topographical variables considered predictive of the physical environment of each cell (Tab.1).

Gridded estimates of these environmental parameters were calculated as follows.

Values of mean annual Temperature and mean annul Precipitation have been extracted from time-series of 35 weather stations homogeneously scattered throughout the study area (Hydrological Annals: *Annali Idrologici del Servizio Idrografico di Stato, della Regione Lazio e dell'Ufficio Centrale di Ecologia Agraria - UCEA*) spanning over a 30 years period. A geostatistical approach (Kriging, a set of linear regression routines used to interpolate data points) was used in order to obtain isolines of the parameters T and P.

On this basis, a surface geostatistical analysis (Cell Statistics) produced mean values for annual T and P for each cell of the grid all across the study area.

Also computed mean annual values and the Lang's rain factor (the relationship between rain and the annual temperature) have been processed by Kriging and Cell Statistics.

A Digital Elevation Model (DEM, 20 m resolution) has been used to produce average values within the quadrates for elevation, slope and aspect. These last two values have been extracted by a specific Spatial Analyst tool in an open source GIS Software (Surface Analyst Tool and Cell Statistics Tool).

An index of "nutrient availability" has been used to quantify the pedological diversity throughout the region. For each cell, a value of average potential soil fertility, based on a 3 degrees adimensional semi-quantitative scale, transformed by the geostatistical processing in 10 classes, has been extracted on the basis of the % cover of each lithotype.

An index of "permeability of the parent material" has been used to quantify changes in soil water drainage due to the lithological diversity throughout the region. For each cell, a value of average water availability, dealing with porosity and permeability characteristics of the different parent material, based on a 10 degrees adimensional semiquantitative scale, transformed by the geostatistical processing in 20 classes, has been extracted on the basis of the % cover of each lithotype.

Descriptive Statistical analysis has been applied to define and characterize the significant parameters to identify the potential cells.

The whole data set (a matrix of 8 environmental parameters for each of the 533 cells) has been analysed comparing the statistical distribution of the cells in which the cork-oak is recorded (green histogram) to the whole set of cells (red histogram).

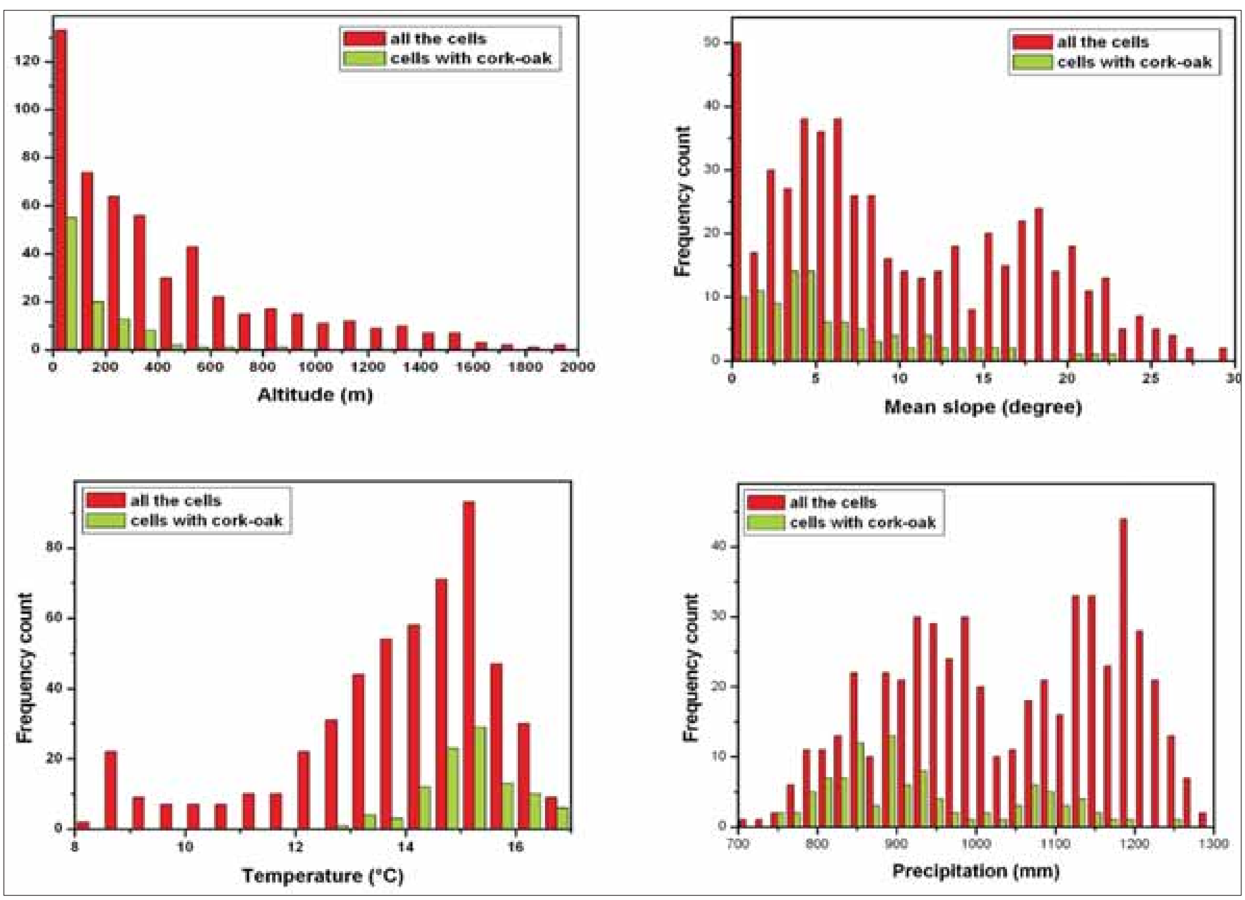


Fig 2) Descriptive Statistical analysis applied to the distribution of the four significant parameters: T, P, Slope and Elevation

In order to investigate the potential range of *Q. suber* we define a BTL (Boolean Threshold Logic) algorithm as a framework to model the fitness.

RESULTS AND DISCUSSION

The output of Descriptive Statistical analysis shows that only T, P, slope and elevation are significant environmental parameters in controlling the distribution of *Q. suber* within the study area. In these cases, each statistical distribution of the cells with cork-oak displays different trends from the ones of the whole set. (Fig. 2). At the other hand the two subsets exhibit similar trends in all other cases.

On the basis of BTL, we characterized a cell as "potential cell" on the basis of the following algorithm ("Algorithm of *Q.suber* in Lazio"):

```
DO i=1,n:
    IF
            Altitude(i) LESS THAN <Mean Altitude>
        AND
            Slope(i) LESS THAN <Mean Slope>
        AND
            Precipitation(i)LESS THAN <Mean Precip
            itation> + σ/2
        AND
            Temperature(i) MORE THAN <Mean tem
            perature>
    THEN
        "Cell(i) is a POTENTIAL CELL"
    ELSE
        "Cell(i) is NOT a POTENTIAL CELL"
    END.
```

Where n = 533 (cells) and σ = standard deviation.

The threshold for each considered parameter is chosen on the basis of the descriptive statistical analysis (see Fig. 2) as the mean value of the statistical distribution with the exception of P which presents a clearly bimodal curve.

According to the output of this analysis, the parameterization of *Q. suber* in the area on the basis of the environmental variables predicts that the cork oak stands are best developed in the ≤ 1109,2 mm rainfall, forest/woodland region, within OGUs where mean annual T is higher than 13,8 °C, where mean elevation does not exceed the isoline of 425,6 m a.s.l. and the mean slope reaches max. 10,2 degrees.

The changes of the significant environmental variables along the geographical and topographical gradients within the study area, show the pattern illustrated in Figures 3, 4, 5 and 6.

This suggests that climatic and topographic constrains overrule at this scale the importance of the two edaphic factors (mean nutrient availability and mean permeability) (Fig. 7).

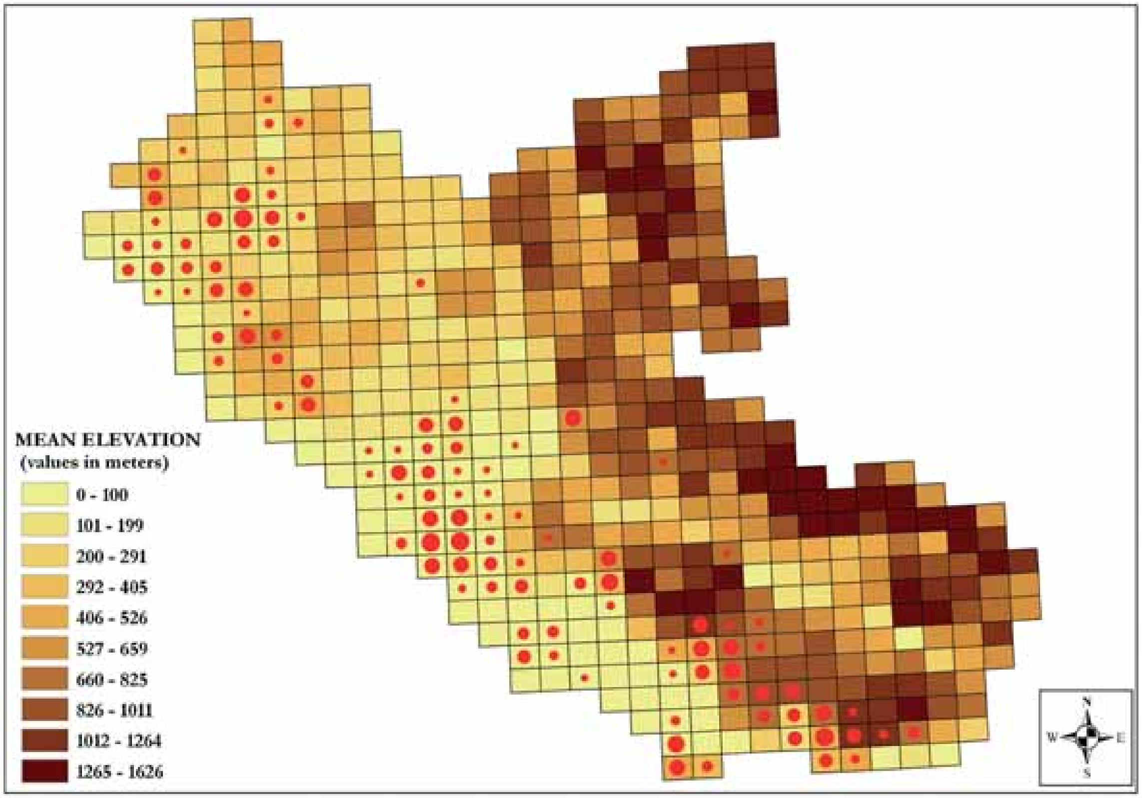
This is against what is traditionally argued about the cork oak, which is considered to be paradigmatic for Mediterranean woody species restricted to outcrops of siliceous bedrock (Pignatti, 2005).

This is by no means suggesting that leached soils or siliceous bedrock are no crucial ecological demands for the competitive ability of *Q. suber*. It means that at the OGUs scale of this investigation, parent material is not a predictor of the colonizing ability of the cork oak, provided the lack of macroclimatic constrains.

Nevertheless an inspection of each map of the geographical pattern of the four significant variables describing the environmental envelope of *Q. suber*, shows that a number of cells with records of the species (Fig.1), lie outside the ranges of one or more of the variables obtained by the parameterization.

Since the simultaneous occurrence of the four previous environmental conditions has been assumed as crucial for the detection of suitable cells, a predictive model for the detection of the potential range of the species in the study area can be produced on this basis (Fig.8).

In this map, the gaps in the continuity of the range of the cork oak in Latium are apparently filled, suggesting full permeability of the cells to the spread and colonization of the cork oak under the ruling climatic conditions. The simulated potential range



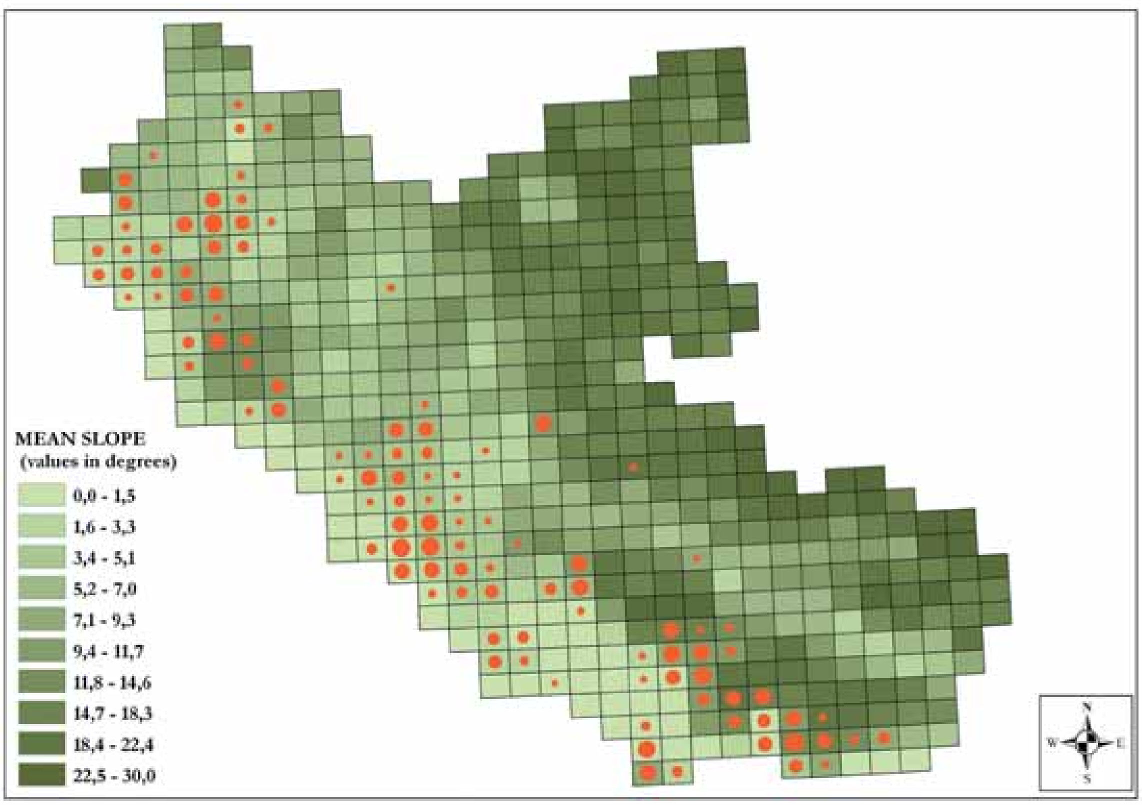
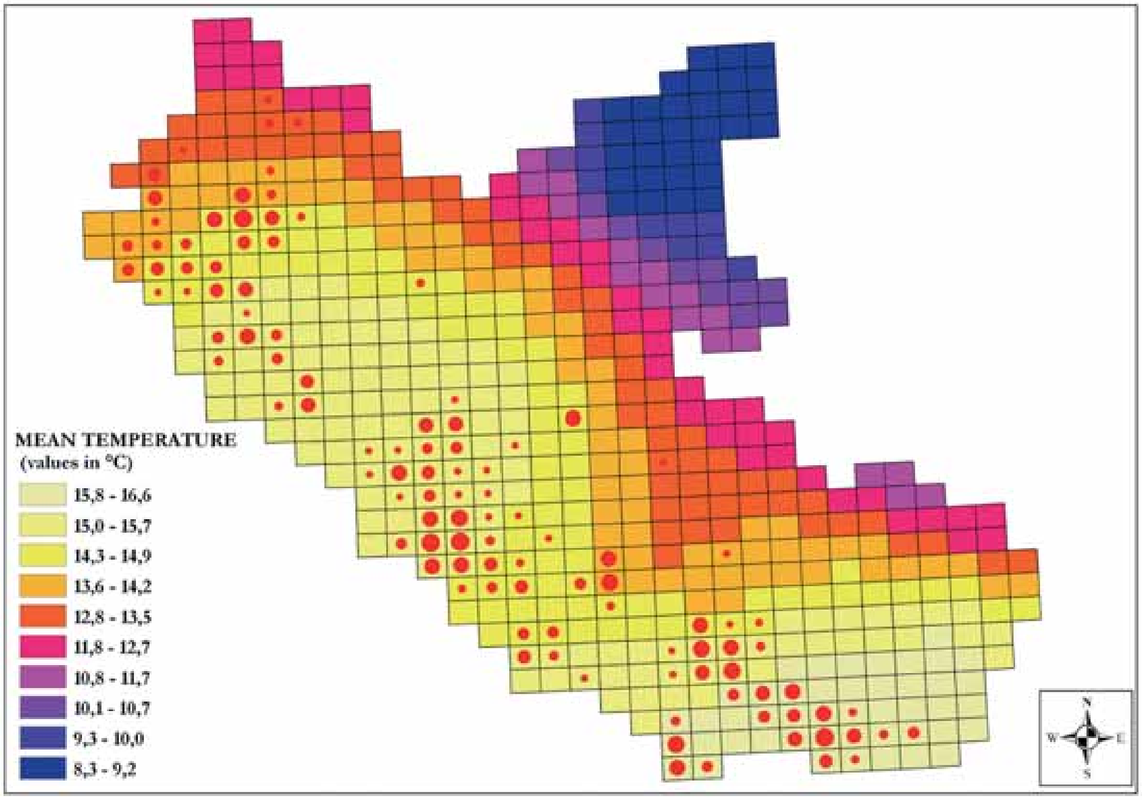


Fig. 3, up - Environmental variable along the geographical and topographical gradients: Elevation
Fig. 4, down - Environmental variable along the geographical and topographical gradients: Slope



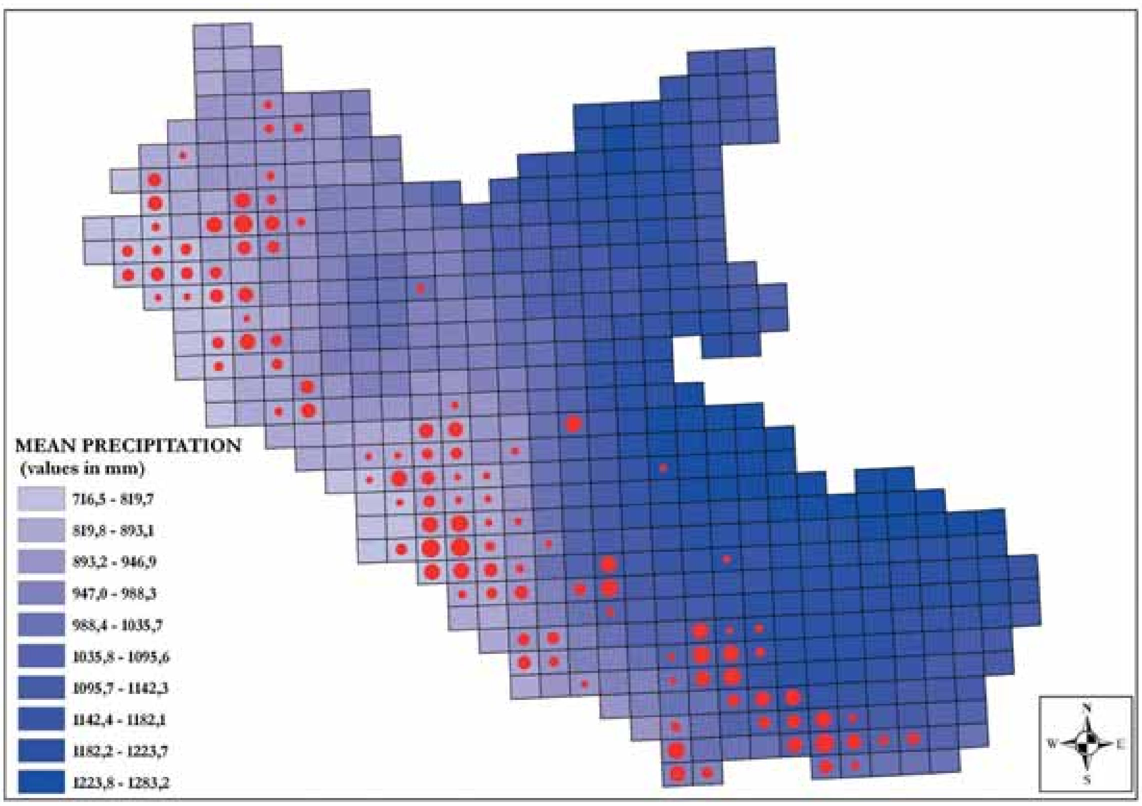


Fig. 5, up - Environmental variable along the geographical and topographical gradients: Temperature
Fig. 6, down - Environmental variable along the geographical and topographical gradients: Precipitation

identifies a larger area than the one occupied by the species today. It reaches further inland in the N part of the Roman Campagna and encompasses most of the present day outposts scattered along the piedmont of the Apennine chain.

The parameterized slope requirements suggest that at least some of the larger gaps observed in the real range on flat lowlands, might be explained as result of the historical human impact (deforestation in the Roman Campagna and in the Pontine marshes). Anthropogenic deforestation apparently affected the uniformity of a pristine spread, considering its rarity or absence in the intensively cultivated subcoastal plains of the Southern Maremma, the Roman Campagna and of the former Pontine marshes. Nevertheless scattered individuals survive here along streams and along the oldest drainage channels, suggesting unusual persistence ability despite of the intensity of the agrarian colonisation (it resprouts from stem buds as only tree species in Europe: Pausas *et al.*,1999). Since the species is able to withstand a high-frequency fire regime (Trabaud *et al.*, 2002) the effects of human disturbance could have been partially mitigated, during the history, by the economic interest in a widespread availability of the cork.

Some disjunct outposts located outside the predicted potential range correspond to OGUs lying within the domain of either too elevated or steep areas (Monti della Tolfa, a subcoastal inselberg N of Rome), too cold (Monte Rufeno, in NW Lazio), too elevated and rainy (a site with a few individuals on an isolated limestone outcrop at the NE piedmont of Monti Lepini, SE of Rome), or too elevated, too rainy and steep (the few individuals isolated in a *Q.pubescens* woodland at the site of Bellegra, on the SW slopes of Monti Prenestini), too rainy and cold (population at Casamari, S slopes of Monti Ernici), both in the territories E of Rome.

Assuming as unrealistic the cases of accidental long distance dispersal events starting from a proximate core-area or of artificial introduction (on the basis of local interviews), this suggests that these sites are not *in equilibrium* with the present environmental conditions at these latitudes. They rather persist thanks to compensating local factors determining spots of low-competition sites scattered sometimes long into the domain of an unfavourable range of one or more of the parameterized variables. Stressing the importance of T on the control of the distribution of *Q.suber* in the region, these sites can be assumed to act as real *refugia*. In this case, the outposts located outside the simulated potential range might be considered as remnants of an earlier penetration of the species further inland and at higher altitudes, providing a parallel shift of the belt of higher temperatures.

These outposts show therefore a pattern of isolation which suggests an overall retreat of the range of the species from a previous inland front, established at the time when a macroclimate with higher T and lower P than today ruled in the inner part of the region. This environmental scenario might have provided the crucial threshold necessary to support a late successional character of *Q. suber* within a species pool of less mesophytic Mediterranean or Submediterranen associates.

Its local range–bulk, at that time, might therefore have been the area of a zonal community dominated by *Q. suber*. On the other hand we know from its coenology (De Lillis *et al.*, 1986), that the competitive ability of the species is today low when compared to its common arboreal, late-successional associates. The cork oak is mostly restricted to permanent communities scattered on oligotrophic-distrophic soils, which also provide favourable sites for the persistence of many other less competitive species.

It is no real forest tree but rather a tree of a savanna-like biome, considering some of its functional traits (the cork-oak is the most light-demanding *Quercus* in Italy and the architecture of its crown is typically adapted to open arboreal groves.

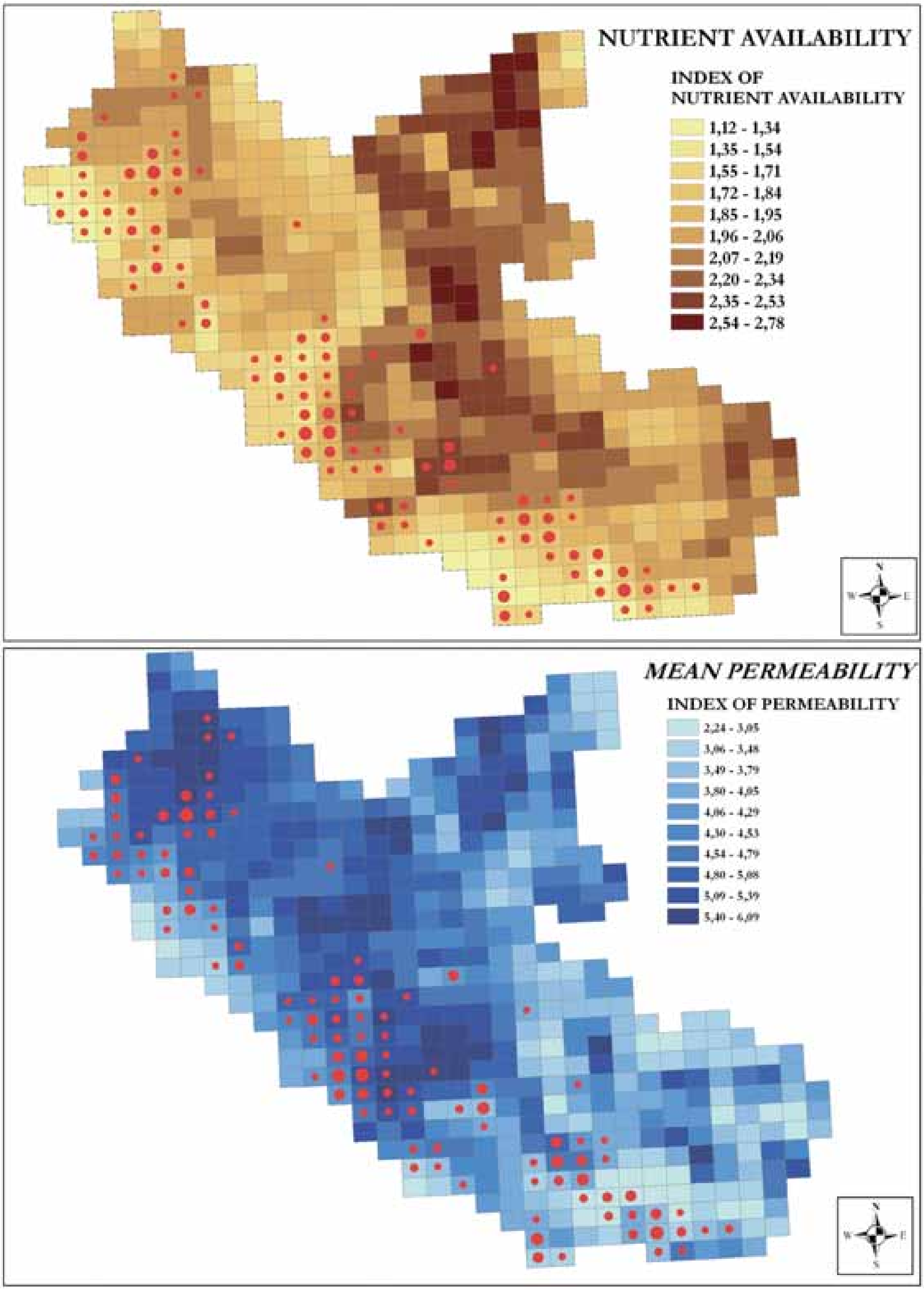


Fig. 7 - Edaphic variables : permeability and nutrient availability

This is supported by the frequent occurrence in the stands of several treelets of an open woodland, often thermophilic relics (*Cercis siliquastrum, Pistacia terebinthus, Carpinus orientalis, Styrax officinalis, Genisteae, Ericaceae*), now merely successional in both evergreen and deciduous forest communities of the region.

The suggested permeability to the colonization of *Q. suber* of the study area today, is therefore only true for what is concerning the macroclimatic envelope. This is supported also by its requirements of sites at low altitudes and on quite even morphology pointed out by the parameterization. This means that while the colonisation at the landscape scale is the legacy of a previous environmental scenario, the present day pattern of scattered stands with character of permanent community, is likely to be the result of the present day climatic constrains.

CONCLUSIONS

On the basis of this parameterization, the present day range of *Q. suber* seems to be mainly determined by macroclimatic constrains (P and T). Among the topographical factors, only elevation and slope are crucial.

At this scale of the OGUs, the model seems to be independent from the edaphic conditions. It does not say anything about the site preference of the species, but suggests its potential capacity to find at present suitable ecotopes within the cells. It simply suggests that the area of the each square is prone to the colonization and establishment of the cork oak, with no reference to competition patterns with other arboreal late or early successional specie.

The human impact might account for local extinction in some districts.

Its present day overall scarcity at the landscape level despite of the spatial connectivity suggested by its simulated potential range, rather shows the importance of competition by other trees in determining its coenological behaviour under the ruling climatic conditions. The processes of range fluctuations revealed by the comparison between the potential simulated range and the distribution of the present day populations suggest a general widespread ongoing process of range reduction in the inner part of the region. Since many inland disjunct outposts lie either outside or at the boundary of this simulated range, their establishment is likely to have originated under macroclimatic conditions different from the present day ones.

The outlined potential range allows the assessment of a relative chronosequence of events in the changes of the local plant cover.

Considering that, according to the model, higher T and lower P should trigger its establishment further inland, the climatic scenario which might account for these changes and the spread of a favourable savanoid biome in the area, suggests a protocratic or, more generally, a terminocratic (*sensu* Walter *et al.*, 1969) behaviour for the cork oak at the time scale of the last glacial cycle. The climatic conditions at the Holocene *optimum*, apparently did not account for the spread of the species further inland.

The simulated potential range is only apparently zonal. Despite of the real spread of the cork oak on different parent materials (ignimbrite, limestone and sand), there is evidence for a former, "fossile" zonal behaviour.

The spatial patterns of the potential range, reveal that inland stands in the SE of the region Lazio are likely to be border-line stands.

Some local "classic" sites are therefore either extrazonal ones or on the way to become relic ones.

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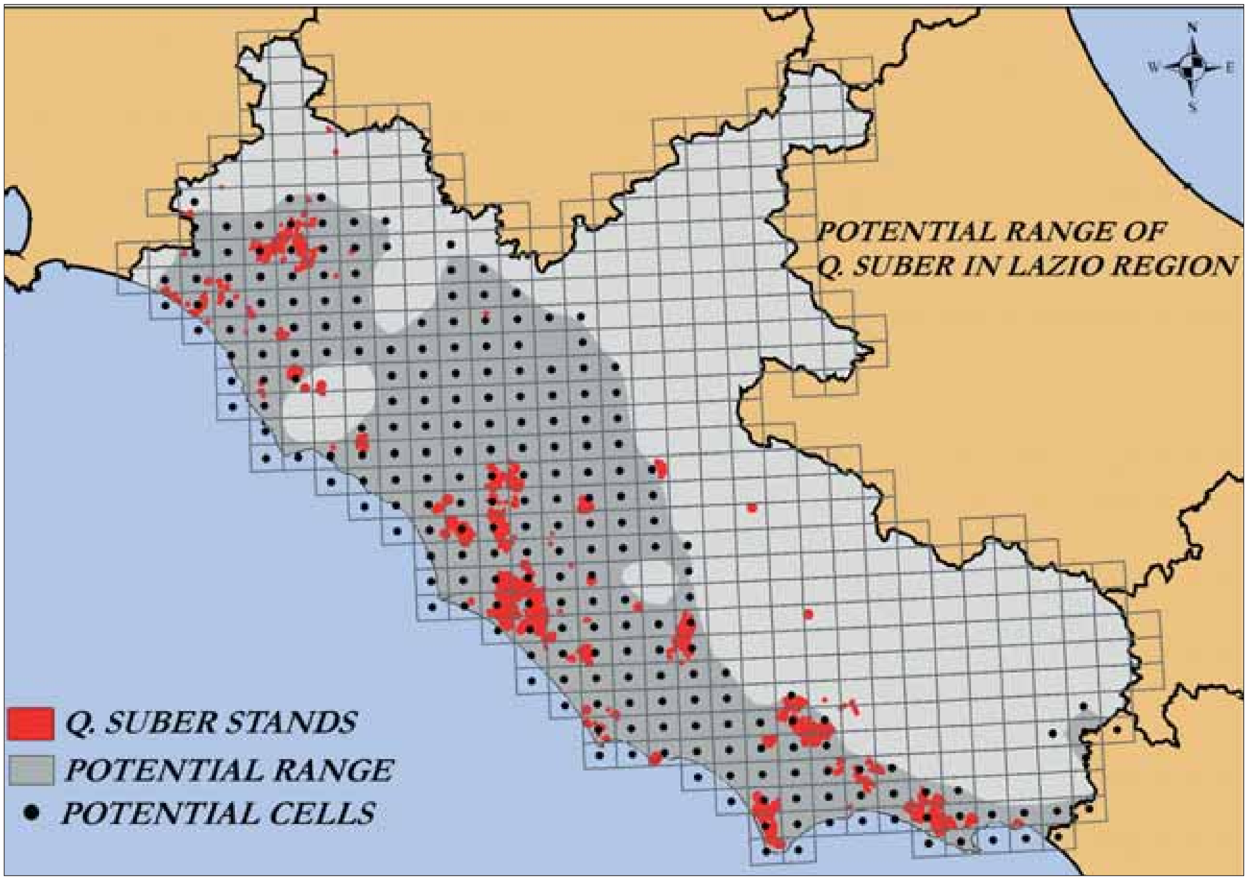

Fig 8) Potential range of *Q. suber* in Lazio according to BTL

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