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ORIGINAL ARTICLE

## Bioclimatic analysis in a region of southern Italy (Calabria)

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### Abstract

In this study, an analysis of precipitation and temperature data has been performed over 67 series observed in a region of southern Italy (Calabria). At first, to detect possible trends in the time series, an analysis was performed with the Mann–Kendall non-parametric test applied at monthly and seasonal scale. An additional investigation, useful for checking the climate change effects on vegetation, has also been included analysing bioclimatic indicators. In particular, Emberger, Rivas-Martinez and De Martonne indices were calculated by using monthly temperature and precipitation data in the period 1916–2010. The spatial pattern of the indices has been evaluated and, in order to link the vegetation and the indices, different indices maps have been intersected with the land cover data, given by the Corine Land Cover map. Moreover, the temporal evolution of the indices and of the vegetation has been analysed. Results suggest that climate change may be responsible for the forest cover change, but, given also the good relationship between the various types of bioclimate and forest formations, human activities must be considered.

**Keywords:** *Bioclimatic indices, vegetation distribution, precipitation, temperature, trend analysis, southern Italy*

### Introduction

The notion of climate, as one of the leading environmental factors governing the distribution of plants and vegetation, has long been recognized (Von Humboldt & Bonpland 1807; Grisebach 1838). The importance of climate studies through its main features, such as temperature, precipitation and evapotranspiration and their interactions, has been indicated in different vegetation or plant geography surveys (Tuhkanen 1980; Box 1981; Walter 1985; Woodward 1987; Prentice 1990). In order to quantify and determine the influence of climate on plants and vegetation, simple variables can be used. However, it has been pointed out that these variables alone do not give enough information and their combination in the form of climatic indices is considered to be useful (De Martonne 1926; Tuhkanen 1980).

The Mediterranean region lies in a transition zone between the arid climate of North Africa and the Temperate and rainy climate of Central Europe and it is affected by interactions between

mid-latitude and tropical processes. Because of these features, even relatively minor modifications of the general circulation, e.g. shifts in the location of mid-latitude storm tracks or sub-tropical high pressure cells, can lead to substantial changes in the Mediterranean climate (Giorgi & Lionello 2008). This condition makes the Mediterranean area a potentially vulnerable region to climatic changes as induced, for example, by increasing concentrations of greenhouse gases (e.g. Lionello et al. 2006; Ulbrich et al. 2006). The Mediterranean climate is characterized by mild, rainy winters and warm, dry summers. These special and unique climatic conditions have great influence on natural physical processes, including soil formation, ecological features, landform development and karst topography as well as human activities (Efe 2005; Atalay 2006; Efe & Greenwood 2007; Kaniewski et al. 2007). Although plant species and communities differ between regions, the dominant vegetation, in the Mediterranean basin, is evergreen woodland with evergreen sclerophyllous shrubs and trees like carob

tree (*Ceratonia siliqua* Linnaeus), cork oak (*Quercus suber* Linnaeus), holm oak (*Quercus ilex* Linnaeus), mastic tree (*Pistacia lentiscus* Linnaeus), kermes oak (*Quercus coccifera* Linnaeus) and fodder shrub (*Medicago arborea* Linnaeus). These species are resistant to summer droughts, have deep rooting systems and a high resprouting capacity.

In the Mediterranean Basin, there have been numerous phytogeographical studies based on the analysis of climatic parameters and many bioclimatic indices have been formulated (De Martonne 1926; Emberger 1930; De Philippis 1937; Rivas-Martinez 1993, 1996).

In Italy, the first phytoclimatic assessment, planned by De Philippis (1937) within national boundaries, used some specific climatic variables, based on precipitation and temperature data, for the study of forest vegetation. At the same time, De Philippis (1937) created a detailed kind of classification, based on the same abiotic parameters, which highlighted a clear zonation of terrestrial vegetation differentiated in *Lauretum*, *Castanetum*, *Fagetum*, *Picetum* and *Alpinetum*. In the last decades, the phytoclimatic knowledge is rapidly improved using some new climatic indices suggested by Thornthwaite and Mather (1957), Montero De Burgos and Gonzalez Rebollar (1974) and Rivas-Martinez (1993). Blasi (1996) characterized the Italian bioclimate by considering 390 thermopluviometric stations distributed along the Italian peninsula. In particular, using monthly mean temperatures and precipitation and through a principal component analysis, 26 climatic types (with subtypes) have been defined. This work has been upgraded by Blasi and Michetti (2005) which identified the phytoclimatic region distribution in Italy (Mediterranean, Temperate, Transitional Mediterranean and Transitional Temperate phytoclimatic regions) and evaluated a phytoclimatic map of Italy with 28 types of phytoclimate. At regional scale, the phytoclimatic studies were performed in some regions, such as Sardinia (Arrigoni 1968), Tuscany (Arrigoni 1973), Umbria (Venanzoni et al. 1996), Lazio (Blasi 1994), Campania (Iovino & Menguzzato 1991), Apulia (Forte & Vita 1998), Basilicata (Cantore et al. 1988) and Sicily (Terzi et al. 2006).

In Calabria, the first analysis on bioclimatic patterns and on geographic distribution of forest vegetation types was carried out by Ciancio (1971). This study, based on the traditional phytoclimatic classification by Pavari, distinguished four bioclimatic areas covering the following regional areas in percentage terms: *Lauretum* hot subtype (52.5%), *Lauretum* medium-cold subtype (26.5%), *Castanetum* (10.7%) and *Fagetum* (10.3%). Pellicone et al. (2014) updated the analysis of Ciancio (1971) using both new variables and new data for the period

1972–2010 and subdivided the region into three main belts: *Lauretum*, 74.4% of the area (cold 9.0%, medium 29.0% and warm 36.4%); *Castanetum*, 15.2% of the surface (cold 10.3% and warm 4.9%); *Fagetum*, 10.4% of the area (cold 1.2% and warm 9.2%). In the analysis of the Italian bioclimate, Blasi (1996) evaluated that the Temperate and the Transitional Temperate regions are distributed all along the Italian peninsula reaching Calabria. In particular, a typical Mediterranean climate has been detected in the lower areas of the region, while a Temperate one has been evaluated for the higher areas (over 1100 m a.s.l.).

Phytoclimatic studies sometimes include indices given by the combination of simple climate parameters such as the mean annual temperature or precipitation. Other times, these surveys may also involve radiation, wind speed, light hours, altitude, latitude, etc. Different studies highlight changes in precipitation and temperature spatial-temporal behaviour, especially in the Mediterranean basin. In particular, several researches have been carried out to investigate trends in annual and seasonal precipitation, at a large scale (Kutiel et al. 1996; Piervitali et al. 1998; Xoplaki et al. 2006), and for entire nations or regions (Esteban-Parra et al. 1998; De Luis et al. 2000; Feidas et al. 2007; Río et al. 2011). Long precipitation records have been investigated in northern and central Italy (Montanari et al. 1996; Demichele et al. 1998; Brunetti et al. 2006b), in southern Italy (Palmieri et al. 1991; Brunetti et al. 2004; Brunetti et al. 2006a; Samui et al. 2011b) and, particularly, in the Calabria Region (Coscarelli et al. 2004; Buttafuoco et al. 2011a, 2011b; Caloiero et al. 2011a; Brunetti et al. 2012; Ferrari et al. 2013; Caloiero et al. 2014; Sirangelo et al. 2015). With respect to the temperature, the majority of these studies have been conducted at large spatial scale (Easterling et al. 2000; Klein Tank & Können 2003; Vose et al. 2004; Vincent et al. 2005) or at national spatial scale (Domonkos & Tar 2003; Brunetti et al. 2006a), while few studies have been made at local scale (Brunetti et al. 2004; Piccarreta et al. 2004; Buttafuoco et al. 2010; Caloiero et al. 2014).

This research aims at analysing the relationship between climate change and forest cover in the Calabria Region (southern Italy). With this aim, a study of precipitation and temperature trends in the Region was performed. Then, the same data-set has been used for the investigation of some of the most common bioclimatic indices and, in order to link the vegetation and the indices, the indices maps have been intersected with land cover data. Finally, the temporal evolution of the indices and of the vegetation have been analysed in order to verify if changes in forest cover can be linked to climatic changes.

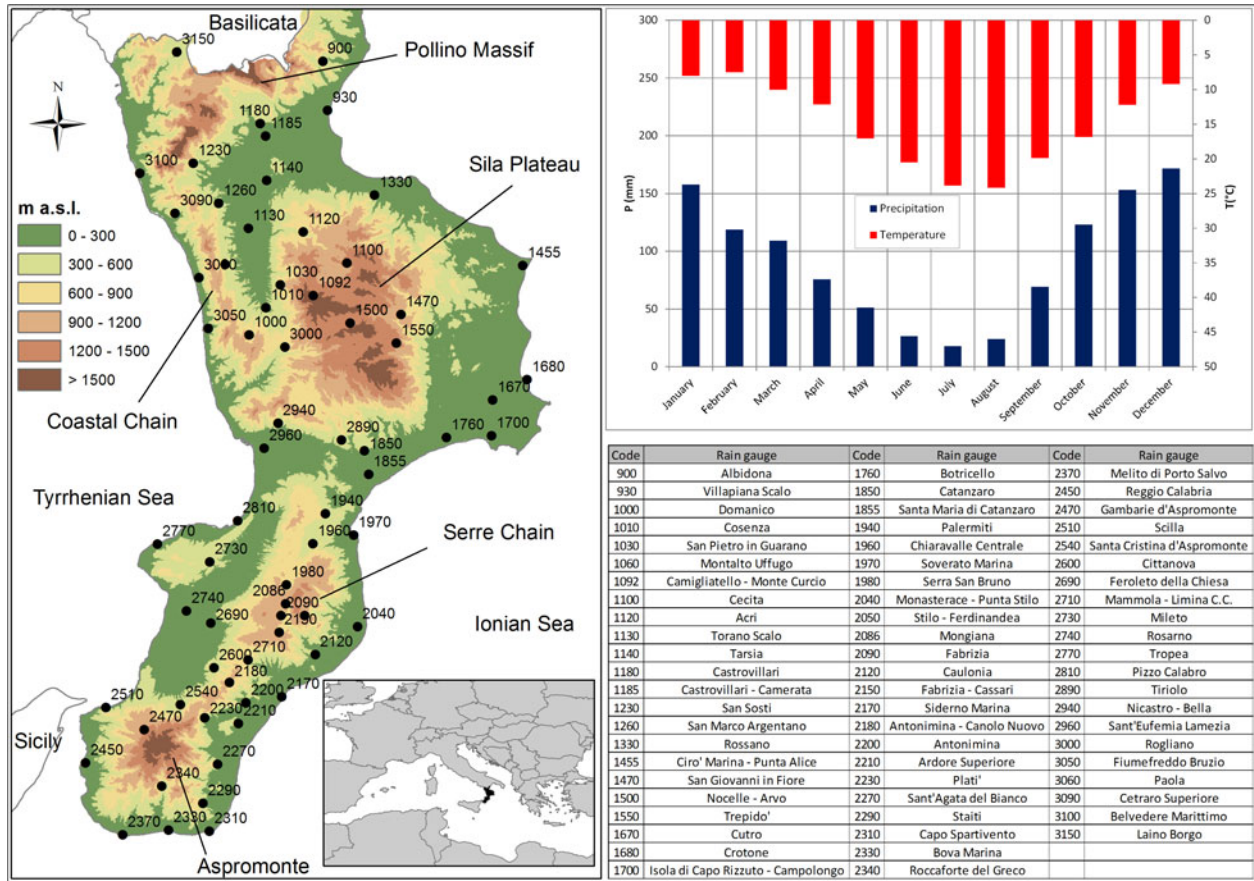


Figure 1. Digital elevation model of the study area including the location and the description of the stations with mean monthly rainfall and temperature values in the Calabria Region.

**Study area and data**

The Calabria Region is a peninsula of 15,080 km<sup>2</sup>, with an oblong shape that occupies the southern part of Italy (Figure 1). Although in Calabria high summits are not frequent, it is one of the most mountainous regions in Italy. Because of its geographic position and its mountainous nature, Calabria has a high climatic variability with a typically subtropical dry summer, also known as the Mediterranean climate. In summer, the influence of the Azores anticyclone supports a rather dry and Temperate weather, while breeze circulations develop on the coast and inland (Buttafuoco et al. 2011a). In the other seasons, Mediterranean cyclogenesis affects the regional climate. Forest distribution reflects the small-scale variability of climate and shows that typical plants associations and exclusive taxonomic entities are frequent over the territory. In general, four fundamental vegetation layers can be identified, according to Pavari's (1916) classification. The first layer, named Lauretum belt, is composed of Mediterranean maquis with Mediterranean pines (i.e. *Pinus halepensis* Miller) from sea level to about 400 m a.s.l. and by oak mixed forests (*Quercus ilex* Linnaeus, *Cupressus* Linnaeus,

*Quercus suber* Linnaeus and *Quercus pubescens* Willdenow) with Mediterranean pines up to 800 m a.s.l. The second layer, named Castanetum belt, is composed by chestnut (*Castanea* Miller), Italian oak (*Quercus* Linnaeus), maple (*Acer* Linnaeus) and alder (*Alnus* Miller) from 800 to 1200 m a.s.l., while beech – silver fir (*Fagus sylvatica* Linnaeus – *Abies alba* Miller), turkey oak – calabrian pine (*Quercus cerris* Linnaeus – *Pinus laricio* Poiret) mixed forests and pure formations of turkey oak (*Quercus cerris* Linnaeus), beech (*Fagus sylvatica* Linnaeus), silver fir (*Abies alba* Miller) and calabrian pine (*Pinus laricio*, Poiret), up to 1660 m a.s.l., belong to the third layer (warm sub-zone of Fagetum belt). The upper side of Fagetum belt with continuous forest cover (cold sub-zone) extends over about 1.4% of total forest area and it comprises high quote species (*Pinus laricio* Poiret, *Fagus sylvatica* Linnaeus and *Pinus leucodermis* Antoine), standing on higher mountain reliefs of the Region (Sila plateau, Aspromonte, Pollino massif). The fourth layer, named Picetum belt, comprises a small distribution of high altitude forest species (*Pinus leucodermis* Antoine and *Fagus sylvatica* Linnaeus) which constitute sparse groups on the peak of Pollino massif.



The monthly and annual rainfall and temperature data-sets used in this work have been selected from the original rain gauge network of Centro Funzionale Multirischi of Calabria Region, which consisted of 311 stations, with a density of one station per 48 km<sup>2</sup>. Taking into account the missing data in the series within the period 1916–2010, ultimately 67 rainfall and temperature series were selected, with an average density of one station per 225 km<sup>2</sup> (Figure 1).

## Methodology

Initially, a trend analysis was performed in order to detect the temporal behaviour of rainfall and temperature in Calabria, using the well-known rank-based non-parametric Mann–Kendall test (Mann 1945; Kendall 1962). Then, a measure of the precipitation effectiveness or aridity of the region calculated from precipitation and temperature has been carried out by evaluating some bioclimatic indices. Moreover, in order to characterize the spatial pattern of these indices, their values have been spatially distributed and, in the attempt to link vegetation types and climatic indices, different maps have been intersected with the Corine Land Cover (CLC) map (Figure 2). Thus, it has been possible to cross the different forest types, with the bioclimatic classes of the different indices used, and to define the related forest surfaces belonging to the different classes. This approach yielded useful data concerning the distribution of forest vegetation in relation to the different bioclimatic indices throughout the region. Finally, in order to assess the impact of climate change on forest cover in Calabria, the temporal evolution of vegetation was also analysed. This is an important issue, in fact land-use cover changes have been widely studied worldwide (e.g. Houghton 1994; Ojima et al. 1994; Lambin et al. 2003; Brown et al. 2005; Lepers et al. 2005), in the Mediterranean basin (e.g. Ales et al. 1992; García-Ruiz et al. 1996; Debussche et al. 1999; MacDonald et al. 2000; Santos 2000) and also in Italy (Falcucci et al. 2007; Marchetti et al. 2014). In particular, Marchetti et al. (2014) in the past 20 years highlighted a marked increase in the forest surface and, at the same time, a considerable reduction in agricultural area.

In this study, all the spatial procedures were performed using Esri ArcGIS 9.3.1.

### Emberger classification

Emberger (1930) classified the Mediterranean climate on the basis of three important climatic parameters: precipitation, temperature and evaporation. The precipitation ( $P$ ) is represented by the annual precipitation (mm). For temperature, the

mean of the maximum temperatures of the hottest month in the year ( $M$ ) and the mean of the minimum temperatures of the coldest month in the year ( $m$ ) were considered because vegetation growth is strictly related to these thermal limits. The temperature parameter is represented by the quotient  $(M/2 + m/2)$ . Evaporation is represented by the temperature range  $(M - m)$  because evaporation frequently increases with it; this parameter expresses the continentality of a climate. All these climatic parameters are represented in the pluviothermic quotient of Emberger, given by the following formula in which the temperature values are expressed in absolute degrees (K):

$$Q = \frac{1000 \cdot P}{((M + m)/2) \cdot (M - m)} = \frac{2000 \cdot P}{M^2 - m^2}. \quad (1)$$

Generally speaking, the Mediterranean climate is more arid when the quotient is smaller (Table I). An improvement in the Mediterranean climate classification was made utilising both the  $Q$  and the minimum temperature of the coldest month. In fact, this last parameter expresses, in a generic and useful way, the degree and the duration of the critical frost period: the lower the temperature of the coldest month, the more severe these conditions are. These two parameters are graphically represented in a climatogram, a chart where on the  $y$ - and  $x$ -axes the temperature of the coldest month and the quotient values are, respectively, represented.

### De Martonne index

The De Martonne index (1926) is calculated using the mean annual precipitation ( $P$  in mm) and the mean annual temperature ( $t$  in °C). The basis of De Martonne's formula gives an index of aridity ( $I_a$ ) which is expressed in the formula:

$$I_a = \frac{P}{t + 10}. \quad (2)$$

Higher  $I_a$  values indicate humid conditions while lower indicate aridity conditions (Table II).

### Rivas-Martinez index

Rivas-Martinez (1996) proposed a more general classification of the climate. Five macrobioclimates have been identified: Tropical, Mediterranean, Temperate, Boreal and Polar. In this case it is important to determine the boundary between the Mediterranean and Temperate macrobioclimates both present in the study area. The procedure involves the use of the Ombrothermic index of the

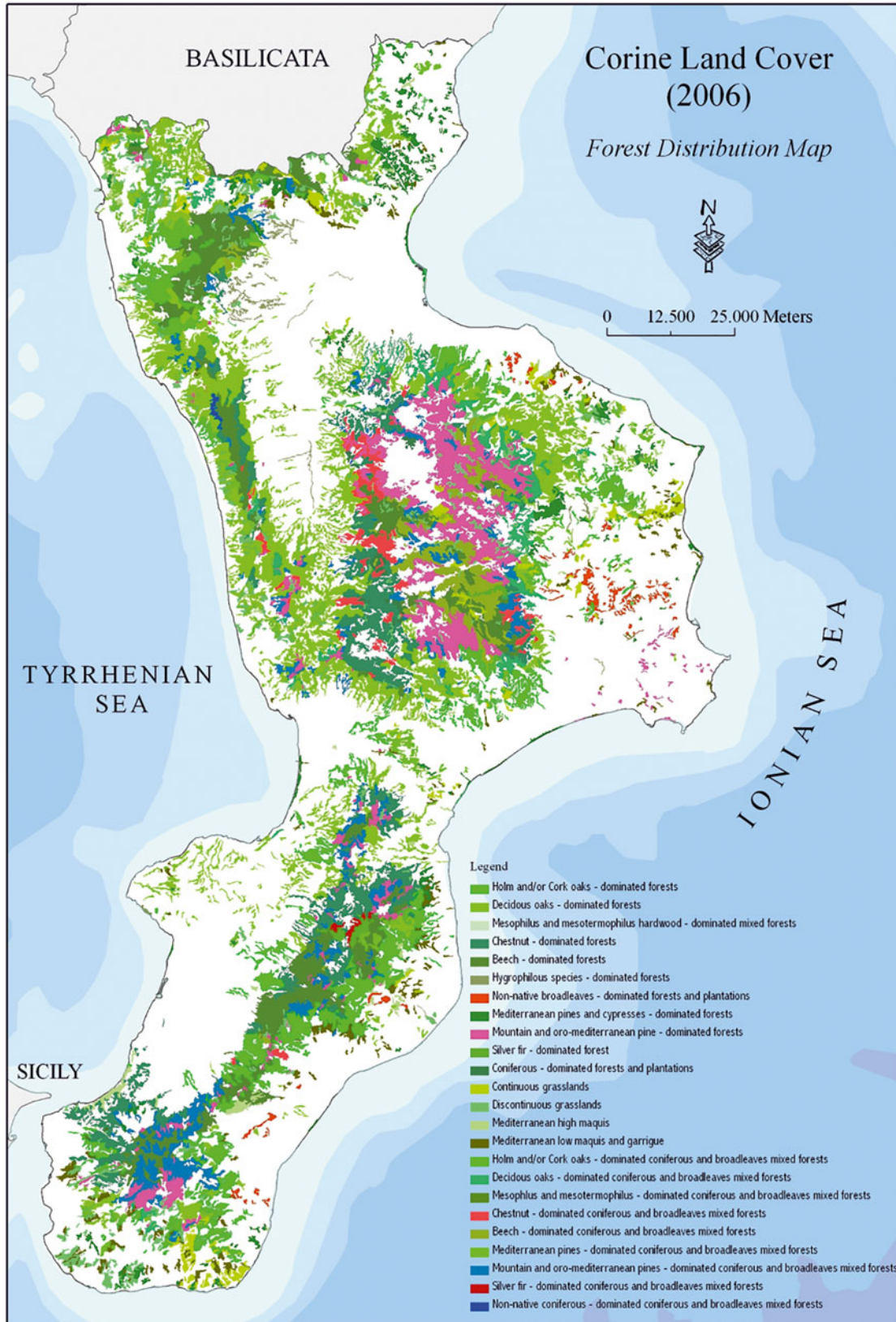


Figure 2. Forest distribution map of Calabria Region according to CLC (2006).

Table I. Climatic classification according to Emberger (1930).

| $Q$      | Climate type |
|----------|--------------|
| Over 150 | Hyper-humid  |
| 98–150   | Humid        |
| 57–98    | Sub-humid    |
| 30–57    | Semi-arid    |
| 17–30    | Arid         |
| 0–17     | Hyper-arid   |

summer period ( $I_{ov}$ ).

$$I_{ov} = \frac{\sum P_{Jun} + P_{Jul} + P_{Aug}}{\sum T_{Jun} + T_{Jul} + T_{Aug}}. \quad (3)$$

If  $I_{ov} < 1.5$ , then the macrobioclimate is Mediterranean; if  $I_{ov} > 2$ , then the macrobioclimate is Temperate; if  $1.5 < I_{ov} < 2$ , then it is a transition area that can be further assigned to a specific macrobioclimate by calculating the summer compensated ombrothermic index ( $I_{ovc}$ ):

$$I_{ovc} = \frac{\sum P_{May} + P_{Jun} + P_{Jul} + P_{Aug}}{\sum T_{May} + T_{Jun} + T_{Jul} + T_{Aug}}. \quad (4)$$

## Results and discussion

The results of the application of the trend analysis to the monthly and seasonal series of precipitation are shown in Figure 3. With regards to the monthly total precipitation, a general negative trend, although not significant for the whole region, was detected for the period 1916–2010, in particular for the autumn and winter periods (Figure 3(a)). In fact, 84.8% and 69.2% of the rain gauges show a negative trend (50.0% and 15.4% significant at 95% of significant level) in winter and autumn, respectively. On a monthly basis, a negative and significant trend was detected in January and November, with, respectively, 34.8% and 46.9% of the rain gauges, showing a negative trend at the 95% significance level. Conversely, summer precipitation shows a positive trend, particularly in July and August in which significant trends were detected in 30.8% and 23.1% of the rain

Table II. Climatic classification according to De Martonne (1926).

| $I_a$   | Climate type |
|---------|--------------|
| Over 60 | Hyper-humid  |
| 30–60   | Humid        |
| 20–30   | Sub-humid    |
| 15–20   | Semi-arid    |
| 5–15    | Arid         |
| 0–5     | Hyper-arid   |

gauges, respectively. A significant negative trend has also been found in February (24.6% of the rain gauges) while a significant positive trend has been also found in September (43.9% of the rain gauges).

In Figure 3(b)–(d), the results of the trend analysis based on the temperature series are shown. In particular, the average temperature (Figure 3(b)) shows a remarkable and positive trend in the spring and summer period, from April to August, with significant trend ranging between 30.8% and 50.8% of the temperature series. A clear negative trend has been detected in September and November, significant for 32.3% and 17.5% of the temperature series, respectively. On a seasonal scale, results show a positive trend in spring and summer periods with percentages of significant trend of 32.3% and 42.2%, respectively, while in autumn a meaningful and negative trend for 19.0% of the stations has been detected.

The maximum temperature (Figure 3(c)) shows a clear upward trend of temperatures both on a monthly and on a seasonal scale, although not significant for many stations. Only in the months of September and October there is the prevalence of a negative trend, significant for 45.3% and 12.5% of the stations, respectively. At seasonal scale, a clear tendency to positive trends in maximum temperatures has been shown, in particular in spring and summer periods, with important percentages ranging from 26.2% for spring to 30.8% of the stations for the summer.

For the minimum temperature (Figure 3(d)) a positive trend for almost all the months has been observed, with significant percentages ranging from 15.9% of the stations in February to 60.9% in July. Only the months of September and November show a statistically significant negative trend (15.4% of the stations for both). At seasonal scale, a positive trend has been shown in spring and in summer (38.5% and 53.1% of the stations, respectively).

Results showed a clear change in trend, either in rainfall or in temperature, in the Calabria Region for the period 1916–2010. Due to the rainfall and temperature changes, in order to investigate the climatic characteristics of Calabria Region, a number of indices were estimated for the whole observation period. In particular, the Emberger, Rivas-Martinez and De Martonne indices were calculated. With regards to the Emberger classification and in particular to the climatogram, five different climates can be identified in the Calabria Region (Figure 4). Most thermopluviometric stations, analysed in this work, fall within semi-arid (28.0%) and sub-humid (28.0%) classes, with hot and very hot conditions. Approximately, 20.0% of the stations belong to the hyper-humid class, with Temperate (11.9%), cool (7.5%) and cold (1.5%) conditions. In particular,



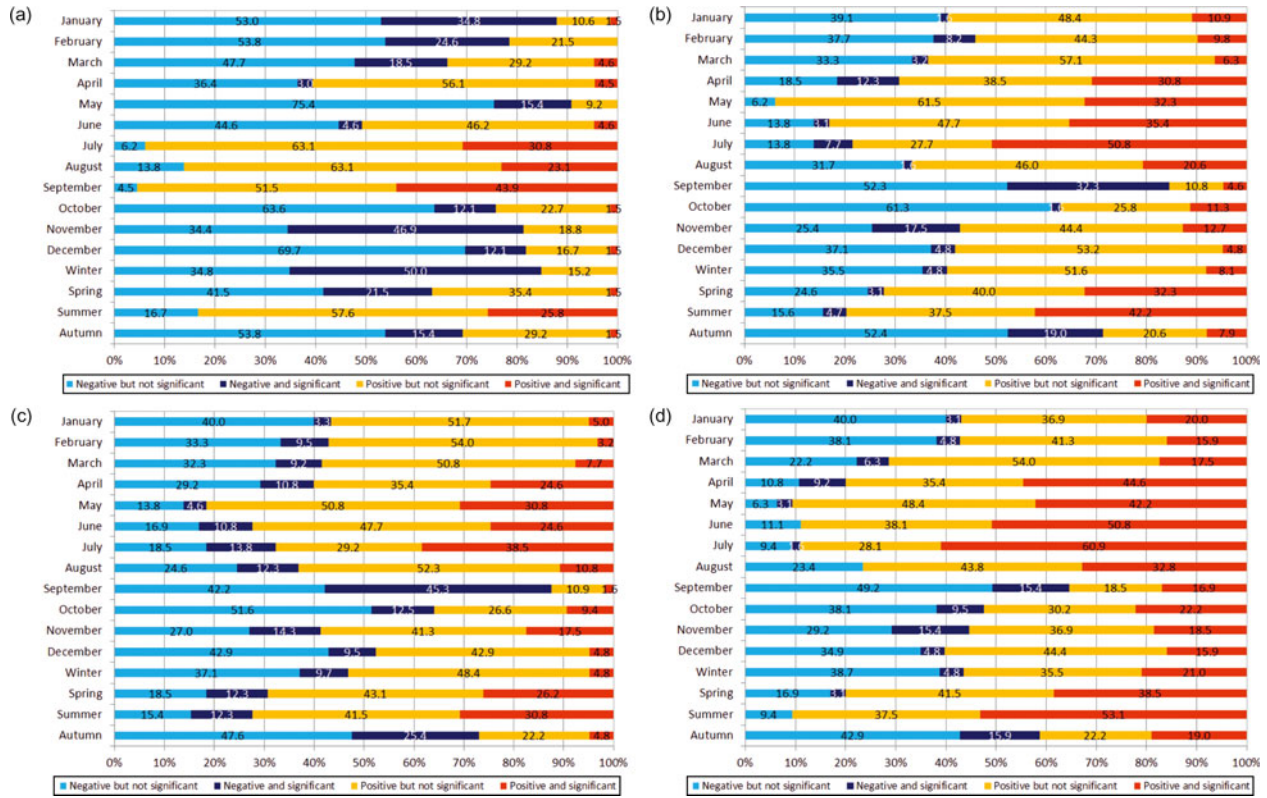


Figure 3. Percentages of series presenting positive or negative (significant or not significant) trends for various time aggregations for (a) rainfall; (b) average temperature; (c) maximum temperature; (d) minimum temperature.

this last state has been evidenced only in the Camigliatello – Monte Curcio (code: 1092, 1730 m a.s.l.) station, one of the highest of the Region. Finally, only two stations show arid conditions, Villapiana (code: 930, 5 m a.s.l.), on the north-eastern side of the Region, and Melito di Porto Salvo (code: 2370, 7 m a.s.l.), in the extreme southern part of the Region, with hot and very hot winter, respectively.

The results obtained from the analysis of Rivas-Martinez index, according with Blasi and Michetti (2005), indicated that most of the rain gauges are located in the Mediterranean region (76.0%) while the remaining part (24.0%) in the Temperate one (Figure 5(a)). Thus, the Mediterranean and the Temperate regions represent two phytogeographic units, distinct but complementary to each other determining the distribution of tree species. The

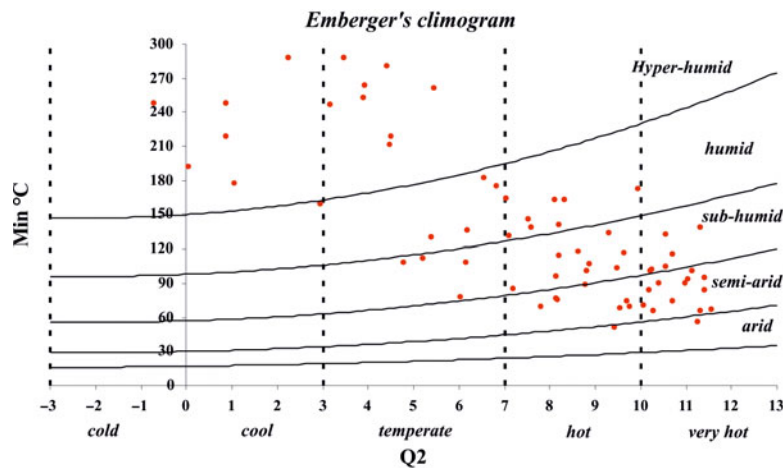


Figure 4. Climate conditions according to Emberger classification. On the y- and x-axes, the temperatures of the coldest month and the quotient values are, respectively, represented.



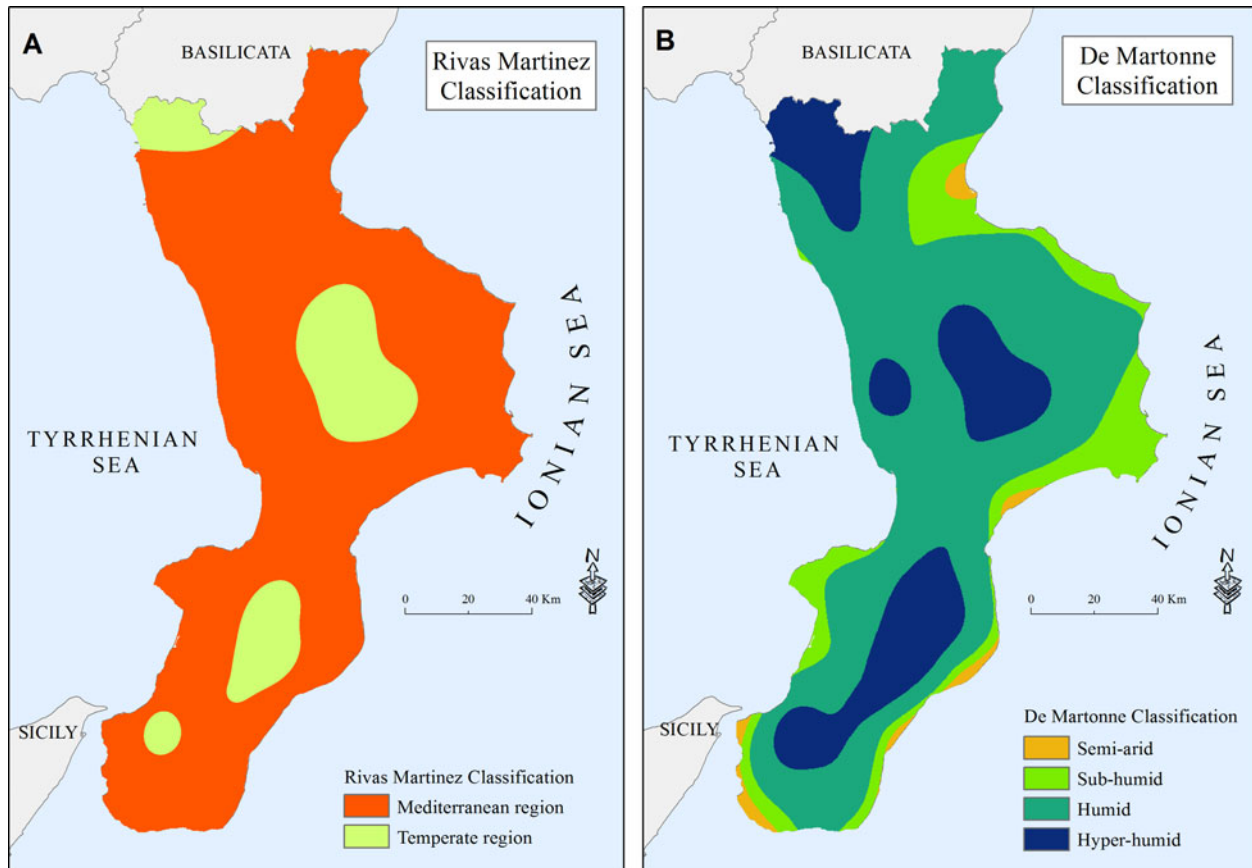


Figure 5. Rivas-Martinez (a) and De Martonne (b) classification maps for Calabria Region.

Mediterranean region, located from sea level up to an altitude of 800–850 m a.s.l. extends from the coastal areas to the lower slopes of the region while the Temperate region, located at 900 m a.s.l., occupies the mountain areas within the region.

The overlay between the CLC and Rivas Martinez maps (Table III and Figure 6(a)) shows that the Mediterranean region is characterized by the dominant presence of two large consortia plants: the maquis shrubland and the basal plane forest with most types of forest categories of Calabria entirely falling within this region. These forests consist mainly in hygrophilous species, such as willows (*Salix* Linnaeus), poplars (*Populus* Linnaeus) and alders (*Alnus* Miller) with mixed forests of conifers and deciduous trees. Predominantly, chestnut (*Castanea* Miller) and beech (*Fagus* Linnaeus) forests also fall within the Mediterranean region, respectively, for 72.0% and 56.0% of their extension, as well as the forests of holm oaks (*Quercus ilex* Linnaeus) and cork oaks (*Quercus suber* Linnaeus) (79%) and the formations of mainly deciduous oaks (91.0%). As expected, forests of Mediterranean pines fall within the Mediterranean region (94.0%).

In this region, there is a good matching of the typical Mediterranean floristic contingent, consisting

of chestnut and oak trees with the Mediterranean climate of the study area, as evidenced by numerous authors (e.g. Quézel & Médail 2002).

Silver fir (*Abies alba* Miller), mountain pine (*Pinus nigra* Arnold, *Pinus laricio* Poiret and *Pinus leucodermis* Antoine) and Douglas fir (*Pseudotsuga menziesii* Mirb. Franco) forests are located in the Temperate region for 79.0%, 57.0% and 79.0%, respectively. The majority of mixed forests, consisting mainly of deciduous trees, fall within the Temperate region, respectively, for 57.0% and 86.0% of their area as well as the coniferous and broadleaves mixed forests with predominance of beech which, for 86.0%, fall within the Temperate region. In particular, silver fir (*Abies alba* Miller), black pine (*Pinus nigra* Arnold) and loricata pine (*Pinus leucodermis* Antoine) forests have been found in the area of Serre chain, in most Sila Plateau and in the highest parts of the Pollino Massif, respectively.

The De Martonne index sub-divides Calabria into four regions, corresponding to the semi-arid, sub-humid, humid and hyper-humid classes (Figure 5(b)). In total, 3.0% of the area, in the Ionian side of the region, lies within the semi-arid category. Moreover, 14.0% of the regional territory falls within the sub-humid class and is located along the Ionian coast and in the southern side of

Table III. Results of the overlay between the CLC and indices maps: percentage of forest (according to the CLC, 2006) falling within the different index classes.

| CLC code | Type of forest  | De Martonne |           |       |             | Rivas Martinez |           |
|----------|---|-------------|-----------|-------|-------------|----------------|-----------|
|          |   | Semi-arid   | Sub-humid | Humid | Hyper-humid | Mediterranean  | Temperate |
| 324      | Mediterranean low maquis and garrigue<br>Silver-fir and/or Norway spruce dominated forests          | 1           | 9         | 63    | 28          | 84             | 15        |
| 3123     | Chestnut-dominated forests  | –           | –         | –     | 100         | 21             | 79        |
| 3114     | Beech-dominated forests   | –           | 1         | 66    | 34          | 72             | 28        |
| 3115     | Holm and/or Cork oaks-dominated<br>coniferous and broadleaves mixed forests                         | –           | –         | 25    | 75          | 56             | 44        |
| 3111     | Mediterranean pines and cypresses-<br>dominated forests   | –           | –         | 62    | 38          | 79             | 20        |
| 3121     | Mountain and oro-Mediterranean pines-<br>dominated coniferous and broadleaves<br>forests            | 3           | 21        | 67    | 8           | 94             | 6         |
| 3122     | Deciduous oaks-dominated broadleaves<br>forests   | –           | 2         | 47    | 50          | 43             | 57        |
| 3112     | Hygrophilous species-dominated forests  | –           | 3         | 77    | 20          | 91             | 9         |
| 3116     | Non-native coniferous-dominated coniferous<br>forests and plantations                               | 1           | 4         | 78    | 17          | 100            | –         |
| 3125     | Non-native broadleaves-dominated forests<br>and plantations   | –           | –         | 98    | 2           | 21             | 79        |
| 3117     | Mesophilous and mesothermophilous<br>hardwood-dominated mixed forests                               | –           | 16        | 81    | 3           | 99             | 1         |
| 3113     | Silver-fir and/or Norway spruce-dominated<br>coniferous and broadleaves mixed forests               | –           | –         | 33    | 67          | 63             | 37        |
| 31323    | Chestnut-dominated coniferous and<br>broadleaves mixed forests                                      | –           | –         | –     | 100         | 18             | 82        |
| 31314    | Non-native conifer-dominated coniferous<br>and broadleaves mixed forests                            | –           | –         | 58    | 42          | 43             | 57        |
| 31325    | Beech-dominated coniferous and broadleaves<br>mixed forests   | –           | –         | 100   | –           | 100            | –         |
| 31315    | Mesophilous and mesothermophilous<br>hardwood-dominated coniferous and<br>broadleaves mixed forests | –           | –         | 21    | 79          | 14             | 86        |
| 31313    | Holm and/or Cork oaks-dominated<br>coniferous and broadleaves mixed forests                         | –           | –         | –     | 100         | 100            | –         |
| 31311    | Mediterranean pines-dominated coniferous<br>and broadleaves mixed forests                           | –           | 12        | 74    | 14          | 57             | 43        |
| 31321    | Mountain and oro-Mediterranean pines-<br>dominated coniferous and broadleaves<br>mixed forests      | –           | –         | 35    | 65          | 94             | 6         |
| 31322    | Deciduous oaks-dominated coniferous and<br>broadleaves mixed forests                                | –           | –         | 81    | 19          | 63             | 37        |
| 31312    |   | –           | –         | 81    | 19          | 87             | 13        |

Tyrrhenian coast. At last, 60.0% of the region can be classified as humid and occupies almost all the region with the exception of the coast and of the main reliefs which lie, as 23.0% of the regional area, in the hyper-humid class.

The overlay map between the CLC and De Martonne map (Table III and Figure 6(b)) shows that 3.0% of the Mediterranean pines forests fall within the semi-arid class, 21.0% falls in the sub-humid one, 67.0% in the wet class and 8.0% in the hyper-humid one. While in the semi-arid class only Mediterranean pine forests fall, in the sub-humid one there are 12.0% of coniferous and broadleaves mixed forests, with predominance of Mediterranean

pines and low percentages of deciduous oaks and hygrophilous species. Most of forests fall within the humid and hyper-humid classes. In particular, the silver fir (*Abies alba* Miller) forests and the formations, mainly consisting of mesophilous and mesothermophilous broadleaves, entirely fall within the hyper-humid class while almost all of the Douglas fir *Pseudotsuga menziesii* (Mirb.) Franco forests fall within the humid one.

Due to the rainfall and temperature changes, with the aim to evaluate the temporal evolution of the indices, three sub-periods of 30 years each, 1921–1950, 1951–1980 and 1981–2010, have been considered. For each sub-period both the Rivas-

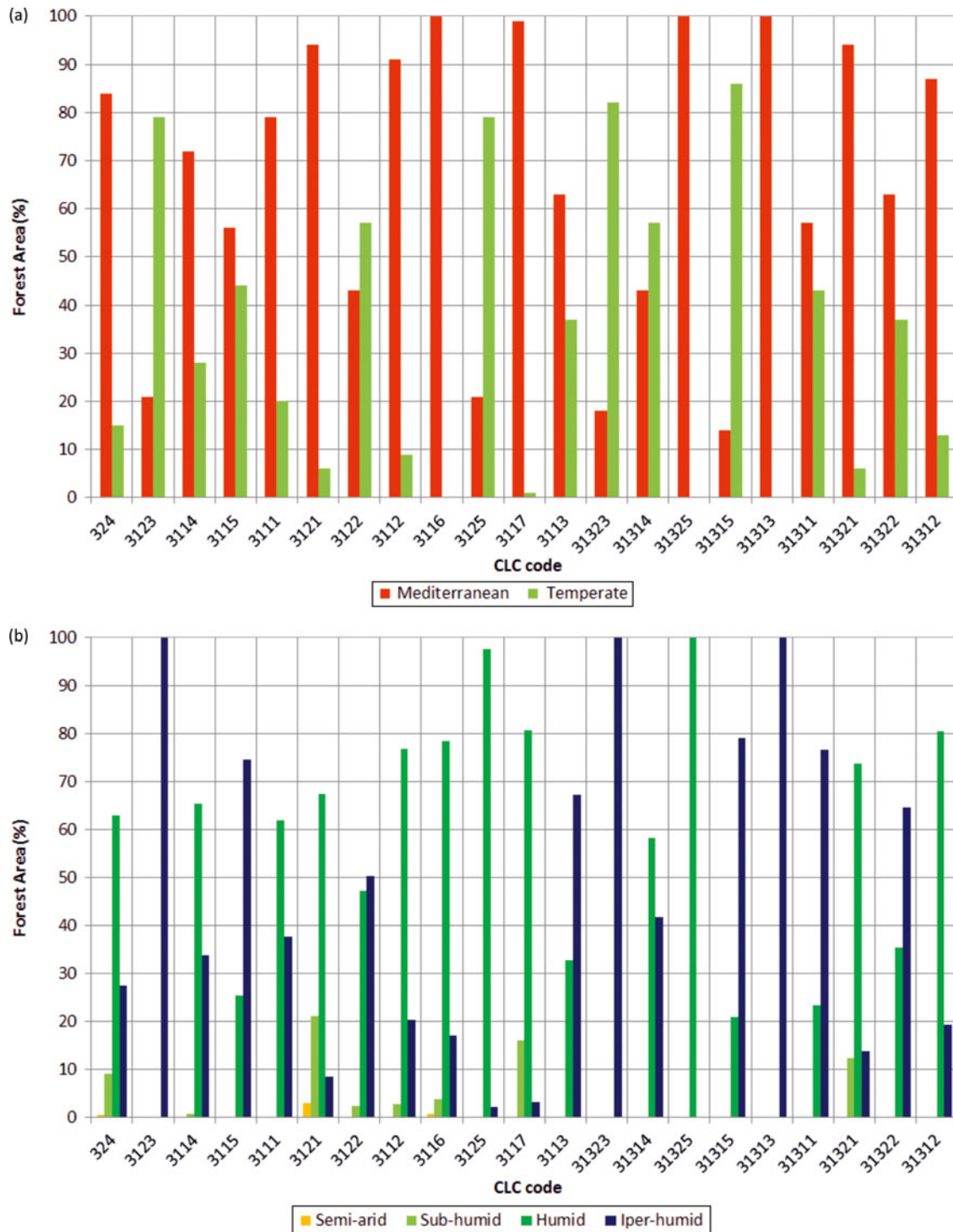


Figure 6. Results of the overlay between the CLC and the indices maps. On the x- and y-axes, the forest code (according to the CLC, 2006) and the percentage of forest falling within the different index classes have been, respectively, represented.

Martinez and the De Martonne indices have been calculated and mapped and the percentage of regional area, falling within the different indices classes, has been evaluated (Table IV). As a result, considering the Rivas-Martinez index, an increase of the areas affected by Mediterranean climate and a consequent reduction of the areas affected by

Temperate climate has been detected. As regards the De Martonne index, a tendency through sub-humid conditions emerged. In fact, while the semi-arid and hyper-humid classes showed a clear reduction, a slightly increase of the humid class and, above all, a marked increase of the sub-humid one have been evaluated.



Table IV. Percentage of regional area falling within the different index classes for three different subperiod of 30 years.

| Index          | Class         | 1921–1950 | 1951–1980 | 1981–2010 |
|----------------|---------------|-----------|-----------|-----------|
| Rivas-Martinez | Temperate     | 18.3      | 15.4      | 15.1      |
|                | Mediterranean | 81.7      | 84.6      | 84.9      |
| De Martonne    | Semi-arid     | 4.9       | 6.7       | 1.3       |
|                | Sub-humid     | 8.9       | 8.7       | 20.5      |
|                | Humid         | 66.3      | 67.9      | 69.9      |
|                | Hyper-humid   | 19.9      | 16.8      | 8.3       |

In order to assess the potential relationship between climate change and forest cover in Calabria, also the temporal evolution of the vegetation was also analysed. In Calabria, an increase of forested area was recorded from 1800 to 1954 (from 184,000 to 397,000 ha), even if between 1940 and 1950 a decrease of 30 ha occurred (Cassa per il Mezzogiorno 1957). In 1950s the Calabria Region was the fifth most wooded Italian region, with a forested area of 375,000 ha and a coefficient of woodland density of 26.0%. In particular, high forests constituted 61.0% of the total regional woody area (12.0% conifers, 46.0% broadleaves, 3.0% mixed conifers and broadleaves), while coppice forests constituted 39.0% (20.0% simple coppice system, 19.0% mixed coppice system). Laricio pine (*Pinus laricio* Poiret) was the dominant species in coniferous forests, whereas chestnut (*Castanea sativa* Miller), beech (*Fagus sylvatica* Linnaeus) and oaks (*Quercus* spp.) dominated the broadleaved forests (Cassa per il Mezzogiorno 1957).

After the Second World War, a new afforestation project was carried out (Regione Calabria 2007), and Calabria forest area increased by 32% between 1960 and 1980 (Iovino 1998). Afforestation mainly concerned inland areas of Presila, Serre and Aspromonte, which were more affected by hydro-geological risk. In the last 40 years, mountain area has been re-colonized by forests while uncontrolled urban development led to a reduction of green areas in the valleys. Besides, after the recovery of humid areas, most of coastal territory has undergone a strong anthropic pressure. Nonetheless, a strongly increasing trend in forested area has occurred in the Region between 1970 and 1990. From the analysis of the distribution of forests along elevation zones it results that 66.7% of forests are located at higher elevations while 28.3% of these forests are within national parks. Finally, it is noteworthy that most of forested area has arisen by semi-natural processes. In particular, silvicultural activities gave rise to 48.7% of forests in Calabria (Regione Calabria 2007). From the analysis of land use by CLC, available for 1990 and 2006, a reduction of 3900 ha of forest area has been detected. In particular, coniferous forests with mixed coniferous underwent

a 3100-ha decrease, while broadleaves forests were reduced by 800 ha.

These results may be linked to the climate change actually in progress, supporting the hypothesis that when extreme values of indices decrease, the development of natural conifer stands is not supported, whereas agro-forest stands and crop and forest cultivations show a steady and/or increasing trend. However, as highlighted by other authors (e.g. Piovesan et al. 2010), the reduction in precipitation during the winter is not a limiting factor for forest vegetation, especially if accompanied by an increase in summer rainfall, as for the Calabria Region. Climate change and extreme climatic parameters, e.g., the drought that affected the Calabria Region at the beginning of this century (Buttafuoco & Caloiero 2014; Buttafuoco et al. 2015), could be responsible for the forest cover change, but, given also the good correlation between the various types of bioclimate and forest formations, human activities must be considered. In fact, in the last years, the Calabria Region has been affected by numerous fires, in particular during the summer period and, different from the past, political action has been lacking with respect to afforestation management.

## Conclusion

This paper analyses the temporal behaviour of annual and monthly precipitation and temperature in a region of southern Italy (Calabria) and its possible influence on the regional land cover through the analysis of some bioclimatic indices. In fact, Calabria, due to its geographical position and for its geomorphological and climatic peculiarities, presents a considerable diversification in terms of vegetation, which also is confirmed from a bioclimatic point of view. Results show a reduction in winter–autumn rainfall, an increase in summer precipitation, a rise of the average temperature, mainly due to an increase of the minimum temperature in late spring and summer and a decrease in the autumn–winter period, mainly due to a reduction in the maximum temperature. These results could confirm the hypothesis of a climate change actually in progress. With regards to the Emberger classification and, in particular, to the

climatogram, five different climates can be identified in the Calabria Region with a predominance of semi-arid and sub-humid classes with hot and very hot conditions. According to previous studies (e.g. Blasi & Michetti 2005), the Rivas-Martinez index indicates that most of the rain gauges are located in the Mediterranean region (76.0%) while the remaining part (24.0%) in the Temperate one. Moreover, the De Martonne index divides Calabria into four regions, corresponding to the semi-arid, sub-humid, humid and hyper-humid classes with 60.0% of the region which can be classified as humid. The temporal analysis of the Rivas-Martinez and the De Martonne indices in three sub-periods of 30 years showed that Temperate and hyper-humid areas decreased in time while Mediterranean and sub-humid areas increased. At the same time, the comparison of the land use between 1990 and 2006 evidenced a reduction of forest area and, above all, a large decrease of coniferous forests. These results may be linked to the climate change actually in progress, but, given also the good relationship between the various types of bioclimate and the forest formations, human activities must also be taken into account.

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