LONG-TERM CHANGES IN PRECIPITATION AND TEMPERATURE PATTERNS AND THEIR POSSIBLE IMPACTS ON VEGETATION (TOLFA-CERITE AREA, CENTRAL ITALY)

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Abstract. Climate change is a major global issue that impacts vegetation, agriculture, biodiversity and human safety. These impacts are predicted to be intense in the Mediterranean region. The aim of this paper is to define how local climatic trends are affecting plant communities in the Tolfa-Cerite area (Northern Latium), which is a semi-coastal area with Mediterranean to broad-leaf vegetation. Climate data analysis covered a long time period (1951-2007), considering 18 gauging stations. Data were analyzed using geostatistical methods and descriptive statistics. Climate trends and drought indicators, in relation to different vegetation associations, were analyzed using the zonal statistic tool (ArcGIS). During the investigated period, rainfall showed a uniform decreasing trend, while temperature increased, with an irregular trend. The specialization of climatic data showed a shift towards a thermo-Mediterranean bioclimate. Local climatic trends showed to have more severe impacts on specific plant communities (mesophilous forests, endangered shrubland-pastures, relict associations of meadows, etc). The observed trends towards aridity occurred in many areas covered by vulnerable plant communities. Considering the predicted changes in climate conditions for the Mediterranean area, these communities will face a further aridity increase. A permanent monitoring of these communities may increase the effectiveness of conservation policies and sustainable regional planning.

Keywords*:* *Bioclimate analysis, climate change, Mediterranean plant communities, Italy*

Introduction

Climate change is currently a major global concern since it could have heavy impacts on living beings, including humans (e.g., Thomas et al., 2004; Hoffman et al., 2009; Fiorillo and McCarthy, 2010). Projected impacts encompass a broad range of effects: the evolution of new plant associations (Jackson and Overpeck, 2000), shifts in the spatial distribution of tree species (e.g., Iverson and Prasad, 1998; Tchebakova et al., 2005; Téllez-Valdéz et al., 2006), animal and insect population decline or shifts (Parmesan et al., 1999; Gibbons et al., 2000; Bombi et al., 2009), reduced food availability and loss in agricultural yield (Ciais et al., 2003; Mendelsohn and Dinar, 2003; Eiji Maeda et al., 2010; Tirado et al., 2010). Many studies (Melillo et al., 1995; Bachelet et al., 2001; Hansen et al., 2001; Shafer et al., 2001; Neilson et al., 2005) agree

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in predicting widespread disruption of native ecosystems caused by the change in climate (see IPCC, 2000) being portrayed by General Circulation Models (GCM) for the near future (Crookston et al., 2010).

The Mediterranean regions are transitional climate regions where it has been hypothesized that climate changes may have pronounced effects (Lavorel et al., 1998; De Luis et al., 2001; Giorgi, 2006; Giorgi and Lionello, 2008). In general, the Mediterranean climate is characterized by cool, wet Winter and hot, dry Summer (Giacobbe, 1964; Henderson-Sellers and Robinson, 1991). The study of several GCM simulations shows a robust picture of climate change over the Mediterranean basin, consisting of a long-term downward trend in rainfall amount (Maheras, 1988; Kutiel et al., 1996; Palutikof et al., 1996; Esteban-Parra et al., 1998; Osborne et al., 2000; IPCC, 2007; Giorgi and Lionello, 2008) and temperature warming (Kutiel and Maheras, 1998; IPCC, 2007) especially in the hot season. Finally, it has been well documented that climate change “will lead to effects such as changes in frequencies of extreme weather events” (IPCC, 2007). An increase in the seasonal variability of climate has also been predicted. However, the Mediterranean basin is characterized by a great variability of climate types (Lionello et al., 2006) and mesoscale features. These features determine climatic gradients within a region, driven by the effects of mountains, valleys and local winds (Somot et al., 2008).

Moreover, climate change in synergy with desertification processes (Puigdefabregas and Mendizabal, 1998; De Luis et al., 2001; Sivakumar, 2007; Salvati et al., 2008), soil erosion (Favis-Mortlock and Savabi, 1996; Williams et al., 1996; Favis-Mortlock and Guerra, 1999; Nearing, 2001; Pruski and Nearing, 2002; Nearing et al., 2005) and land degradation (Attorre et al., 2007) may affect, to different extents, vegetation (e.g., Sabatè et al., 2002; Walther, 2003; Piovesan et al., 2008, Jump and Penuelas, 2005; Jiao et al., 2009).

Bioclimatology is an ecological science dealing with the relations between climate and the distribution of living species, which define specific bioclimatic regions (Rivas Martinez, 1993; Rivas Martinez, 1996). Bioclimatic indicators are based on formulas that measure climatic factors and conditions that may positively/negatively affect vegetation and may correlate to the main type of vegetation of an area. The Tolfa-Cerite area is a coastal and semi-coastal area in Central Italy, where it has previously been hypothesized a transitional shift from a defined Mediterranean to a Temperate bioclimate (Blasi et al., 1999). Thus, vegetation of this area is likely to be sensitive in relation to a shift in climate patterns, since it is already on the boundary between two bioclimatic areas.

Hence, the objective of this paper is to analyze and integrate geostatistical methods and a bioclimatic approach to quantify the effects of recent climate variations on actual vegetation. The aims of this paper are to (i) describe the bioclimate and define the climate trends within a sensitive study area through geostatistical analyses, and (ii) relate these trends to vegetation defining which are the plant communities that will experience the greatest change in climate conditions. This analysis may be useful to define which are the most vulnerable plant communities in the area in prediction of the projected climate changes for the Mediterranean basin.

Methods

Methodology for the analysis of climate and vegetation data is detailed in separate paragraphs.

Study area

The investigated area is located in the Rome prefecture (Latium, central Italy) and covers a total surface area of 556 Km^2 (*Fig. 1*). The area is delimited between longitude 11° 44' – 12° 11'and latitude 41° 55' – 42° 14' and it is bounded by the Tyrrhenian Sea on the West, by the Monti Sabatini on the East, and the Monti Cimini and the Mignone river on the North. The area is characterized by lowlands, hills and low mountains (the highest peak of Tolfa Mountains is the Monte delle Grazie, 616 m), which constitute a single morphological element, but are defined by different geological features. Some mountains are of volcanic origin, others are formed by older sedimentary deposits of flyschoid origin (Devoto and Lombardi, 1977; Contoli et al., 1980; Angelelli and Faramondi, 1995; Lombardi, 2000). The Southern sector, along the coastline, is typified by more recent geological formations with marine and fluvial sediments.

The typical landscape is characterized by dispersed towns and villages, a mosaic of pastures, cultivated land and woodlands. This landscape has been modified by a millenarian human activity: the area is inhabited since the end of the Bronze Age (9th-8th centuries B.C.) (Mandolesi, 1999) and there are several archeological settlements and historical monuments.

The 60% of the total surface of the study area is covered by woodland and semi-natural vegetation (Blasi, 2010). In the lower belt, vegetation is mainly Mediterranean with forests dominated by *Quercus ilex* L. and plant communities of the *Quercetea ilicis*. However, the 47% of woodlands is composed by broad-leaf species (especially on the hilly belt): *Fagus sylvatica* L., *Quercus cerris* L., *Carpinus betulus* L., *Ostrya carpinifolia* Scop. and *Castanea sativa* Miller (Anzalone, 1961; Spada, 1977; Di Pietro, 2010). Atypical plant communities consist of prairies of Sulfur springs, low belt beech forests and uncommon pastures communities (e.g., *Cynaro-Cichorietum pumili*) (Fanelli et al., 2007). The area includes many sites of the Natura 2000 network [the Tolfa hilly area is a SPA (Special Protection Area) (Council Directive 79/409/CEE)].

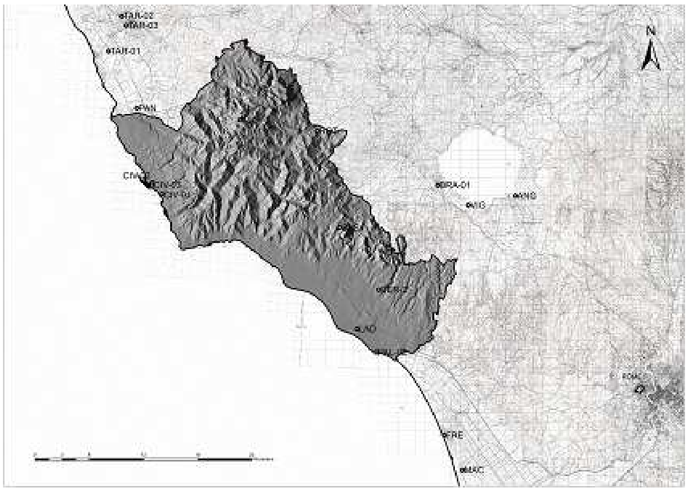

Figure 1. *Geographical position of the considered gauging stations within and nearby the study area*

Climate data

Climate stations within 30km of the research area, encompassing the broadest possible elevation range, were selected to capture the variation of the region (altitude and distance from the sea).

Climate data were obtained from the CRA-CMA (Consiglio per la Ricerca e la Sperimentazione in Agricoltura – Unità di Ricerca per la Climatologia e la Meteorologia applicate all'Agricoltura) for the period 1951-2007. Stations with limited years of registration were not considered. As regards the selected stations, years with lacking periods of registration were eliminated from the pool of data.

At the end of this initial screening, we analyzed data registered at six thermo-pluviometric gauging stations (Allumiere, Bracciano 1, Cerveteri 2, Civitavecchia 1, Maccarese, Tarquinia 1), seven pluviometric gauging stations (Anguillara Sabazia, Fregene, Ladispoli, Pantano Tarquinia, Rota, Sasso Furbara, Tarquinia 2) and five gauging stations with only temperature data (Civitavecchia 2, Civitavecchia 3, Palo Laziale 2, Tarquinia Portaccia, Vigna di Valle). Gauging stations with rainfall data are 13, with temperature data are 11. During the period 1951-1980 some of the gauging stations were inactive (three for rainfall and four for temperature). However, we statistically interpolated the missing values for temperature (see below). Nine stations are within the study area while nine are nearby (*Fig. 1*).

Climate indicators

For each station, the average was calculated of the monthly and annual values of maximum, minimum and medium temperature of monthly and annual amounts of rainfall. Higher and lower values of both temperature and rainfall were calculated. Trends in temperature and in rainfall were also calculated on a seasonal basis.

Bioclimatic indexes allow synthesizing complex relations among different sets of climatic data (Blasi, 1996). The following bioclimatic indexes were calculated: Bagnouls-Gaussen Aridity Index (BGI) (Bagnouls and Gaussen, 1953); Mitrakos indexes, for cold and drought stresses (YCS, WCS, YDS, SDS) (Mitrakos, 1980); Emberger rainfall index (Q) (Emberger, 1955); De Martonne aridity index (De Martonne, 1926); Rivas Martinez indexes (It, Ic, IO, Ios2, Ios3, Ios4) for defining the bioclimatic areas (Rivas Martinez, 1993; Rivas Martinez, 1996; Rivas Martinez and Loidi Arregui, 1999). The moving average of temperature and rainfall was also calculated, considering a window range of ten years for the whole study period (1951-2007). The outputs of these analyses were used to create graphs and spotlight trends in variations of rainfall and temperature regimes and to define the most likely period of shifting of climate conditions.

Temperature and rainfall data were then analyzed parting data in two periods (1951-1980 and 1978-2007), considering the 1980s as a break point, to highlight the variability pattern and trends in their distribution (Giavante et al., 2009). For each station, the averages of monthly and yearly rainfall and temperature values were calculated considering the two new periods and then compared, reporting any monthly, seasonal and annual variation. Bioclimatic indexes were elaborated for these new periods as well. Three gauging stations (Cerveteri 2, Tarquinia 1, and Fregene) were not used in this comparison as regards the rainfall data since data were missing for one of the two periods. Temperature data were lacking at Cerveteri 2, Palo Laziale 2, Tarquinia 1, and Tarquinia Portaccia for the period (1951-1980). These missing data were interpolated using a simple linear regression method (Goovaerts, 2000). Rainfall is a parameter with a nonlinear distribution, with random variations that could seldom be inferred. Temperature, on the other hand, has more regular trends in a small area and is mainly affected by elevation.

Geostatistical methods were used to interpolate the spatial correlation between neighboring observations to predict attribute values at unsampled locations in relation to the distance and similarity of close stations (Ordinary Kriging - Tabios and Salas, 1985; Phillips et al., 1992; Goovaerts, 2000; Attorre et al., 2007). Rainfall and temperature data were regionalized using a standardized Ordinary Kriging interpolation method (Benavides et al., 2007) using the Spatial Analyst tool in ArcGis 10.0 (ESRI, Redlands, CA, 2006).

Climatic maps for the two periods were produced in relation of several climate parameters (Annual mean of medium temperature, annual mean precipitation, mean of minimum temperature of January and February; mean of maximum temperature of July and August; mean precipitation of October, November, December and July). A standard error prediction map was produced to estimate the precision of the spatialization process for each map (Hartkamp et al., 1999). Afterward, the raster files contained in the ordinary kriging maps of the annual mean of medium temperature, the maps of annual mean precipitation and the maps of the BGI index were used to obtain three new derived maps. Values of the datasets of the period 1978-2007 were subtracted from the values of the period 1951-1978 using the ArcGIS tool “raster calculator” (in numerical values), obtaining the following maps:

(i) map of the variation of the annual mean precipitation (difference between the total amounts);

(ii) map of the variation of the annual mean of medium temperature (difference between the two values);

(iii) map of the difference of BGI values.

Vegetation and climate analysis

The vegetation map of the Rome Province (Fanelli et al., 2007) was uploaded in ArcGIS. This map has a scale of 1: 25.000 and it depicts the real vegetation areas detailing the plant community syntaxa. Each polygon is characterized by a vegetation type. However, since some vegetation categories were describing very similar plant communities, these polygons were re-categorized in more comprehensive categories. Then, the raster files (and related layers) of the three above mentioned (i-iii) maps where overlaid to the vegetation map using ArcGIS.

The “zonal statistic” tool provided by ArcGIS was used to define the variation of precipitation, temperature and BGI index values for each vegetation category and each polygon, considering minimum, maximum and the average values. Polygons defined by the same vegetation category have a diverse distribution in relation to climate patterns.

Results

Results on climate analysis are showed in summary paragraphs. The analysis of climate change in relation to vegetation data are reported subsequently.

Rainfall distribution

The Ordinary Kriging map of annual mean precipitation is reported in *Fig. 2* along with the related standard error prediction map. It is possible to define an increasing gradient of rainfall amount from the coast to the uplands.

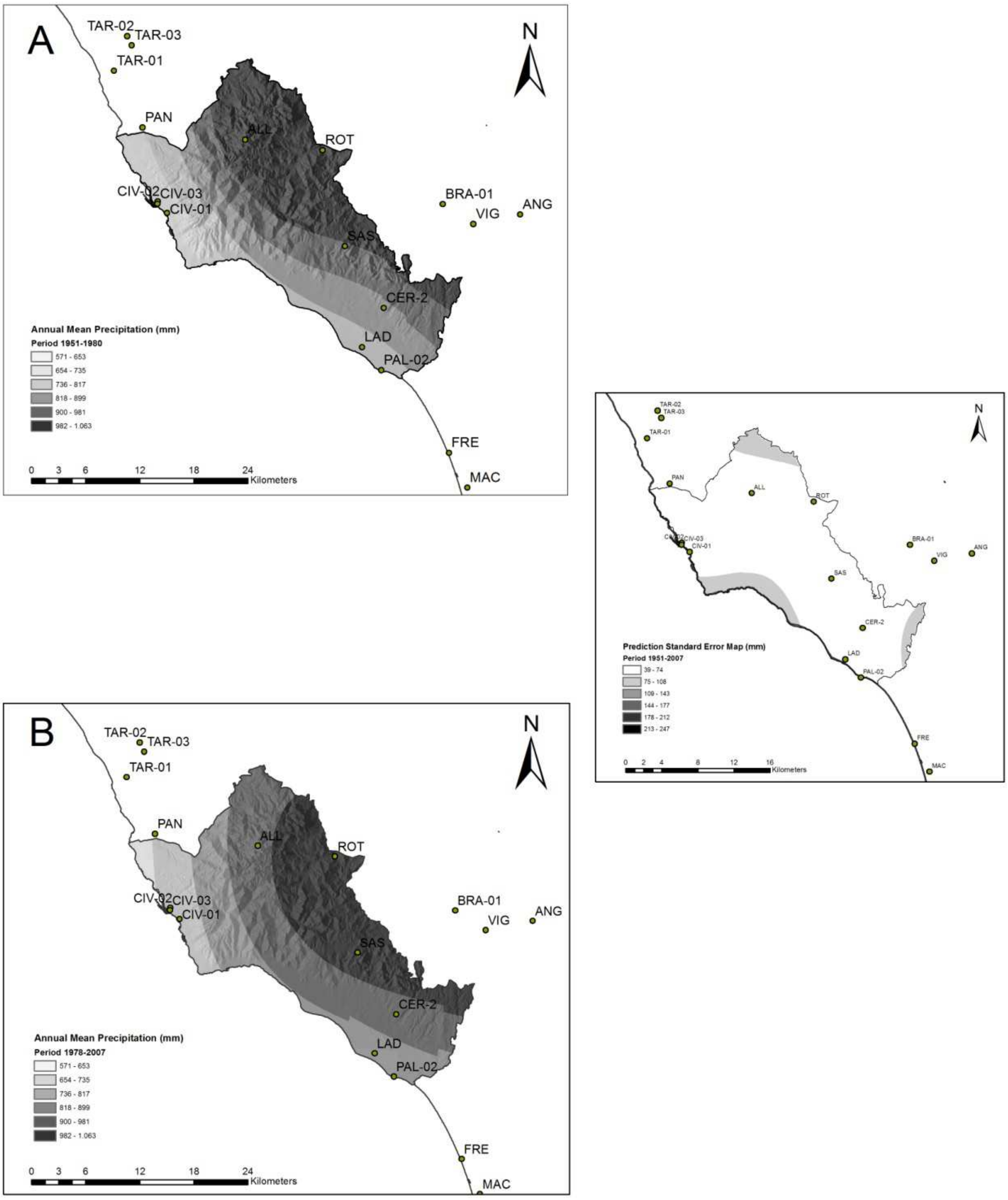

Figure 2. *Ordinary Kriging spatialization of annual mean precipitation (in mm) considering the periods 1951-1980 (a) and 1978-2007 (b) and standard error map related to the whole period*

During 1951-1980 (*Table 1*) the rainiest month was November, while the driest month was July. The highest value of annual rainfall (1117.8 mm) was registered at Rota (191 m above sea level); only at four gauging stations the average annual rainfall

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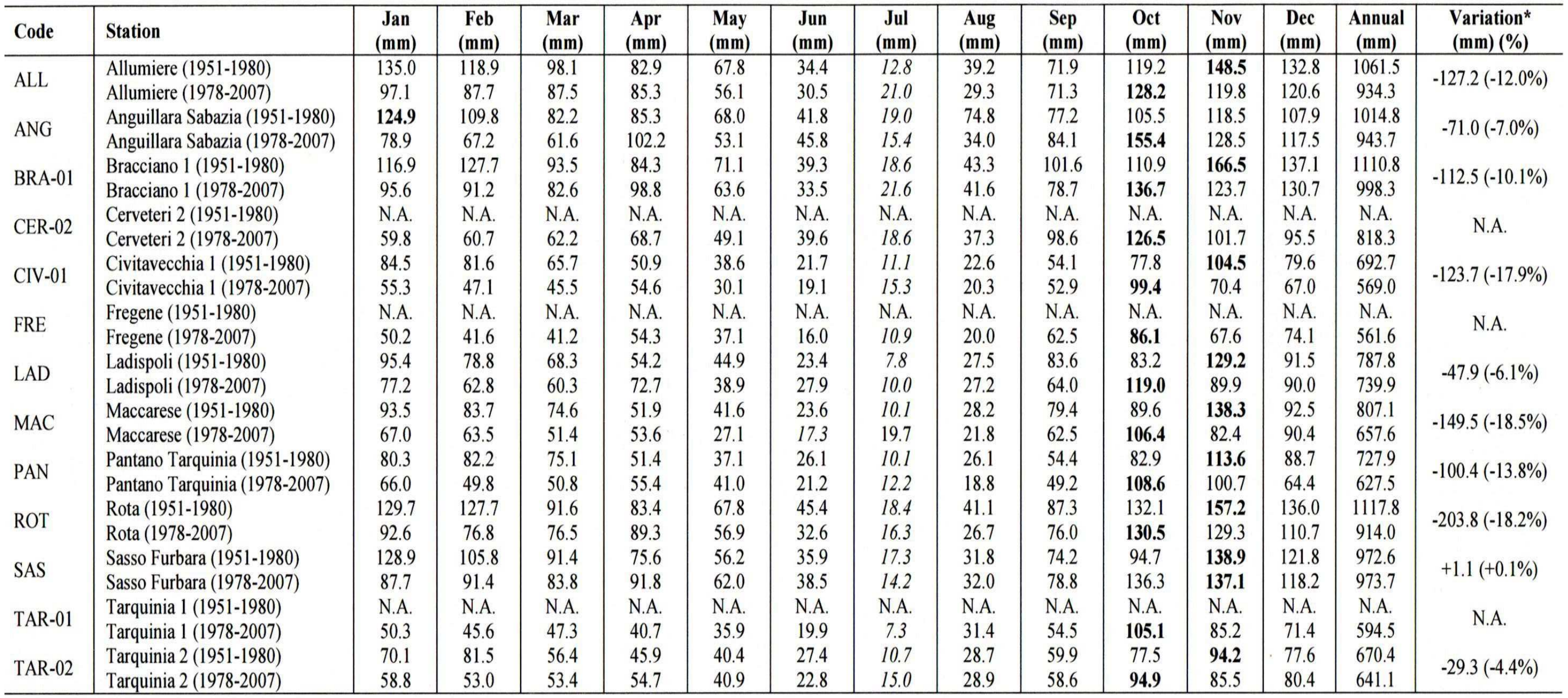
is higher than 1000 mm. The highest value (166.5 mm) of monthly rainfall was registered at Bracciano 1 (228 m above sea level). The lowest value of annual rainfall (670.4 mm) was registered at Tarquinia 2 (14 m above sea level, a.s.l.). The lowest value of monthly rainfall (7.8 mm) was registered at Ladispoli (5 m a.s.l.) in July.

During 1978-2007 (*Table 1*) the rainiest month was October while the driest month was July. The highest value of annual rainfall (998.3 mm) was registered at Bracciano 1; at all the gauging stations the average annual rainfall was less than 1000 mm. The highest value (155.4 mm) of monthly rainfall was registered at Anguillara Sabazia (160 m a.s.l.) in October. The lowest value of annual rainfall (569.0 mm) was registered at Civitavecchia 1 (5 m a.s.l.). The lowest value of monthly rainfall (10.0 mm) was registered at Ladispoli (5 m a.s.l.) in July.

In *Fig. 2* it is showed the Ordinary Kriging map of Annual mean precipitation (in mm) of the two considered periods (1951-1980; *Fig. 2a* – 1978-2007; *Fig. 2b*). The decrease of rainfall is evident for the whole area, and especially for the hilly areas. In the study area, a decrease of annual rainfall in nine out of 10 stations was observed ranging from 18.5 % (81.5 mm) at Maccarese to 4.4 % (29.3 mm) at Tarquinia 2. A slight (1.1 mm, 0.1 %) increase in annual rainfall amount was observed only in Sasso Furbara, an upland and wooded area. A reduction in rainfall was also highlighted on a seasonal basis. The decrease, considering the rainfall amount, was maximum during Autumn, a typical wet season in the Mediterranean region. The highest decrease in annual rainfall, considering the absolute value in mm, was calculated for the Rota station, with an estimated reduction of 203.8 mm (18.2 % of the total).

The moving average of the annual rainfall, calculated for pluviometric stations, also highlighted a decreasing trend (an example is provided in *Fig. 3*).

Table 1. *Average monthly and annual values of precipitation (in mm) for the two periods (1951-1980 and 1978-2007). The variation in rainfall was calculated subtracting the more recent period to the first one. The rainiest months are in bold, the driest months in italic*



Code	Station	Jan (mm)	Feb (mm)	Mar (mm)	Apr (mm)	May (mm)	Jun (mm)	Jul (mm)	Aug (mm)	Sep (mm)	Oct (mm)	Nov (mm)	Dec (mm)	Annual (mm)	Variation* (mm) (%)
ALL	Allumiere (1951-1980)	135.0	118.9	98.1	82.9	67.8	34.4	*12.8*	39.2	71.9	119.2	**148.5**	132.8	1061.5	-127.2 (-12.0%)
	Allumiere (1978-2007)	97.1	87.7	87.5	85.3	56.1	30.5	*21.0*	29.3	71.3	**128.2**	119.8	120.6	934.3	
ANG	Anguillara Sabazia (1951-1980)	**124.9**	109.8	82.2	85.3	68.0	41.8	*19.0*	74.8	77.2	105.5	118.5	107.9	1014.8	-71.0 (-7.0%)
	Anguillara Sabazia (1978-2007)	78.9	67.2	61.6	102.2	53.1	45.8	*15.4*	34.0	84.1	**155.4**	128.5	117.5	943.7	
BRA-01	Bracciano 1 (1951-1980)	116.9	127.7	93.5	84.3	71.1	39.3	*18.6*	43.3	101.6	110.9	**166.5**	137.1	1110.8	-112.5 (-10.1%)
	Bracciano 1 (1978-2007)	95.6	91.2	82.6	98.8	63.6	33.5	*21.6*	41.6	78.7	**136.7**	123.7	130.7	998.3	
CER-02	Cerveteri 2 (1951-1980)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	Cerveteri 2 (1978-2007)	59.8	60.7	62.2	68.7	49.1	39.6	*18.6*	37.3	98.6	**126.5**	101.7	95.5	818.3	
CIV-01	Civitavecchia 1 (1951-1980)	84.5	81.6	65.7	50.9	38.6	21.7	*11.1*	22.6	54.1	77.8	**104.5**	79.6	692.7	-123.7 (-17.9%)
	Civitavecchia 1 (1978-2007)	55.3	47.1	45.5	54.6	30.1	19.1	*15.3*	20.3	52.9	**99.4**	70.4	67.0	569.0	
FRE	Fregene (1951-1980)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	Fregene (1978-2007)	50.2	41.6	41.2	54.3	37.1	16.0	*10.9*	20.0	62.5	**86.1**	67.6	74.1	561.6	
LAD	Ladispoli (1951-1980)	95.4	78.8	68.3	54.2	44.9	23.4	*7.8*	27.5	83.6	83.2	**129.2**	91.5	787.8	-47.9 (-6.1%)
	Ladispoli (1978-2007)	77.2	62.8	60.3	72.7	38.9	27.9	*10.0*	27.2	64.0	**119.0**	89.9	90.0	739.9	
MAC	Maccarese (1951-1980)	93.5	83.7	74.6	51.9	41.6	23.6	*10.1*	28.2	79.4	89.6	**138.3**	92.5	807.1	-149.5 (-18.5%)
	Maccarese (1978-2007)	67.0	63.5	51.4	53.6	27.1	*17.3*	19.7	21.8	62.5	**106.4**	82.4	90.4	657.6	
PAN	Pantano Tarquinia (1951-1980)	80.3	82.2	75.1	51.4	37.1	26.1	*10.1*	26.1	54.4	82.9	**113.6**	88.7	727.9	-100.4 (-13.8%)
	Pantano Tarquinia (1978-2007)	66.0	49.8	50.8	55.4	41.0	21.2	*12.2*	18.8	49.2	**108.6**	100.7	64.4	627.5	
ROT	Rota (1951-1980)	129.7	127.7	91.6	83.4	67.8	45.4	*18.4*	41.1	87.3	132.1	**157.2**	136.0	1117.8	-203.8 (-18.2%)
	Rota (1978-2007)	92.6	76.8	76.5	89.3	56.9	32.6	*16.3*	26.7	76.0	**130.5**	129.3	110.7	914.0	
SAS	Sasso Furbara (1951-1980)	128.9	105.8	91.4	75.6	56.2	35.9	*17.3*	31.8	74.2	94.7	**138.9**	121.8	972.6	+1.1 (+0.1%)
	Sasso Furbara (1978-2007)	87.7	91.4	83.8	91.8	62.0	38.5	*14.2*	32.0	78.8	136.3	**137.1**	118.2	973.7	
TAR-01	Tarquinia 1 (1951-1980)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
	Tarquinia 1 (1978-2007)	50.3	45.6	47.3	40.7	35.9	19.9	*7.3*	31.4	54.5	**105.1**	85.2	71.4	594.5	
TAR-02	Tarquinia 2 (1951-1980)	70.1	81.5	56.4	45.9	40.4	27.4	*10.7*	28.7	59.9	77.5	**94.2**	77.6	670.4	-29.3 (-4.4%)
	Tarquinia 2 (1978-2007)	58.8	53.0	53.4	54.7	40.9	22.8	*15.0*	28.9	58.6	**94.9**	85.5	80.4	641.1	

*Variation in Annual Rainfall was obtained subtracting the Average Annual Rainfall of the period 1978-2007 to the Average Annual Rainfall of the period 1951-1980.

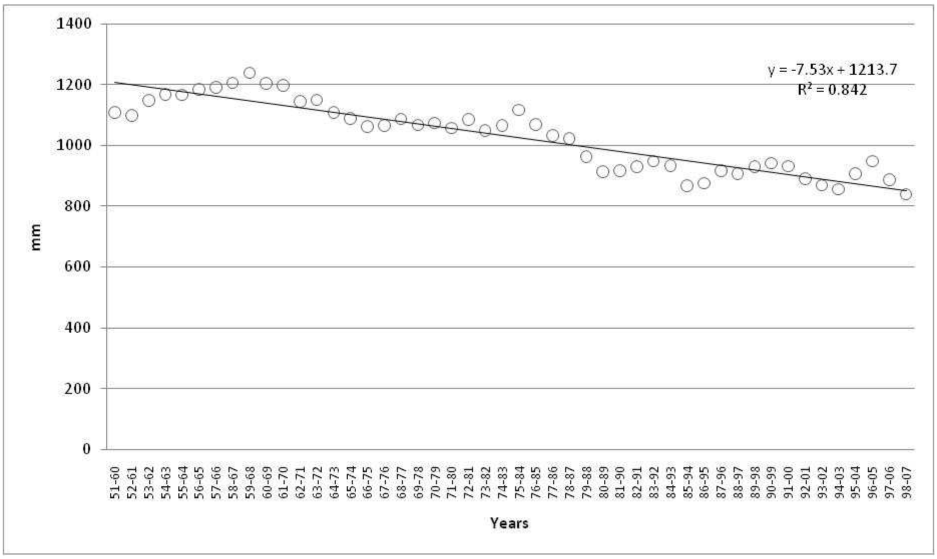


Figure 3. *Moving average of annual rainfall measured at the Rota station with the related trend line and R-squared value*

Temperature regimes

The Ordinary Kriging map of annual medium temperature is showed in *Fig. 4*. The coastal area of Civitavecchia showed to be the hottest area, while the Tolfa hilly area the coldest one.

During the period 1951-1980 (*Table 2*) the hottest months were August and July, with average medium temperatures between 21.6 °C (Allumiere) and 23.9 °C (Civitavecchia 2). Gauging stations that are located along the coast (stations of Civitavecchia, Fregene, Ladispoli, Maccarese, Palo Laziale 2, Pantano Tarquinia, Tarquinia 1 and Tarquinia 2) registered an average annual temperature of 15.9 °C. In inland areas (Allumiere, Anguillara Sabazia, Bracciano 1, Cerveteri 2, Rota, Sasso Furbara and Vigna di Valle) the average annual temperature was lower (14.8 °C). The highest value of the monthly average of maximum temperature (27.5 °C) was registered at the gauging station of Maccarese. The coldest month was January with the lowest values for Allumiere (6.5 °C medium temperature and 3.3 °C minimum temperature). The average minimum temperatures never fell below 0 °C, except in one monthly registration at Vigna di Valle (-1.4 °C in February 1956).

During the period 1978-2007 (*Table 2*) the hottest months were July and August, with average temperatures between 22.2 °C (Allumiere) and 25.1 °C (Civitavecchia 1). At sea level (same stations as above), the average annual temperature was 16.6 °C, while in the inland area was lower (15.2 °C). The highest values of maximum temperature were registered in August (mainly) with values ranging from 27.8 °C (Civitavecchia 1) to 26.3 °C in July at the station of Allumiere. The coldest months were January and February, with the lowest value for Allumiere (6.1 °C medium temperature and 3.4 °C minimum temperature). The average minimum temperature never fell below 0 °C, except in one monthly registration of Allumiere (-0.5 °C, January of 1981).

In all stations, the comparison of the two temperature datasets indicated that the annual average temperature increased from 0.1 °C to 1.0 °C. The increase in temperature was higher for minimum temperature than for maximum temperature, generally for all the considered stations. In all stations, the maximum temperature increased during the Summer, with a variable trend for the other seasons. The moving averages of mean annual temperature (calculated for the thermo-gauging stations) generally showed an increasing trend. *Fig. 5* shows the moving average of the minimum annual temperature of the station of Vigna di Valle.

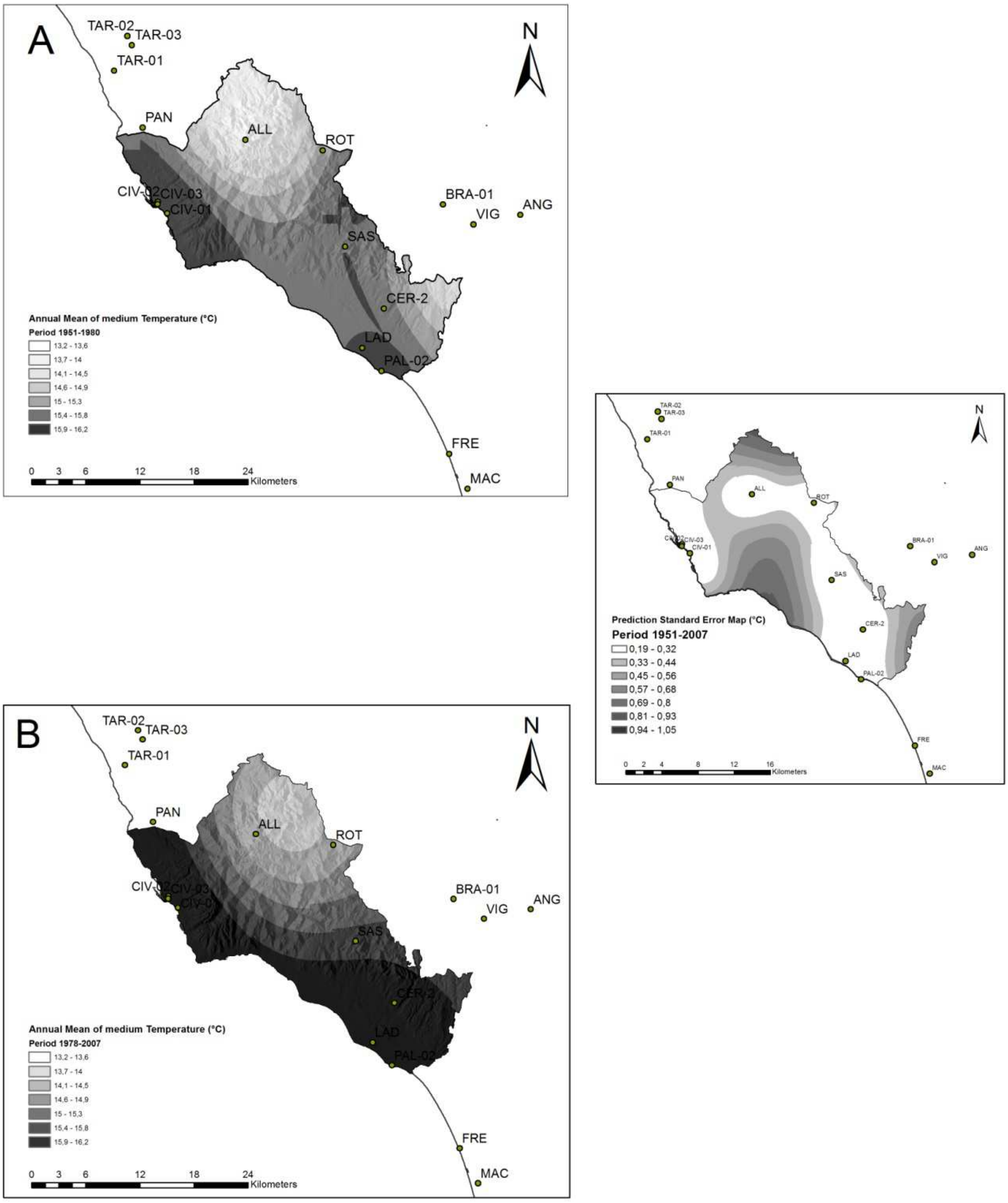


Figure 4. *Ordinary Kriging spatialization of annual mean medium temperature (in °C) considering the periods 1951-1980 (a) and 1978-2007 (b) and standard error map related to the whole period*

Table 2. *Average monthly and annual values of medium temperature (in °C) for the two periods (1951-1980 and 1978-2007). The variation in temperature was calculated subtracting the more recent period to the first one. The coldest months are in bold, the hottest months in italic*

Code	Station	Jan (°C)	Feb (°C)	Mar (°C)	Apr (°C)	May (°C)	Jun (°C)	Jul (°C)	Aug (°C)	Sep (°C)	Oct (°C)	Nov (°C)	Dec (°C)	Annual (°C)	Variation ** °C)
ALL	Allumiere (1951-1980)	**6.5**	7.0	9.0	11.6	15.7	19.2	*21.6*	21.4	18.9	14.8	10.6	7.3	13.6	0.4
	Allumiere (1978-2007)	**6.1**	6.6	8.9	11.4	16.0	19.7	*22.2*	22.1	19.0	15.3	10.2	7.2	13.7	
ANG	*Anguillara Sabazia (1951-1980)	**8.4**	9.0	10.6	12.9	16.9	20.4	22.7	*22.9*	20.8	16.9	12.7	9.3	15.3	0.5
	*Anguillara Sabazia (1978-2007)	**8.6**	9.1	11.0	13.2	17.5	21.0	23.2	*23.7*	21.3	17.8	12.9	9.8	15.8	
BRA-01	Bracciano 1 (1951-1980)	**7.7**	8.6	10.5	12.4	16.8	20.2	21.7	*22.8*	20.4	16.7	12.1	8.7	14.9	0.4
	Bracciano 1 (1978-2007)	**7.9**	8.6	10.7	13.0	17.6	21.1	22.0	*23.1*	20.8	17.0	12.2	9.1	15.3	
CER-02	*Cerveteri 2 (1951-1980)	**8.8**	9.4	10.9	13.2	17.1	20.6	22.9	*23.2*	21.1	17.3	13.2	9.8	15.6	0.6
	*Cerveteri 2 (1978-2007)	**9.1**	9.6	11.4	13.5	17.7	21.3	23.5	*24.0*	21.7	18.3	13.5	10.4	16.2	
CIV-02	Civitavecchia 1 (1951-1980)	**9.2**	9.8	11.4	13.7	17.5	21.2	23.6	*23.8*	21.5	17.8	13.9	10.4	16.2	1.0
	Civitavecchia 1 (1978-2007)	**10.2**	10.7	12.4	14.6	18.8	22.2	24.5	*25.1*	22.6	19.3	14.6	11.5	17.2	
CIV-02	Civitavecchia 2 (1951-1980)	**9.6**	10.2	11.3	13.7	17.6	21.0	23.7	*23.9*	21.8	17.8	13.8	10.6	16.2	0.4
	Civitavecchia 2 (1978-2007)	**10.1**	10.2	11.9	13.7	17.7	21.2	23.6	*24.4*	22.0	18.9	14.5	11.3	16.6	
CIV-03	Civitavecchia 3 (1951-1980)	**10.0**	10.6	11.7	13.6	17.0	20.5	23.1	*23.5*	21.4	17.9	14.1	11.0	16.2	0.5
	Civitavecchia 3 (1978-2007)	**9.8**	10.2	11.9	13.9	17.8	21.4	24.2	*24.5*	22.6	18.9	14.1	11.1	16.7	
FRE	*Fregene (1951-1980)	**9.2**	9.8	11.2	13.5	17.3	20.8	23.2	*23.5*	21.5	17.7	13.6	10.2	16.0	0.6
	*Fregene (1978-2007)	**9.7**	10.1	11.8	13.9	18.0	21.5	23.7	*24.3*	22.1	18.8	14.0	10.9	16.6	
LAD	*Ladispoli (1951-1980)	**9.2**	9.8	11.2	13.5	17.3	20.8	23.2	*23.5*	21.4	17.7	13.6	10.2	15.9	0.6
	*Ladispoli (1978-2007)	**9.6**	10.1	11.8	13.8	18.0	21.5	23.7	*24.3*	22.1	18.7	14.0	10.9	16.5	
MAC	Maccarese (1951-1980)	**8.3**	9.1	10.6	13.1	17.1	20.5	22.5	*22.7*	20.8	17.0	13.1	9.2	15.3	0.7
	Maccarese (1978-2007)	**9.1**	9.6	11.3	13.4	17.8	21.2	23.1	*23.7*	21.4	18.4	13.4	10.2	16.0	
PAL-02	*Palo Laziale 2 (1951-1980)	**9.2**	9.8	11.2	13.5	17.3	20.8	23.2	*23.5*	21.4	17.7	13.6	10.2	15.9	0.7
	*Palo Laziale 2 (1978-2007)	**9.7**	10.1	11.8	13.8	18.0	21.5	23.7	*24.3*	22.1	18.8	14.0	10.9	16.6	
PAN	*Pantano Tarquinia (1951-1980)	**9.0**	9.6	11.1	13.3	17.2	20.7	23.1	*23.3*	21.3	17.5	13.4	10.0	15.8	0.6
	*Pantano Tarquinia (1978-2007)	**9.4**	9.9	11.6	13.7	17.9	21.4	23.6	*24.2*	21.9	18.5	13.8	10.6	16.4	
ROT	*Rota (1951-1980)	**8.2**	8.8	10.5	12.8	16.8	20.3	22.6	*22.8*	20.6	16.7	12.5	9.1	15.1	0.5
	*Rota (1978-2007)	**8.4**	8.9	10.9	13.0	17.4	20.9	23.1	*23.6*	21.1	17.6	12.7	9.6	15.6	
SAS	*Sasso Furbara (1951-1980)	**7.6**	8.2	10.0	12.3	16.4	20.0	22.2	*22.4*	20.1	16.1	11.8	8.5	14.6	0.4
	*Sasso Furbara (1978-2007)	**7.6**	8.1	10.2	12.5	17.0	20.6	22.7	*23.1*	20.4	16.8	11.9	8.8	15.0	
TAR-01	*Tarquinia 1 (1951-1980)	**9.2**	9.8	11.2	13.5	17.3	20.8	23.2	*23.5*	21.5	17.7	13.6	10.2	15.9	0.7
	*Tarquinia 1 (1978-2007)	**9.8**	10.1	11.8	13.8	18.0	21.5	23.7	*24.3*	22.1	18.8	14.0	10.9	16.6	
TAR-02	*Tarquinia 2 (1951-1980)	**9.1**	9.7	11.2	13.4	17.3	20.8	23.1	*23.4*	21.4	17.6	13.5	10.1	15.9	0.6
	*Tarquinia 2 (1978-2007)	**9.6**	10.0	11.8	13.8	18.0	21.5	23.7	*24.3*	22.1	18.7	13.9	10.8	16.5	
TAR-03	*Tarquinia Portaccia (1951-1980)	**9.1**	9.7	11.2	13.4	17.3	20.8	23.1	*23.4*	21.4	17.6	13.5	10.1	15.9	0.6
	*Tarquinia Portaccia (1978-2007)	**9.6**	10.0	11.7	13.8	18.0	21.5	23.7	*24.3*	22.0	18.7	13.9	10.8	16.5	
VIG	Vigna di Valle (1951-1980)	**6.9**	7.7	9.4	11.9	16.2	20.0	*22.3*	22.1	20.0	15.6	11.1	7.8	14.3	0.4
	*Vigna di Valle (1978-2007)	**7.2**	7.8	9.9	12.1	16.7	20.4	22.8	*22.9*	20.4	16.5	11.4	8.3	14.7	

* Values interpolated using the linear regression method.

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**Variation in Annual Mean Medium Temperature was obtained subtracting the Annual Mean Medium Temperature of the period 1978-2007 to the Annual Mean Medium Temperature of the period 1951-1980

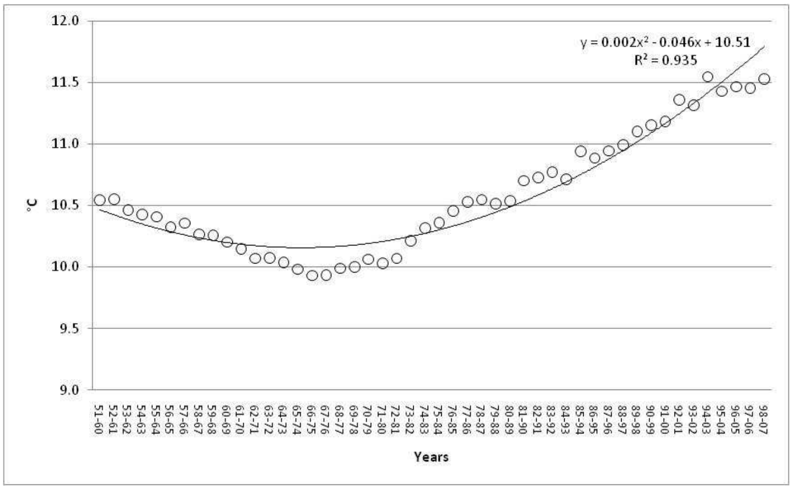


***Figure 5.** Moving average of the annual minimum temperature at the station of Vigna di Valle with the related trend line and R-squared value*

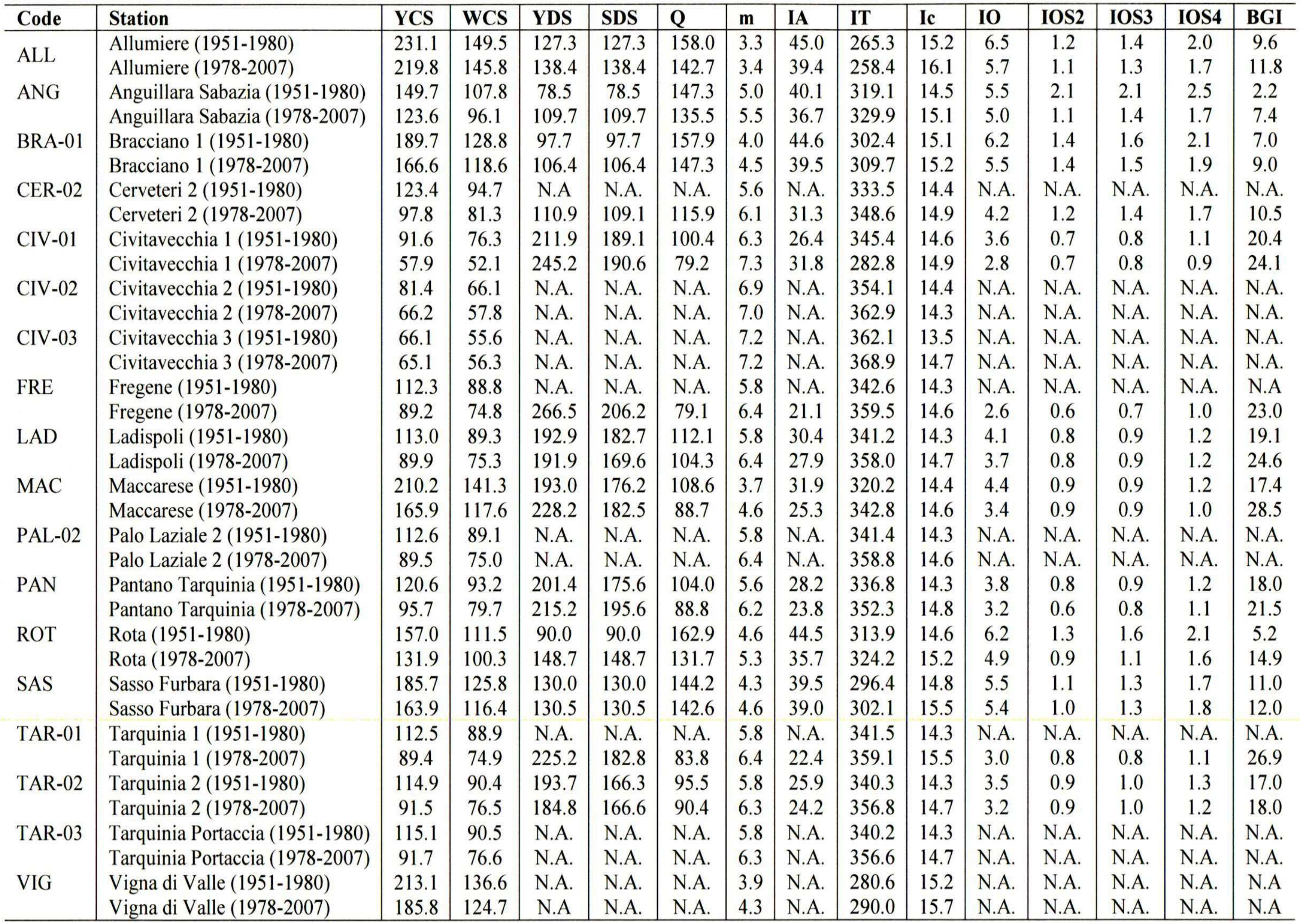
Bioclimatic Indexes

During the period 1951-1980 (*Table 3*), the calculation of Mitrakos indexes showed that the station with the higher drought stress (both annual and Summer) was Civitavecchia 1. The station with the highest cold stress (both annual and Winter) was Allumiere. According to the bioclimatic classification of Emberger (Q), all stations with available data were classified as humid. According to the elaboration of Rivas Martinez indexes, all the gauging stations belonged to the Mediterranean area, excluding Bracciano, Anguillara Sabazia and Rota, which classified within the Temperate area. The values of the BGI indicated a humid climate for all the stations.

During the period 1978-2007 (*Table 3*), the calculation of Mitrakos indexes showed that the station with the highest drought stress (both annual and Summer) was Fregene. The station with the highest cold stress (both annual and Winter) was Allumiere. According to the bioclimatic classification of Emberger (Q), Allumiere, Anguillara Sabazia, Bracciano 1, Cerveteri 2, Ladispoli, Rota, Sasso Furbara and Tarquinia 2 were humid, while Civitavecchia 1, Fregene, Maccarese, Pantano Tarquinia and Tarquinia 1 were sub-humid. According to the elaboration of Rivas Martinez indexes all the gauging stations belonged to the Mediterranean area.

The comparison of Mitrakos indexes shows that, for all the stations, the annual and Winter cold stresses have markedly decreased in a percentage ranging from 1.3% to 31.7%. Summer drought stress has increased for the majority of stations (not for Ladispoli); the annual drought stress has increased too (but not for Ladispoli and Tarquinia 2). The Emberger biclimatic classification of Civitavecchia 1, Fregene, Maccarese, Pantano Tarquinia and Tarquinia 1 shifted from humid to sub humid. According to the Rivas Martinez classification all the stations that were classified as Temperate shifted into the Mediterranean belt. According to the Rivas Martinez classification three stations (Allumiere, Bracciano 1 and Rota) change their ombrotype (Rivas Martinez 1993) from humid to sub-humid; other three other stations (Civitavecchia 1 and Maccarese and Pantano Tarquinia) changed from sub-humid to dry. The variations of the BGI values over the two periods are showed in *Fig. 6*.

Table 3. *Bioclimatic Indexes values for the two periods (1951-1980 and 1978-2007). YCS= Year Cold Stress; WCS= Winter Cold Stress; YDS= Year Drought Stress; SDS= Summer Drought Stress; Q= Emberger rainfall index; AI= De Martonne Aridity Index; IT= Thermicity Index; Ic= Continentality Index; IO= Ombrothermic Index; IOS2= Ombrothermic Index of the warmest two months of Summer; IOS3= Ombrothermic Index of Summer; IOS4= Ombrothermic Index of Summer plus the previous month); BGI= Bagnouls-Gaussen Aridity Index*



Code	Station	YCS	WCS	YDS	SDS	Q	m	IA	IT	Ic	IO	IOS2	IOS3	IOS4	BGI
ALL	Allumiere (1951-1980)	231.1	149.5	127.3	127.3	158.0	3.3	45.0	265.3	15.2	6.5	1.2	1.4	2.0	9.6
	Allumiere (1978-2007)	219.8	145.8	138.4	138.4	142.7	3.4	39.4	258.4	16.1	5.7	1.1	1.3	1.7	11.8
ANG	Anguillara Sabazia (1951-1980)	149.7	107.8	78.5	78.5	147.3	5.0	40.1	319.1	14.5	5.5	2.1	2.1	2.5	2.2
	Anguillara Sabazia (1978-2007)	123.6	96.1	109.7	109.7	135.5	5.5	36.7	329.9	15.1	5.0	1.1	1.4	1.7	7.4
BRA-01	Bracciano 1 (1951-1980)	189.7	128.8	97.7	97.7	157.9	4.0	44.6	302.4	15.1	6.2	1.4	1.6	2.1	7.0
	Bracciano 1 (1978-2007)	166.6	118.6	106.4	106.4	147.3	4.5	39.5	309.7	15.2	5.5	1.4	1.5	1.9	9.0
CER-02	Cerveteri 2 (1951-1980)	123.4	94.7	N.A	N.A.	N.A.	5.6	N.A.	333.5	14.4	N.A.	N.A.	N.A.	N.A.	N.A.
	Cerveteri 2 (1978-2007)	97.8	81.3	110.9	109.1	115.9	6.1	31.3	348.6	14.9	4.2	1.2	1.4	1.7	10.5
CIV-01	Civitavecchia 1 (1951-1980)	91.6	76.3	211.9	189.1	100.4	6.3	26.4	345.4	14.6	3.6	0.7	0.8	1.1	20.4
	Civitavecchia 1 (1978-2007)	57.9	52.1	245.2	190.6	79.2	7.3	31.8	282.8	14.9	2.8	0.7	0.8	0.9	24.1
CIV-02	Civitavecchia 2 (1951-1980)	81.4	66.1	N.A.	N.A.	N.A.	6.9	N.A.	354.1	14.4	N.A.	N.A.	N.A.	N.A.	N.A.
	Civitavecchia 2 (1978-2007)	66.2	57.8	N.A.	N.A.	N.A.	7.0	N.A.	362.9	14.3	N.A.	N.A.	N.A.	N.A.	N.A.
CIV-03	Civitavecchia 3 (1951-1980)	66.1	55.6	N.A.	N.A.	N.A.	7.2	N.A.	362.1	13.5	N.A.	N.A.	N.A.	N.A.	N.A.
	Civitavecchia 3 (1978-2007)	65.1	56.3	N.A.	N.A.	N.A.	7.2	N.A.	368.9	14.7	N.A.	N.A.	N.A.	N.A.	N.A.
FRE	Fregene (1951-1980)	112.3	88.8	N.A.	N.A.	N.A.	5.8	N.A.	342.6	14.3	N.A.	N.A.	N.A.	N.A.	N.A
	Fregene (1978-2007)	89.2	74.8	266.5	206.2	79.1	6.4	21.1	359.5	14.6	2.6	0.6	0.7	1.0	23.0
LAD	Ladispoli (1951-1980)	113.0	89.3	192.9	182.7	112.1	5.8	30.4	341.2	14.3	4.1	0.8	0.9	1.2	19.1
	Ladispoli (1978-2007)	89.9	75.3	191.9	169.6	104.3	6.4	27.9	358.0	14.7	3.7	0.8	0.9	1.2	24.6
MAC	Maccarese (1951-1980)	210.2	141.3	193.0	176.2	108.6	3.7	31.9	320.2	14.4	4.4	0.9	0.9	1.2	17.4
	Maccarese (1978-2007)	165.9	117.6	228.2	182.5	88.7	4.6	25.3	342.8	14.6	3.4	0.9	0.9	1.0	28.5
PAL-02	Palo Laziale 2 (1951-1980)	112.6	89.1	N.A.	N.A.	N.A.	5.8	N.A.	341.4	14.3	N.A.	N.A.	N.A.	N.A.	N.A.
	Palo Laziale 2 (1978-2007)	89.5	75.0	N.A.	N.A.	N.A.	6.4	N.A.	358.8	14.6	N.A.	N.A.	N.A.	N.A.	N.A.
PAN	Pantano Tarquinia (1951-1980)	120.6	93.2	201.4	175.6	104.0	5.6	28.2	336.8	14.3	3.8	0.8	0.9	1.2	18.0
	Pantano Tarquinia (1978-2007)	95.7	79.7	215.2	195.6	88.8	6.2	23.8	352.3	14.8	3.2	0.6	0.8	1.1	21.5
ROT	Rota (1951-1980)	157.0	111.5	90.0	90.0	162.9	4.6	44.5	313.9	14.6	6.2	1.3	1.6	2.1	5.2
	Rota (1978-2007)	131.9	100.3	148.7	148.7	131.7	5.3	35.7	324.2	15.2	4.9	0.9	1.1	1.6	14.9
SAS	Sasso Furbara (1951-1980)	185.7	125.8	130.0	130.0	144.2	4.3	39.5	296.4	14.8	5.5	1.1	1.3	1.7	11.0
	Sasso Furbara (1978-2007)	163.9	116.4	130.5	130.5	142.6	4.6	39.0	302.1	15.5	5.4	1.0	1.3	1.8	12.0
TAR-01	Tarquinia 1 (1951-1980)	112.5	88.9	N.A.	N.A.	N.A.	5.8	N.A.	341.5	14.3	N.A.	N.A.	N.A.	N.A.	N.A.
	Tarquinia 1 (1978-2007)	89.4	74.9	225.2	182.8	83.8	6.4	22.4	359.1	15.5	3.0	0.8	0.8	1.1	26.9
TAR-02	Tarquinia 2 (1951-1980)	114.9	90.4	193.7	166.3	95.5	5.8	25.9	340.3	14.3	3.5	0.9	1.0	1.3	17.0
	Tarquinia 2 (1978-2007)	91.5	76.5	184.8	166.6	90.4	6.3	24.2	356.8	14.7	3.2	0.9	1.0	1.2	18.0
TAR-03	Tarquinia Portaccia (1951-1980)	115.1	90.5	N.A.	N.A.	N.A.	5.8	N.A.	340.2	14.3	N.A.	N.A.	N.A.	N.A.	N.A.
	Tarquinia Portaccia (1978-2007)	91.7	76.6	N.A.	N.A.	N.A.	6.3	N.A.	356.6	14.7	N.A.	N.A.	N.A.	N.A.	N.A.
VIG	Vigna di Valle (1951-1980)	213.1	136.6	N.A.	N.A.	N.A.	3.9	N.A.	280.6	15.2	N.A.	N.A.	N.A.	N.A.	N.A
	Vigna di Valle (1978-2007)	185.8	124.7	N.A	N.A.	N.A.	4.3	N.A.	290.0	15.7	N.A.	N.A.	N.A.	N.A.	N.A

N.A.=Not Available

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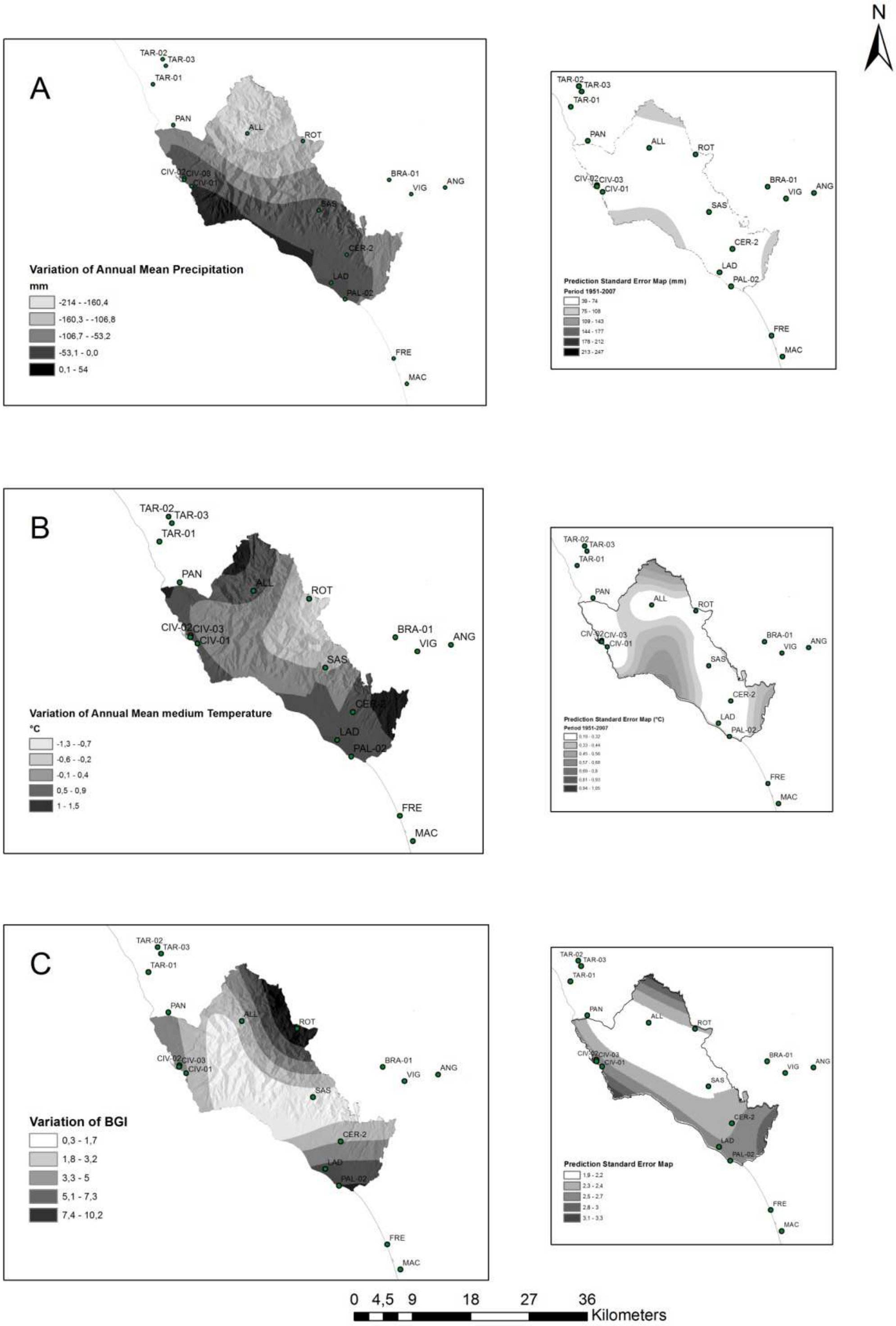

Figure 6. Ordinary Kriging spatialization of the variation of the annual mean precipitation (a), annual mean of medium temperature (b) and of the BGI value (c). Related standard error maps are on the right

Climate change and vegetation

According to our analyses, the broadleaf forests are the most affected by decrease in annual rainfall amount (*Table 4*) in the study area. Woodlands belonging to the vegetation association *Carpino-betuli-Coryletum avellanae*, which are located in narrow valleys on tuff substrata (Fanelli et al., 2007), were subjected to an average decrease of rainfall of 196.4 mm over thirty years (the whole area, on average, had a annual rainfall of 896.3 mm for the period 1951-1980 and of 767.2 mm for the second period). Temperate woodlands dominated by *Quercus robur* L. (*Hieracio racemosi-Quercetum petraeae* Pedrotti, Ballelli, Biondi 1982) experienced a decrease in rainfall that ranges from a minimum of 46.0 mm to a maximum of 214.3 mm (-188.7 mm on average). Chestnut forests of the *Carpinion* alliance, located on acid vulcanite soils, experienced an average decrease of 187.0 mm while the forest communities dominated by *Fagus sylvatica* L. and *Ilex aquifolium* L. [*Anemono apenninae-Fagetum sylvaticae* (Gentile 1969) Brullo 1984] in Allumiere were subjected to a decrease of 180.0 mm of rainfall (*Fig. 7*).

An average decrease of 161.2 mm of rainfall was calculated for the thermophilous sub-acidophilus woodland dominated by *Quercus cerris* L. [*Rubio-Quercetum cerridis* (Pignatti E. e S., 1968) Bas Petroli et al. (1988)], which is the most widespread woodland. *Quercus ilex* L. forests [*Viburno-Quercetum ilicis* (Br.-Bl. 1936) Rivas-Martinez, 1975] were not really affected by a decrease in rainfall (only 27 mm). The acidophilus community *Rusco aculeati-Quercetum ilicis* Biondi, Gigante, Pignateli, Venanzoni 2002 var. *Erica arborea* L. experienced an average decrease of 144.0 mm of rainfall. Some pastures also faced an important reduction of rainfall: e.g., meadows with *Gaudinia fragilis* (L.) P. Beauv. and *Cynosurus cristatus* L. (-169.7 mm) (*Gaudinio-Cynosurietum cristati* Fanelli 1997), prairies dominated by *Dasypyrum villosum* (L.) Borbàs (*Vulpio-Dasypiretum* Fanelli 1998) (-92.0 mm).

The plant communities more heavily affected by temperature increases are the igrophilous broadleaf woodlands of the flood plains. Specifically, the alluvial forests dominated by *Alnus glutinosa* (L.) Gaertn. (*Aro italici-Alnetum glutinosae* Pedrotti and Gafta 1996) and the riparian poplar woodlands (*Populetum albae* Tchou Yen-Cheng 1949) faced a temperature increase of 0.8 °C (average of the annual medium temperature). The alophilous and sub-alophilous communities of dunes experienced an increase of 0.7 °C. A moderate increase of temperature was also calculated for *Castanea sativa* forests of the *Carpinion* alliance (0.5 °C).

Aridity index calculations display that shrub communities faced the highest aridity increase, including evolving stadia of the Mediterranean *Quercus cerris* woodland (8.54) and communities of the *Rusco aculeati-Quercetum ilicis* Biondi, Gigante, Pignateli, Venanzoni 2002 var. *Erica arborea* L. (7.02). Woodlands of *Carpinus betulus* L. and *Corylus avellana* L. (*Carpino betuli-Coryletum avellanae* 1982 Ballelli, Biondi & Pedrotti 1980) (5.81) also faced an increase of aridity. Among the forests, an increase of aridity was also calculated for the re-colonizing woodland dominated by *Quercus pubescens* (*Roso sempervirentis-Quercetum* pubescentis Biondi 1986) (5.05) (BGI shifting from 0.58 to 9.98 in different localities).

Table 4. *Zonal statistic analysis of the annual mean precipitation, annual mean of medium temperature and of the BGI value [with the related surface area (Area), Minimum (min), Maximum (max), Mean (Mean) and standard deviation (STD)] in relation to vegetation syntaxa (from Fanelli et al., 2007, mod)*

	Temperature					Precipitation					BGI				
Vegetation Syntaxa	Area (ha)	Min	Max	Mean	STD	Area (ha)	Min	Max	Mean	STD	Area (ha)	Min	Max	Mean	STD
Alophilous and sub-alophilous vegetation of dunes	43.3	0.56	1.21	0.72	0.18	43.3	-70.06	10.58	-23.87	36.22	432.5	1.30	4.70	2.90	1.56
Anemono apenninae-Fagetum sylvaticae (Gentile 1969) Brullo 1984	43.8	0.42	0.51	0.46	0.02	44.6	-184.41	-173.48	-180.02	3.06	437.5	1.94	2.79	2.33	0.21
Aro italici-Alnetum glutinosae Pedrotti and Gafta 1996	2.8	0.78	0.81	0.80	0.01	2.0	-45.65	-41.44	-43.21	1.41	27.5	2.01	2.24	2.15	0.08
Aro italici-Ulmetum minoris Rivas-Martýnez ex Lopez 1976	2.0	0.38	0.41	0.40	0.01	2.5	1.29	5.04	3.58	1.23	20.0	0.53	0.61	0.57	0.03
Arundinetum pliniane Biondi, Brugiapaglia, Allegrezza et Ballelli 1992	0.8	0.38	0.39	0.38	0.01	0.8	1.45	2.25	1.85	0.32	7.5	0.53	0.56	0.55	0.01
Arundini donax-Convolvoletum sepium R. Tx. et Oberd. Ex O. Bol_s 1962	49.8	0.23	0.73	0.54	0.15	49.6	-32.73	35.52	-7.17	18.11	497.5	0.33	6.48	3.39	1.53
Asparago acutifolii-Ostryetum carpinifoliae Biondi 1982	539.3	-0.79	0.89	0.02	0.54	539.0	-214.02	-34.45	-120.32	72.89	5392.5	0.44	6.68	3.13	1.60
Associations of the *Cistion ladaniferi* Br.-Bl. 1940	0.3	0.74	0.74	0.74	0.00	0.3	-193.46	-193.46	-193.46	0.00	2.5	2.50	2.50	2.50	0.00
Association with *Phragmites australis* (Cav.) Trin. Ex Steud and *Arundo donax* L.	0.8	0.78	0.79	0.79	0.00	1.5	-61.02	-59.70	-60.38	0.45	7.5	4.66	4.67	4.67	0.01
Association with *Rubus ulmifolius* Schott and *Rubus caesius* L.	143.0	-0.60	1.43	0.51	0.47	143.0	-200.84	34.31	-46.04	55.91	1430.0	0.56	7.67	2.95	1.62
Association with *Spartium junceum* L.	76.8	-0.10	0.97	0.50	0.38	75.4	-211.67	37.31	-83.76	95.82	767.5	0.31	4.66	2.05	1.28
Association with *Spartium junceum* L. and *Rubus ulmifolius* Schott	3.0	0.47	0.50	0.49	0.01	4.0	-45.63	-42.90	-44.38	0.84	30.0	1.31	1.34	1.32	0.01
Associations of the *Pruno-Rubion*	260.0	-0.57	1.45	0.55	0.36	258.0	-177.19	27.46	-74.17	46.78	2600.0	0.88	7.88	2.84	1.86
Carici remotae-Fraxinetum oxycarpae (Koch ex Faber 1936) Pedrotti (1970) 1992	0.8	0.23	0.23	0.23	0.00	0.5	24.83	25.09	24.96	0.13	7.5	0.69	0.72	0.70	0.01
Carpino betuli-Coryletum avellanae 1982 Ballelli, Biondi & Pedrotti 1980	1.0	0.22	0.24	0.23	0.01	0.5	-196.49	-196.34	-196.42	0.07	10.0	5.77	5.85	5.81	0.03
Cercidi-Aceretum monspessulani Lucchese e Pignatti 1998	103.0	-0.99	0.59	0.04	0.26	104.4	-212.01	-50.30	-142.27	39.31	1030.0	1.02	8.73	3.00	2.56
Chestnut forests of the *Carpinion* alliance	174.5	-0.22	0.95	0.50	0.27	170.3	-205.52	-112.63	-186.97	13.97	1745.0	1.91	4.96	2.99	0.63
Community with *Rubus ulmifolius* Schott sensu Fanelli 2002	111.0	-0.27	1.42	0.25	0.44	111.9	-205.24	4.30	-93.58	55.48	1110.0	0.31	7.67	2.16	1.82
Cynaro-Cichorietum pumili Lucchese et Pignatti 1990	955.5	-0.92	1.31	-0.01	0.43	953.2	-212.57	44.98	-72.62	46.58	9555.0	0.30	9.78	2.46	2.33
Cytiso villosi-Quercetum suberis Testi, Lucattini et Pignatti 1994	217.5	-0.05	0.72	0.25	0.15	216.1	-178.55	-15.93	-66.58	42.65	2175.0	0.60	3.64	1.47	0.61
Evolving stadia of *Aceri-Quercetum ilicis* Brullo e Marcenò 1984	1.5	0.23	0.23	0.23	0.00	1.5	2.55	3.57	3.13	0.32	15.0	0.44	0.46	0.45	0.01
Evolving stadia of *Quercus cerris* L. forests	7.8	-0.46	-0.40	-0.43	0.02	7.5	-177.97	-175.82	-176.97	0.57	77.5	8.30	8.75	8.54	0.11
Fraxino orni-Quercetum ilicis Horvatic	365.8	-0.64	1.49	0.43	0.44	360.6	-214.05	-11.01	-94.18	73.74	3657.5	0.51	7.48	2.59	1.79

(1956) 1958														
Gaudinio-Cynosurietum cristati Fanelli 1997	6.8	0.03	0.21	0.08	0.06	7.3	-170.99	-168.27	-169.73	0.64	67.5	2.82	3.87	3.57	0.34
Hieracio racemosi-Quercetum petraeae Pedrotti, Ballelli, Biondi 1982	1037.3	-0.72	0.88	0.36	0.26	1034.1	-214.28	-46.01	-188.72	21.01	10372.5	1.08	8.77	4.31	1.85
Laguro ovati-Dasypiretum villosi Fanelli 1998	559.0	-0.01	1.24	0.31	0.20	561.7	-67.43	47.67	-5.06	18.36	5590.0	0.31	4.99	1.45	0.94
Lonicero etruscae-Rosetum sempervirentis Cutini, Fabozzi, Fortini, Armanini, Blasi 1996	375.8	-0.94	1.01	0.13	0.34	375.4	-208.43	45.55	-74.07	67.06	3757.5	0.49	9.46	2.07	2.03
Mespilo germanicae-Quercetum frainetto Biondi, Gigante, Pignatelli, Venanzoni 2001	6449.5	-1.17	1.49	-0.06	0.47	6424.8	-165.70	-13.88	-60.58	25.32	64495.0	0.34	8.92	1.81	1.32
Mosaic of alophilous vegetation	42.3	0.67	0.77	0.71	0.03	42.3	-20.89	-12.73	-16.34	2.49	422.5	4.21	5.52	4.97	0.37
Mosaic with *Rubus* sp. pl. and *Prunus* sp. pl.	2.3	0.17	0.21	0.19	0.01	2.5	-33.83	-32.68	-33.34	0.34	22.5	1.07	1.08	1.08	0.00
Pastures of the *Echio-Galaction* with *Pyrus spinosa* Forssk. Trees	3534.0	-1.23	1.10	-0.19	0.54	3542.0	-214.38	26.52	-100.83	56.37	35340.0	0.34	10.13	3.74	2.70
Phragmitetum australis (Allorge 1921) Pignatti 1953	1.8	0.45	0.45	0.45	0.00	1.8	-6.58	-6.39	-6.45	0.06	17.5	3.18	3.38	3.28	0.07
Populetum albae Tchou Yen-Cheng 1949	38.5	0.32	1.44	0.75	0.24	36.3	-191.44	-4.44	-32.41	28.92	385.0	2.03	6.31	4.63	1.19
Potentillo-Polygonetalia	19.0	-0.24	0.62	0.07	0.31	19.5	-101.17	-0.67	-53.88	41.51	190.0	0.43	4.27	2.05	1.19
Prunetalia spinosae R. Tuxen 1952	1939.0	-1.22	1.47	0.09	0.39	1916.4	-213.49	42.80	-110.34	62.95	575.0	1.23	5.29	3.34	1.19
Pruno-Crataegetum Hueck 1931	4.3	0.18	0.22	0.20	0.01	3.8	13.94	17.16	15.78	0.98	42.5	1.17	1.34	1.25	0.06
Querco-Ulmetum Issler 1924	82.0	-0.68	1.47	0.37	0.38	85.2	-176.70	24.46	-35.51	52.89	820.0	0.47	10.04	2.13	1.74
Roso sempervirentis-Quercetum pubescentis Biondi 1986	521.8	-1.06	1.06	-0.05	0.69	522.9	-214.27	29.80	-143.34	60.48	5217.5	0.58	9.98	5.05	2.66
Rubio-Quercetum cerridis (Pignatti E. e S. , 1968) Bas Petroli *et al.* (1988)	6062.8	-1.26	1.02	0.08	0.56	6067.9	-214.39	-30.73	-161.20	38.20	60627.5	0.67	10.15	4.50	2.55
Rusco aculeati-Quercetum ilicis Biondi, Gigante, Pignateli, Venanzoni 2002 var. *Erica arborea* L.	37.5	-1.04	0.75	-0.49	0.79	35.8	-198.90	-32.60	-144.05	38.50	375.0	2.23	8.89	7.02	2.37
Salicetum albae Issler 1926	2.8	-0.31	0.47	0.32	0.29	3.8	-153.45	-19.14	-69.49	47.40	27.5	3.62	4.92	3.89	0.48
Silybo-Urticetum Br.-Bl. 1936	420.5	-0.54	0.87	-0.09	0.20	420.5	-212.14	-34.58	-108.26	39.44	4205.0	0.63	9.96	2.26	2.35
Thero-Brachypodion	1.8	0.41	0.43	0.42	0.00	2.0	-17.45	-15.48	-16.36	0.67	17.5	3.45	3.51	3.48	0.02
Urban areas and cultivated surfaces	25152.2	-1.25	1.50	0.48	0.41	25054.6	-214.29	54.40	-48.32	58.60	251522.0	0.30	10.06	3.13	2.01
Viburno-Quercetum ilicis (Br.-Bl. 1936) Rivas-Martinez 1975	117.8	-0.10	0.74	0.11	0.17	118.2	-77.89	2.16	-27.00	13.95	1177.5	0.30	3.46	0.61	0.67
Viburno-Quercetum ilicis (Br.-Bl. 1936) Rivas-Martinez 1975 with *Phillyrea latifolia* L.	3238.5	-0.09	1.06	0.37	0.32	3233.2	-210.80	46.70	-53.90	67.06	32385.0	0.30	6.67	1.49	0.88
Vulpio-Dasypiretum Fanelli 1998	2550.3	-1.06	1.05	-0.01	0.49	2559.5	-214.39	13.38	-92.06	60.17	25502.5	0.37	9.88	2.55	2.23

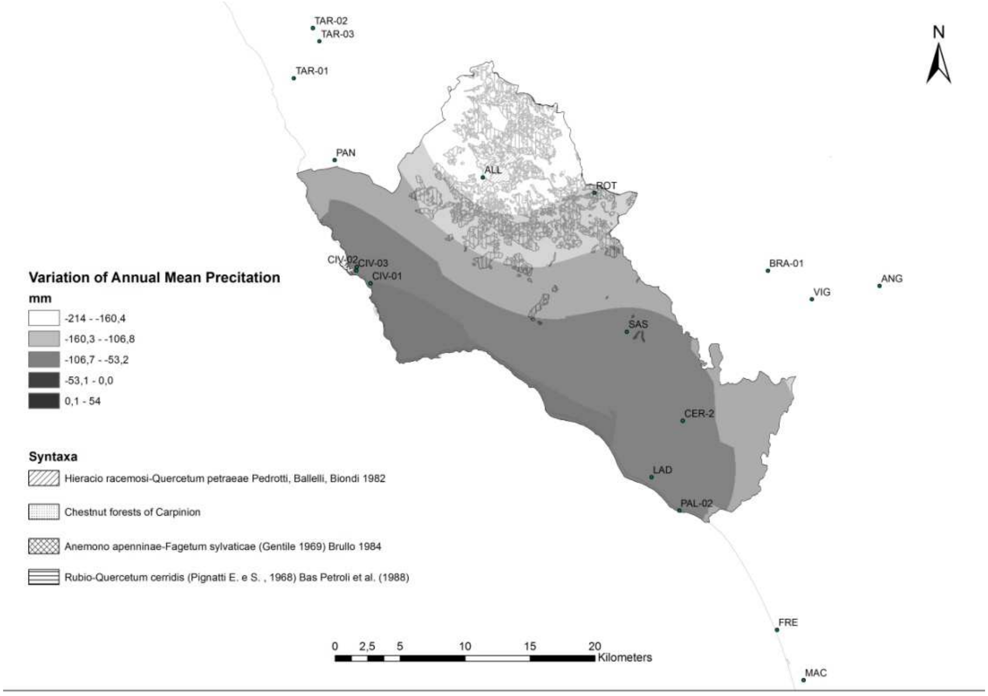

Figure 7. *Forest communities (from Fanelli et al., 2007, mod.) in the area experiencing the highest decrease in annual rainfall*

Discussion

Climate change is a cutting edge topic of research and it has been widely analyzed, predicted and forecasted at regional, national and supranational scale. However, how climate could change is still controversial (especially at local scale), as well as how it could impact plants and other living beings. In the Mediterranean basin, which has strong mesoscale features (Somot et al., 2008), local climatic studies can contribute to provide data in supporting or contrasting provisional models and theories at larger scale. Our research, developed in a Mediterranean-Temperate boundary area (Blasi et al., 1999) could provide useful data in this sense and create a positive background for further studies. Our approach tested different methods, bioclimatic and geostatical, to depict various aspects of the climate change in the Tolfa-Cerite area in relation to vegetation.

Our analysis seems to support the general negative trend in precipitation amount that has been observed in other Mediterranean areas (Giorgi and Lionello, 2008). Projected changes for the future (2071-2100) in rainfall consist in an average reduction of 8-36% (minimum and maximum) in Central Italy (Giorgi and Lionello, 2008). According to our results, precipitations are currently decreasing at comparable rates. Moreover, an increase in temperature has been observed, even if this trend is less evident in the analyzed period. Projected changes in temperature (Giorgi and Lionello, 2008), for the same period, consist in an average increase of 2.7-4.2 °C (minimum and maximum). Analyses suggest that climate change in the study region is trending to greater aridity, and projections of climate change point to a further aridity increase. Current trends in climate conditions and future scenarios have implications for regional scale vegetation as it has been tested for some Mediterranean plant communities or species (Martinez-Vilalta et al., 2002; Thuiller et al., 2004; De Dato et al., 2008; Ogaya et al., 2011).

It was observed a reduction in Autumn rainfall and this phenomenon may reduce the groundwater recharge. This reduction is partially balanced by a certain increase of rainfall during Summer, but this increase, which is expressed in percentage, correspond to a low increase in millimeters of rainfall. This phenomenon is in countertendency at projected increase of Summer drought. Geostatistical methods for the regionalization of rainfall were useful in defining its spatial distribution; the comparison of the two periods provided a visual and immediate output of changes in precipitation patterns. This analysis spotlights a clear decrease in rainfall amounts, especially in the hilly belt, while this decrease is less marked along the coast. This result may be useful in planning *ad hoc* management policies, especially as regards agriculture, irrigation, management of groundwater resources and natural vegetation conservation. Two out of the four forest communities that experienced the highest decrease in rainfall amount are listed in the Habitat Directive (92/43/CEE): the *Castanea* (9260) and *Fagus* forests (9210).

Changes in temperature are less evident, but these results might have been flattened by average values. However, it was possible to highlight a certain increasing trend in temperature, and this increase was higher for minimum than for maximum temperatures. In the study area it seems also that hilly areas were more affected by this increase in temperature values. This trend could be particularly worrying for the Tolfa area since there grow extra-zonal forests of *Fagus sylvatica* and other broad leaf woodlands. An increase of temperature seems to positively affect the growth of this species (Sabatè et al., 2002), but not if associated with a decrease in rainfall (Piovesan et al., 2008).

The area showed transitional bioclimatic features (Blasi et al., 1999) in the first analyzed period (1951-1980), but during the second period it is possible to highlight a reclassification of the whole area in the Mediterranean bioclimatic belt. This may indicate an ongoing process of vegetation shift, and probably also a change in plant distribution patterns but more analyses are required to better understand this ongoing processes.

In general, it seems that vegetation is experiencing a reduction of rainfall on the hilly belt and an increase of temperature on the coastal areas. However, it is not possible to quantify the possible effects of climate change on vegetation since long term studies are required to better understand this dynamic and complex interaction. A reduction of rainfall and an increase of temperature, together, lead to an increase in climate aridity which, however, is more marked on the hilly belt. Also, it is noteworthy that many forest associations are facing this problem with a greater extent than other plant communities. Among them, the less vulnerable, and the most affected by aridity, are the riparian forest and the broadleaf tree communities.

Conclusions

This study highlighted a variation in climatic conditions using different analyses and approaches. It also highlighted that these variations occurred in many areas covered by vulnerable plant communities. These variations may be particularly dangerous for extra-zonal forests that usually grow at higher elevations and represent a very distinctive element of the landscape of the area. Moreover, a reduction in rainfall and a shift of precipitation patterns could reduce the recharge of groundwater, thus affecting both agriculture and water availability for the rapidly growing urban settlements in the area. Conservation policies and sustainable regional planning are needed to effectively protect these vulnerable plant communities. They may benefit from a permanent and integrated monitoring system of climate conditions and plant distribution.

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