ANNALI DI BOTANICA
Ann. Bot. (Roma), 2010

MICROCLIMATIC RESPONSES OF PLANT COMMUNITIES TO CLIMATIC CHANGES: A STUDY CASE IN THE MEDITERRANEAN COASTAL VEGETATION NEAR ROME

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ABSTRACT - The aim of this study is to investigate the microclimates of the different plant communities in the Castelporziano Estate to identify changes at short and medium time, caused by interacting factors at local scale like anthropic disturbance, climatic change and territory management. Air temperature and humidity, soil temperature and PAR (Photosynthetic Active Radiation) were monthly monitored. Measurements were taken in 21 stations, 6 of which along a transect in the vegetation of the dunes and the other 15 stations in forest associations. The dataset have been processed using different statistical treatments: (1) analysis of variance to evaluate the homeostatic capacity of the different communities; (2) analysis of microclimatic deviations values from mesoclimatic data, represented by Castelporziano Estate meteo-climatic stations, to detect microclimatic differences; (3) Multivariate Cluster Analysis to classify the different microclimates. Three main results were obtained: (1) comparison between microclimatic parameters measured during 2007-2008 and previous ones (2003) showed a general tendency of all forest types to shift towards xerophile conditions: air humidity decreased in a large percentage (20%). The woodland with major risk is the *Lauro-Carpinetum* that looses the 18% of air humidity in a very short period (5 years); (2) vegetation of the dunes displays homeostatic capacity in relationship with structural complexity increasing from pioneer communities of *Cakiletum maritimae* to mature stands of *Viburno-Quercetum ilicis*; (3) Cluster Analysis, performed on microclimatic data, allowed to classify vegetation in three different groups, confirming the same patterns obtained by floristic composition. Microclimate resulted a valid and robust tool to detect the ecological *status* of species and communities, and to follow their temporal changes.

KEY WORDS - MICROCLIMATE, CLIMATIC CHANGES, OAK FOREST VEGETATION, VEGETATION OF THE DUNES.

INTRODUCTION

At a local scale, forest trees and stands have a marked influence on the climatic conditions; thus it is possible to define microclimates. These effects depend on local climatic characteristics and stand type (Aussenac, 2000; Weng *et al.*, 2007).

Microclimate is the climate near the ground, for instance from the ground surface to the height of the plant canopy (Anthes *et al.*, 1981; Strahler and Strahler, 1987); so within a regional climate that has a particular temperature and precipitation regime, microclimate varies as a result of local topography. One of the most important elements of local topography affecting microclimate is the lateral redistribution of water. In addition, microclimate involves the effects of wind that impacts soil by causing erosion, especially on bare sandy soil. Furthermore, microclimate affects transmission and removal of heat and water to and from the soil (Turner *et al.*, 2001). Three major linkages exist from soil to vegetation: anchorage, the fraction of soil water available for plants, and nutrients (Monger *et al.*, 2006).

Received September 10, 2009
Accepted November 29, 2009

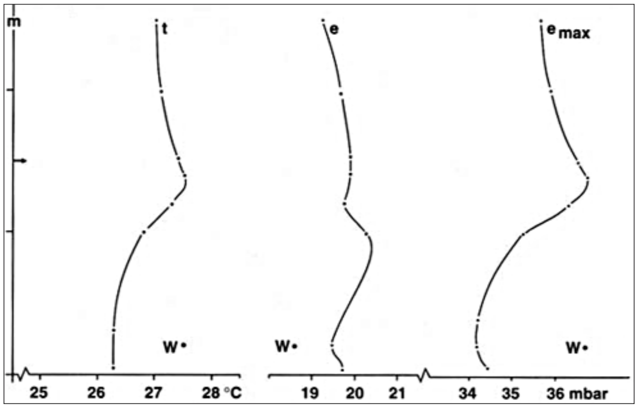


FIGURE 1. Temperature and vapor pressure profiles in and above an oak wood, 15 m tall (see narrow). Data from an instrument shelter outside the wood are indicate by W. Data from Heckert (1959).

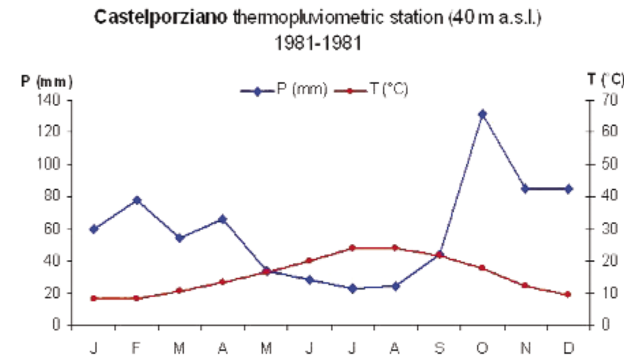


FIGURE 2. Climatic diagram.

Natural forests are heterogeneous because of the mixed tree composition, the mixture of different age and size classes and the pattern of smaller and larger treefall gaps. In the vertical direction there is often a continuous development of branches and leaves; as a result a forest develops its own microclimate. Unfortunately there are only a few reliable measurements from primeval forests. Much of what we know about the microclimate in forests is based on woodlands with a structure which may be quite different from natural forests. For instance, in planted woods with a dense canopy and very little understorey there is more wind and exchange of air with the atmosphere above and outside the wood. This leads to an even microclimate, which is often not greatly different from the microclimate in low dense vegetation; this is illustrated in the Figure 1 (Heckert, 1959; Stoutjesdijk and Barkman, 1992). Finally, phenology represents a sensitive tool in identifying how plant species and communities respond to regional climate conditions and to climatic changes (Chmielewski and Rötzer, 2001).

STUDY AREA

Castelporziano Estate, the Presidential Reserve, a 5000 ha natural protected area along the Tyrrhenian coast near Rome, including the presence of two Sites of Community Importance (SCI), is an ideal study area because of the very high diversity and vast pre-existing knowledge of the flora. About 900 species of plants have been listed in the Estate (Pignatti *et al.*, 2001). This very high diversity is due both to natural integrity of the area, that presents only limited settlings, and to diverse geomorphology and pedology, enhancing a rich mosaic of habitats, each with particular plant and animal communities.

Castelporziano is an important geographical area because it represents a key-hotspot of biodiversity; in fact, one of the most relevant peculiarities of this Reserve is the presence of different plant associations representative of three different biomes coexisting at very small distance: Mediterranean evergreen forest, deciduous oak forest and a residual nucleus of *laurisilva*. This last forest type is favoured by a humid microclimate in the gorges located in the N-NE of the Reserve. Castelporziano Estate became a protected Natural Reserve on 1999; since that time, in the forest antropogenic activities as grazing and cutting are forbidden, but a long-term historical disturbance affected the area, mainly due to ancient burning and heavy wild boars and fallow deer grazing causing the lacking of recruitment in the deciduous oak communities. The populations of the ungulates have high density and are regulated by density-independent (oak seed productivity) and density-dependent factors. Their increase in the last times are due to lacking of predators, both man and animals.

In the regions with Mediterranean bioclimate the vegetation is exposed in summer to severe water stress because of the elevate temperature and aridity; during this period the evaporation is high and rainfall almost completely lacking (Pignatti, 1984).

Castelporziano is characterised by a Mediterranean climate (Bianco and Martelli, 2001), with a drought period from may to august (Figure 2), mitigated by nocturnal condensation, soil capacity of meteoric water conservation and by the presence of a superficial water-table (Macuz *et al.*, 2006; Vincenzi *et al.*, 2006; Bucci, 2006).

Methods

Data field collecting: the measurements taken according to standard criteria (Barkman, 1977; De Lillis *et al.*, 1986), were done once per month in 21 sample sites representative of the main plant associations (Figure 3), 6 of which along dune transect and the other 15 in forest communities (plant associations monitored and their acronyms are reported in Appendix). For each observation, measurements were taken in 5 points within each sample site to obtain a number of replicates allowing a statistical data treatment. The mean values of these 5 measurements were utilized in the data elaboration.

Measured parameters were: air temperature (T°C); air humidity (H%); photosynthetic active radiation-PAR (Watt/m2/sec); soil temperature (T°C).

Each measure was taken at three levels: at soil level, at 150 cm above soil, at 25 cm soil depth.

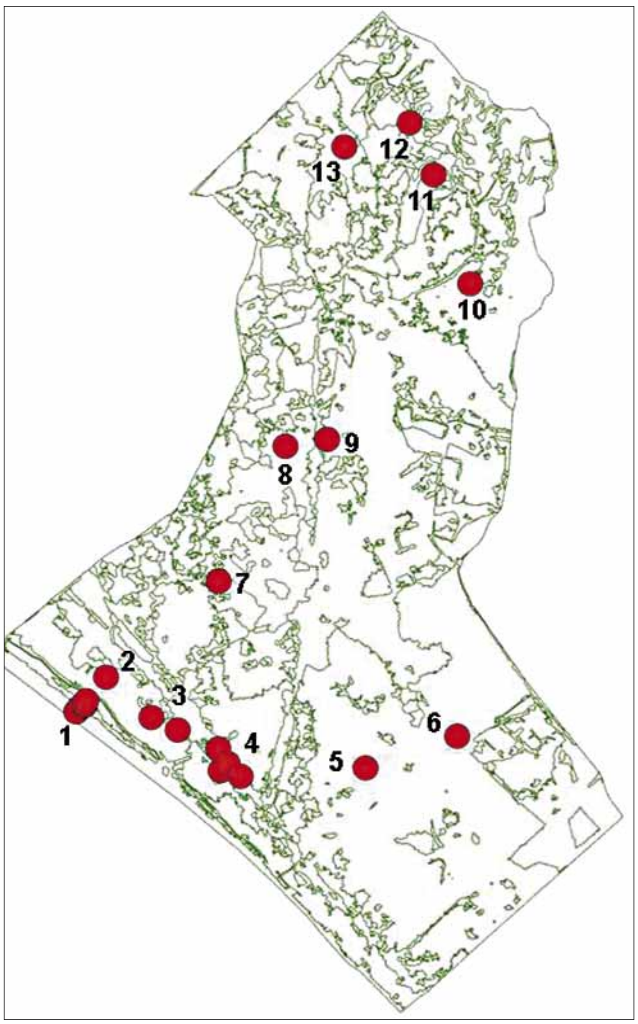


FIGURE 3. Location of the sampling sites. 1: Dune series; 2: VQIm; 3: VQI; 4: CF; 5: EQFor; 6: EQFbet; 7: VQIsm; 8: EQFer; 9: EQFor; 10: EQFer; 11: LC; 12: LC; 13: VQIs. The acronyms of the communities are reported in Appendix.

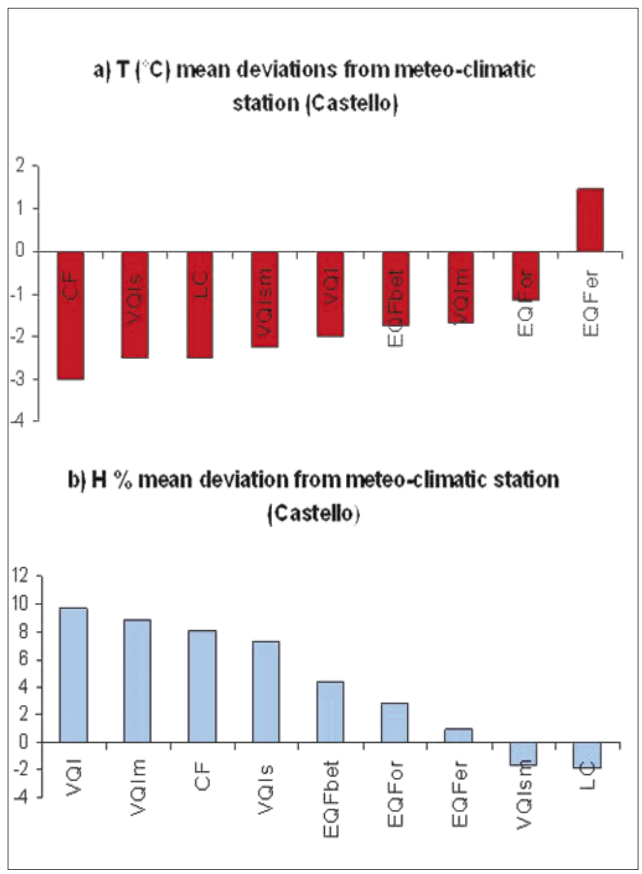


FIGURE 4. Deviations values from meteo-station data of temperature (a) and humidity (b) in the communities.

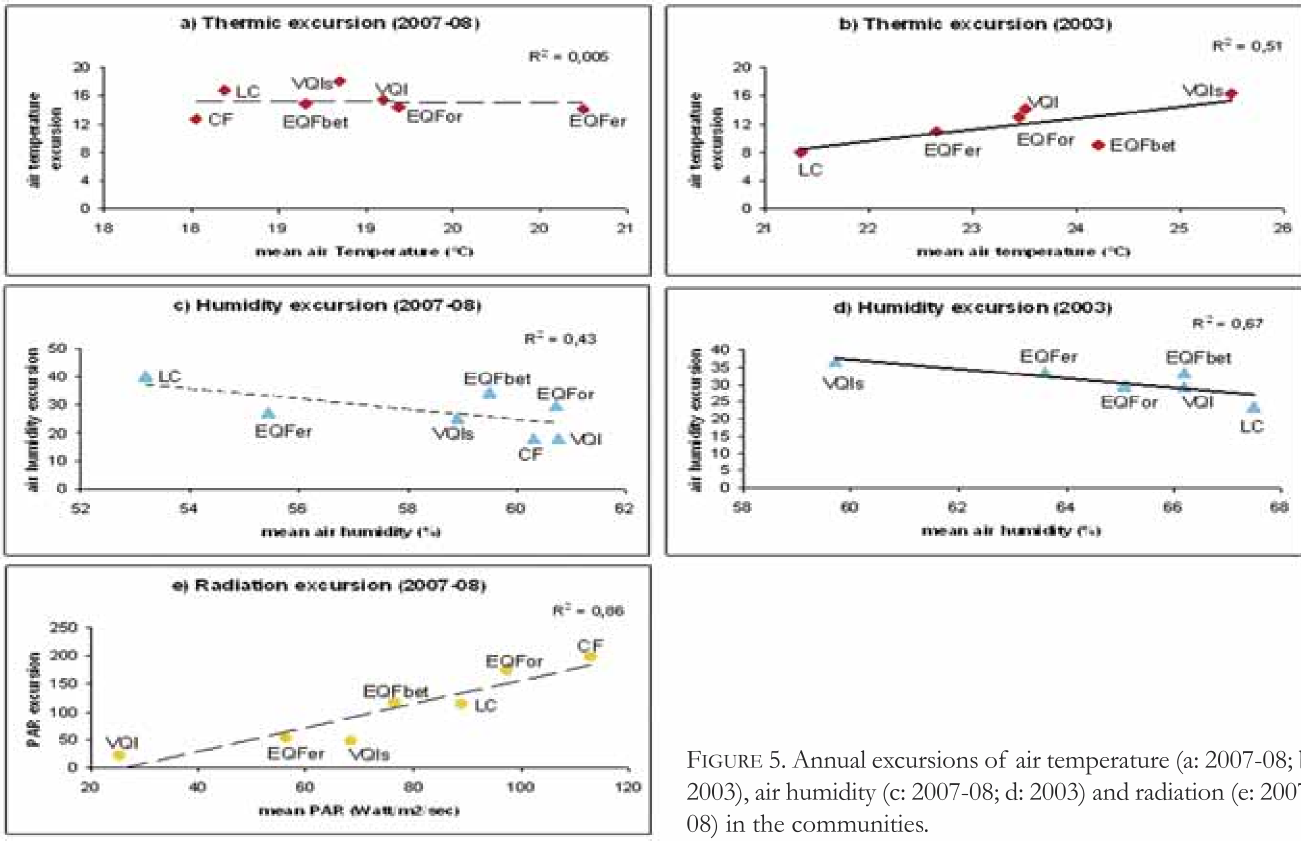


FIGURE 5. Annual excursions of air temperature (a: 2007-08; b: 2003), air humidity (c: 2007-08; d: 2003) and radiation (e: 2007-08) in the communities.

Instruments utilized were:

Thermometer-Hygrometer: Temperature range: 0 +50 °C (Accuracy = ± 0.5°C); Humidity range: 10% to 90% (Accuracy = ± 2.5%);

Photoradiometer: spectral measurement range: 400-700 nm (Accuracy = 5%);

Geothermometer: Temperature range: -10 +70 °C (Precision Temperature = ±1°C).

Ellenberg indicators (Ellenberg, 1974) were utilized to compare microclimatic temporal variations with environmental factors expressed by vegetation.

The dataset have been processed to the following statistical treatments:

Analysis of microclimatic deviations values from mesoclimatic data, represented by Castelporziano meteo-climatic stations to detect microclimatic differences. Meteo-climatic stations collect data hourly during the day. Microclimatic deviations have been calculated as follows:

the day values of parameters measured in each sample site (air temperature, soil temperature, air % humidity, radiation) have been subtracted from correspondent day values of meteo-stations;

mean annual values from sample sites have been subtracted from mean annual mesoclimatic data referred to 2003, 2007, 2008 years;

2- Analysis of variance to evaluate the homeostatic capacity of the different communities;

3- Multivariate Cluster Analysis to classify the different microclimates.

RESULTS

Mean annual data (Table 1) allowed to classify the microclimates of the investigated communities (Table 2). In the dune transect, mean annual data (Table 1) stress the homeostatic capacity increase of vegetation (Pignatti, 1959) from the pioneer *Cakiletum mar-*

	T 1	T 2	Ts	H 1	H 2	PAR1	PAR2
CK	23,6	20,8	19,4	48,8	56,3	1719,0	1773,0
SE	24,6	20,5	18,2	48,8	58,4	827,3	1620,4
AA	23,3	21,0	17,4	50,6	55,5	663,5	1769,4
AM	22,3	21,1	15,9	55,7	55,8	406,0	1681,3
JM	22,2	22,1	16,3	57,8	52,4	237,5	1727,5
VQIm	20,2	20,0	14,8	61,7	59,8	24,7	27,6
VQI	19,9	19,8	14,8	61,7	59,6	20,8	31,0
EQFer	20,0	22,0	14,3	53,5	50,6	46,7	60,4
EQFor	19,7	19,5	14,5	59,5	58,8	85,4	107,6
VQIs	19,5	19,3	13,9	58,1	54,2	62,2	83,5
EQFbet	19,3	18,9	14,2	58,1	56,7	60,3	81,8
CF	18,7	18,6	14,3	61,3	59,5	93,8	104,8
LC	18,2	18,2	12,9	55,9	51,3	54,0	62,6

TABLE 1. Mean annual data: T1 = air temperature (°C) at soil level, T 2 = air temperature (°C) at 150 cm, H1 = air humidity (%) at soil level, H 2 = air humidity (%) at 150 cm, PAR1= Photosynthetic active radiation (watt/m2/sec.) at soil level, PAR2 = Photosynthetic active radiation (watt/m2/sec.) at 150 cm, Ts = soil temperature (°C) at -20cm depth. The acronyms of the communities are reported in Appendix.

CK	thermophile, xeric, heliophile
SE	thermophile, xeric, heliophile
AA	thermophile, xeric, heliophile
AM	thermophile, xeric, heliophile
JM	thermophile, humid, shady
VQIm	thermophile, humid, shady
VQIsm	mesophile
VQI	thermophile, humid, shady
EQFer	thermophile, xeric, shady
EQFor	mesophile, humid, shady
VQIs	mesophile
EQFbet	mesophile, humid, shady, fresh soil
CF	mesophile, humid, heliophile
LC	mesophile, humid, shady

TABLE 2. Microclimatic classification of the monitored communities. The acronyms of the communities are reported in Appendix.

autumn	**EQFer**	**EQFor**	**EQFbet**	**LC**	**CF**	**VQIs**	**VQI**
Air T°	18,2	18,6	16,7	16,4	16,9	18	18,9
Air H%	72,4	77,8	80,9	76,8	67,7	75,5	66,2
PAR	66,6	45,5	72,8	38,9	133,6	55,9	18,4
Soil T° (-20cm)	13	14,7	13,4	12,1	11,6	13,5	13
winter							
Air T°	15,8	12,8	12,8	11,3	13,1	11,1	12
Air H%	45,1	48	46,3	36,4	49,6	50,2	49
PAR	66	189,7	77,6	123,2	221,4	41,9	23,7
Soil T° (-20cm)	10,4	9,8	9,4	8,4	10	8,9	9,1
spring							
Air T°	18,1	18	17,5	17	16,4	17,2	18,2
Air H%	54,9	57,8	60,9	58,5	61	56	62
PAR	69,8	139,6	135,9	128,7	73,7	89,2	38,7
Soil T° (-20cm)	12,3	12,5	12,5	10,7	12,8	11,7	12,8
summer							
Air T°	29	27,3	27,7	28,1	25,7	29,2	27,4
Air H%	49,3	59,2	49,8	41,1	62,9	53,9	65,9
PAR	23	15,1	19,3	64,7	23,5	86,3	20,5
Soil T° (-20cm)	19,9	20,1	20,5	19,7	20,1	20,2	21,1

TABLE 3. Mean seasonal data of air temperature (°C), air humidity (%), Photosynthetic active radiation (watt/m2/sec.), soil temperature (°C) recorded in the forest communities. The acronyms of the communities are reported in Appendix.

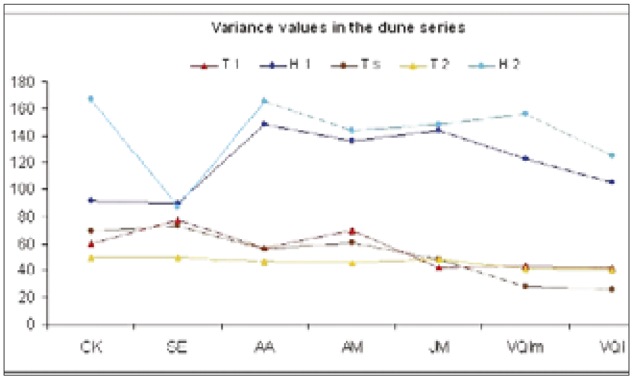


FIGURE 6. Variability of the microclimatic parameters expressed by mean variance values in the dune series: T1=air temperature (°C) at soil level, T 2=air temperature (°C) at 150cm, H1= air humidity (%) at soil level, H 2= air humidity (%) at 150cm, Ts=soil temperature (°C).

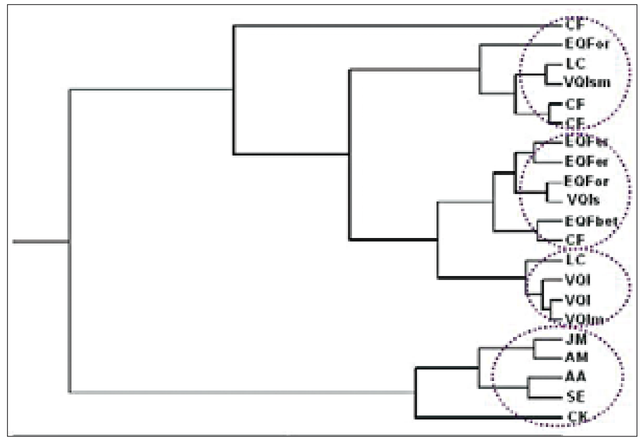


FIGURE 7. Cluster Analysis performed on microclimatic data recorded in the forest communities: four clusters representing different vegetation types are highlighted.

itimae (CK) community to mature stands of *Quercus ilex* woodland (VQI), in relationship with changes in vegetation structure (Potter Brian *et al.*, 2001; Larcher, 1993).

Seasonal trends in the woodlands (Table 3): in autumn the oak woodland with *Carpinus betulus* (EQFor) is the most humid, the holm oak forest (VQI) is the most shady and dry; the woodland with *Fraxinus oxycarpa* (CF) is the most heliophile and mesophile. In winter the VQI is the most humid and mesophile, while the woodland with *Laurus nobilis* (LC) is the most dry with the lowest soil temperature. In spring CF is the most humid, mesophile and shady woodland, with the highest soil temperature value. In summer LC is the most xeric, thermophile and heliophile woodland; only soil temperature displays the lowest value.

Mean deviations of air temperature (T°) and humidity (H%) from the values of the meteorological station (Castello, 40 m a.s.l.) in Castelporziano Estate allowed to discriminate the microclimatic responses of the different forest communities: along the temperature gradient (Figure 4a), woodland with *Fraxinus oxycarpa* (CF) is the most mesophile; along the humidity gradient (Figure 4b), *Quercus ilex* woodland and maquis are the most humid communities, while mixed *Quercus suber* woodland (VQIsm) and the woodland with *Laurus nobilis* and *Carpinus betulus* (LC) are the most xeric. This result appears in contrast with the ecological adaptation normally attributed to these communities.

In general, small deviations from mesoclimatic data (meteo-station data) indicate a microclimate weakly characterized: *Erica arborea silvofacies* of the *Echinopo-Quercetum frainetto* is the forest community where the microclimatic values are nearest to those of the meteo-station (Figure 4 a-b).

In the woodlands the annual excursions of air temperature (Figure **5a-b**), air humidity (Figure **5 c-d**) and radiation (Figure **5e**) show gradients along which the communities are distributed.

Nowadays radiation (Figure **5e**) has the highest R^2 value (0.86), instead of T° (R^2=**0.005**) (Figure 5a). Evidently, radiation in the forest ecosystem is the most important factor in structuring vegetation.

In comparison with the excursions values recorded in the year 2003 (Figure **5d**), LC and VQI have an opposite position in the humidity gradient. In the temperature gradient EQFer displays the highest excursion value (Figure 5a).

Annual variability in the vegetation of the dunes: the variance analysis showed that in this series (Figure 6) the highest variability is referred to air humidity: this parameter is more influenced by seasonal-macroclimatic variations. *Sporobolo-Elymetum farcti* (SE) has a first mitigation effect on the dunes microclimate, *Ammophiletum arundinaceae* (AA), with its closer structure, induces a further decrease of air temperature and an increase of air humidity.

Microclimates classification based on Cluster Analysis: four main clusters (Figure 7) were obtained through microclimatic values: the clusters reflect the same patterns based on the floristic composition of the plant communities investigated in a previous study (Pignatti *et al.*, 2001).

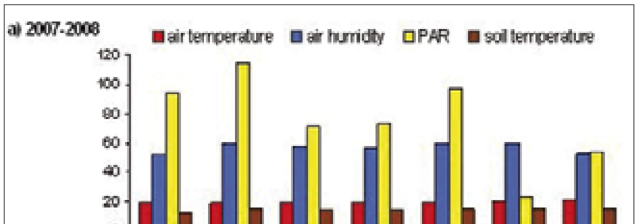
1st cluster: the most xeric communities of the dune vegetation

2nd cluster: evergreen woodlands, maquis (VQI, VQIm) and *Lauro-Carpinetum*

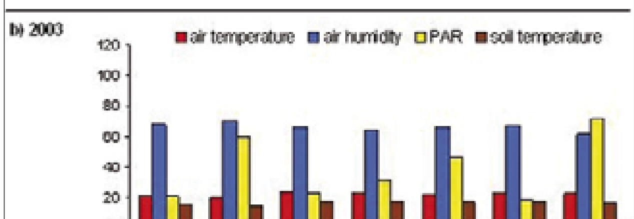
3rd cluster: deciduous oak woodlands

4th cluster: hygrophyle woodlands with *Fraxinus oxycarpa*

Diachronic comparison between 2003 and 2008 through microclimatic parameters and Ellenberg indicators: in the years 2007-08 (Figure 8a) in comparison with year 2003 (Figure 8b), in all forest communities it is remarkable the general tendency of PAR to increase, air temperature and humidity to decrease, soil temperatures to decrease: nowadays the soils maintain homeostatic capacity against the strong changes in other environmental parameters.



	LC	fras	C bet	Sug	C cr	Lec.	C er
air temperature	18,4	18,8	19,1	19,4	19,6	19,9	21,0
air humidity	51,0	59,9	57,4	56,2	59,2	59,8	52,0
PAR	93,4	114,1	71,1	72,9	96,5	22,9	53,5
soil temperature	12,6	14,4	14,2	13,9	14,5	14,6	14,3



	LC	fras	C bet	Sug	C cr	Lec.	C er
air temperature	21,2	20,1	24,3	22,8	22,3	23	22,7
air humidity	68	70,5	66,4	64,7	66,6	67,5	61,8
PAR	21	60,1	23	30,8	46,9	18,5	72,2
soil temperature	15,5	15,1	17,3	18	16,8	17,7	16,2

FIGURE 8. Comparison between 2003 (a) and 2008 (b) of microclimatic data in the forest communities. The acronyms of the communities are reported in Appendix.

The woodland with major risk is the *Lauro-Carpinetum* that looses the 18% of air humidity in a very short period (5 years) (Figure 8a-b). In the 2003 this forest community was the most humid, with the only exception of hygrophile woodlands near the ponds. This relics of *laurisilva* forest, surviving in the subcoastal Tyrrhenian belt in very small patches, could disappear faster than foreseen.

Ellenberg indicator values (Ellenberg, 1974) for light-L (Figure 9a), soil moisture-F (Figure 9b) and nutrients-N (Figure 9c) are in agreement with microclimatic data: all forest communities become more heliophile, xeric and oligotrophic: the decrease of soil nutrients and moisture represents an effective indicator of environmental menace for the surviving of these woodlands.

DISCUSSION AND CONCLUSION

The microclimates of the Castelporziano forest communities are quite different (Tables 1 and 2):

Mediterranean vegetation, characterized by the highest thermophily (*Viburno-Quercetum ilicis maquis*, *Viburno-Quercetum ilicis suberetosum, Viburno-Quercetum ilicis*);

Mesic communities with affinity for central-European vegetation (*Lauro-Carpinetum*, *Carici remotae-Fraxinetum oxycarpae)* are the most mesophile and humid;

Communities with affinity for South-East European vegetation (*Echinopo-Quercetum frainetto*) display intermediate microclimates.

Within each community above mentioned it is possible to recognize further differences related to vegetation structure and soil characteristics (Weng *et al.*, 2007). For example, in the Mediterranean evergreen

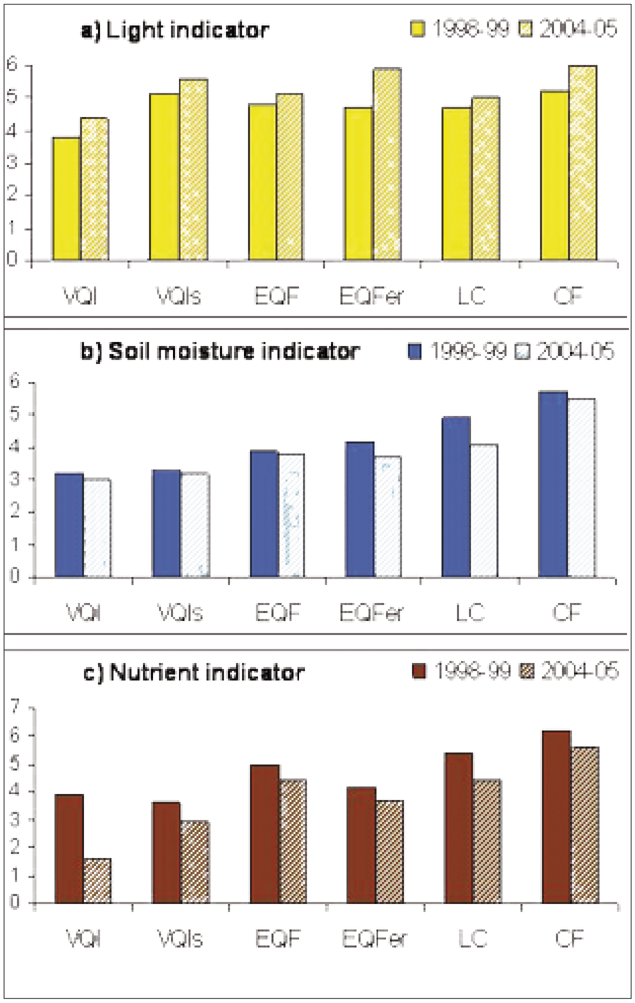


FIGURE 9. Comparison between 2003 and 2008 of Ellenberg indicators: light-L (a), soil moisture-F (b) and nutrients-N (c) in the forest communities. The acronyms of the communities are reported in Appendix.

vegetation, *Quercus suber* woodlands (VQIs) show higher radiation values in comparison with the other evergreen communities (VQI and VQIm), in relationship with its more open canopy. In the mesic communities, *Lauro-Carpinetum* association has a cooler soil (12.9 °C) than *Carici remotae- Fraxinetum oxycarpae* (14.3 °C) (Table 1).

During the seasons (Table 3), differences in radiation and temperature values recorded in the different *silvofacies* of the deciduous oak woodlands are strongly influenced by phenological conditions (Chmielewski and Rötzer, 2001). In winter, the *Erica arborea silvofacies* displays higher air temperature and lower radiation in comparison with the other two *silvofacies* (*Carpinus orientalis* and *C. betulus*); *Erica arborea* forms a dense evergreen belt near the ground mitigating the air temperature, while the other two oak communities are more exposed to radiation and winter temperature, when the canopy is lacking. In the year 2003, characterized by the highest drought of the last ten years, *Carpinus orientalis silvofacies* showed the highest values of radiation annual excursion in spring and not in the winter, in relationship with the delay of the canopy development, caused by the extended drought period (Testi *et al.*, 2006).

Since 2003, *Erica arborea silvofacies* displayed a major affinity with the evergreen *Quercus suber* woodland rather than with the other two deciduous oak *silvofacies* (Testi *et al.*, 2006). Nowadays, this condition is emphasized by the lowest deviation values of temperature and humidity from meteo-station (Figure 4), and by the highest annual temperature excursion (Figure 5a). Rapid changes observed in a short time suggest a possible successional trend favouring the expansion of this vegetation type against the other deciduous oak communities. Each of the investigated forest types is producing different ecological conditions. Indeed, the xeric summer period is mitigated by the elevate water content in the soils: in the Mediterranean zone, the soil is an homeostatic factor, representing a *key element* for the surviving of these communities. Furthermore, correlation found between microclimatic air temperature and AWC (available soils water capacity) (Testi *et al.*, 2006), confirmed the soil capacity to mitigate microclimate of the whole forest. Data set collected over 2007-2008 years show that the relationship between soil and microclimate probably is becoming weaker. All the woodlands displayed a decrease of the air humidity, menacing the future of this coastal forest belt and the communities diversity. In only five years the microclimatic vegetation responses changed towards more xeric, heliophile and oligotrophic conditions, and this although the reference year (2003) was characterized by a particularly hot and dry summer; even in the case that a humid period will follow, it is difficult to foreseen the times of resilience for species and communities. Furthermore, the conservation of homeostatic capacity for this forest ecosystem is menaced by the fact that there is a superficial water-table recharged only by rainfall (Macuz *et al.*, 2006, Vincenzi *et al.*, 2006, Bucci, 2006). Rainfall in this last period displayed very large variations in the amount and seasonal distribution, interacting with the cycles of water and nutrients (Turner *et al.*, 2001).

Microclimatic and macroclimatic changes interact with each other. At macroscale level, in the last 150 years the mean global surface temperature has increased by 0.76 °C and the observed warming has been greater in the Northern Hemisphere that in the Southern one; furthermore, climate changes are making the Mediterranean environment particularly vulnerable, because several factors, such as land use, atmospheric concentration of carbon dioxide, biotic exchanges, etc., can affect biodiversity conservation (IPCC, 2007; Szpunar *et al.*, 2008). At local scale, Castelporziano Reserve represents a key-hotspot of biodiversity in the Mediterranean Region; for this reason, this kind of diachronic study is an useful tool to identify changes at short and medium time. Microclimatic observed trends towards more xeric, heliophile and oligotrophic conditions are in agreement with macroclimatic studies; therefore the considerable alteration of environmental balance is taking place suggesting predictions on the biotic changes; e.g., in the Castelporziano Reserve, the expansion of deciduous oak forest type with *Erica arborea* could affect biodiversity of the area at community and species level. Finally, microclimatic and macroclimatic changes interact with other impact factors: the heavy wild boars and fallow deer grazing causing the lacking of recruitment in the deciduous oak forest, agricultural water captation in the surrounding territory, the presence of the large urbanized area of Rome. All these factors are responsible for the anthropogenic disturbance related to soil and atmospheric pollution.

In conclusion, all data treatments appear in agreement with each other in describing the microclimatic responses of the communities. The results can be summarized in five main points:

1) Comparison between microclimatic parameters measured during 2007-2008 and previous ones (2003) showed a general tendency of all forest types to shift towards xeric conditions: air humidity decreased in a large percentage (20%).

2) Cluster Analysis performed on microclimatic data allowed to classify vegetation in four different groups, reflecting the same patterns obtained by floristic composition.

3) Vegetation of the dunes displays homeostatic capacity in relationship with structural complexity increasing from pioneer communities of *Cakiletum maritimae* to mature stands of *Viburno-Quercetum ilicis.*

4) Along the dune transect it is particularly evident the capacity of living organism to modify abiotic factors of the ecosystem.

5) Microclimate shows relationships with plant communitie's phenology.

Microclimate resulted a valid and robust tool to detect the ecological *status* of species and communities, and to follow their temporal changes.

ACKNOWLEDGEMENTS

This study was financiated by Accademia delle Scienze, Castelporziano Reserve. We acknowledge the Direction of the Castelporziano Reserve for providing meteorological data.

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APPENDIX

Plant associations monitored

VQI - *Viburno-Quercetum ilicis* Rivas-Martínez 1975, on recent dune
VQIm - *Viburno-Quercetum ilicis maquis* Rivas-Martínez 1975, on recent dune
VQIs - *Viburno-Quercetum ilicis suberetosum*: xeric facies with *Stipa bromoides* on old dune
VQIsm - *Viburno-Quercetum ilicis suberetosum*: mixed facies with *Q. cerris* on old dune
EQFer -*Echinopo-Quercetum frainetto* Blasi et Paura 1993: *Erica arborea silvofacies*, on old dune
EQFor - *Echinopo-Quercetum frainetto* Blasi et Paura 1993: *Carpinus orientalis silvofacies*, on old dune
EQFbet - *Echinopo-Quercetum frainetto* Blasi1993: *Carpinus betulus silvofacies*, on old dune
CF - *Carici remotae- Fraxinetum oxycarpae* Koch ex Faber 1936, in interdune depressions
LC - *Lauro-Carpinetum* Lucchese et Pignatti 1990, on tuffs in the gorges
CK – *Cakiletum maritimae* Pignatti 1953, on dunes
SE – *Sporobolo-Elymetum farcti* Br.-Bl. 1933, on dunes
AA – *Ammophiletum arundinaceae* Br.-Bl. 1933 , on dunes
AM – *Anthemis maritima* community , on dunes
JM – *Juniperetum macrocarpae-phoeniceae* , on dunes.