Ann. Bot. Fennici 52: 1–18 ISSN 0003-3847 (print) ISSN 1797-2442 (online)
Helsinki 30 January 2015

Bioclimatology and vegetation series in Sicily: a geostatistical approach

Giuseppe Bazan[1,*], Pasquale Marino[1], Riccardo Guarino[1], Gianniantonio Domina[2] & Rosario Schicchi[2]

[1)] *Dipartimento di Scienze e Tecnologie Biologiche, Chimiche e Farmaceutiche, Università degli Studi di Palermo, Via Archirafi 38, IT-90123 Palermo, Italy (*corresponding author's email: giuseppe.bazan@unipa.it)*
[2)] *Dipartimento di Scienze Agrarie e Forestali, Università degli Studi di Palermo, Via Archirafi 38, IT-90123 Palermo, Italy*

Received 3 Apr. 2013, final version received 29 Dec. 2014, accepted 2 Jan. 2014

Bazan, G., Marino, P., Guarino, R., Domina, G. & Schicchi, R. 2015: Bioclimatology and vegetation series in Sicily: a geostatistical approach. — *Ann. Bot. Fennici* 52: 1–18.

Tackling the Sicilian woody vegetation as a case-study, this work aims to verify the correspondence between Rivas-Martínez's bioclimatic units and the main vegetation series in the Mediterranean region. Following this approach, one macrobioclimate and 25 bioclimatic type belts can be recognized in Sicily. By means of a geostatistical analysis based on WorldClim data sets, cartographic models of the distribution range of each single bioclimatic unit were obtained and combined with vegetation data, in order to develop a new regional spatial framework, integrating climatic and vegetation data. Fidelity of each vegetation unit to a given climatic range was then evaluated as percent distribution of the occupied surface within a given bioclimatic unit, while the predictive power of the WorldClim data sets was tested by using half of the spatial data of the processed vegetation units as independent variables. Our results suggest that: (1) any kind of numerical threshold used to define bioclimatic units is not effective *a priori*, but only after it has been adjusted to the territory and to the spatial scale used to set the model; (2) bioclimatic indices being an empirical tool, the model can be trained and eventually adjusted when applied to different territories; (3) fidelity of vegetation units to a given bioclimatic unit is highly variable; (4) the mechanistic pitfall that climatophilous vegetation has to be necessarily linked to a single bioclimatic unit should be avoided.

Introduction

Bioclimatology is an ecological science that studies the relationship between climate and distribution of organisms and their communities. In vegetation science, it began with the studies of correlations between temperature and precipitation, and distribution of plant communities. The most recent advances in the discipline incorporated all relevant information on biogeocoenoses (defined as a land unit created by the interaction between vegetation and soil biota) and the new concepts of dynamic-catenal phytosociology, i.e. sigmeta, geosigmeta and geopermasigmeta according to the terminology of Rivas-Martínez (2007; *see* also "Nomenclature and terms used", below).

Bioclimatic variables are those climatic features that are physiologically relevant to plant growth and distribution. They are, therefore, widely used in studies on spatial distribution patterns and vegetation mapping (Franklin 1995, Bohn & Neuhäusl 2003, Blasi 2010), for predicting consequences of climate change for species distribution (Sykes *et al*. 1996, Peng 2000, Walther *et al*. 2002), in managing and monitoring invasive alien species (Arriaga *et al*. 2004), and in regional planning (Bryan *et al*. 2005).

Predictive vegetation mapping is a process in which empirically established rules are used to create maps of environmental variables such as soils, geology, topography and climate, for habitat modelling. Such rules range from assumed informal relationships to sophisticated statistical models. These models can be set either in a context of vegetation gradient analysis, i.e. according to the continuum model (Gleason 1926, Whittaker 1951, Austin 1985) or in the conceptual framework of phytosociology, which classifies discrete Zürich-Montpellier School vegetation types (Braun-Blanquet 1951, Tüxen 1956, Pedrotti 2013). Accurate bioclimatic maps are essential in both approaches to vegetation distribution.

Recently, a considerable interest in relations between bioclimatic and landscape classification has arisen (del Arco-Aguilar *et al*. 2009, Mesquita & Sousa 2009, Metzger *et al*. 2013).

In this work, we examined the relations between vegetation series and climate by means of geostatistical analysis of WorldClim data sets using bioclimatic indices introduced by Rivas-Martínez (1994). Our aims were: (1) to check the accuracy of the WorldClim data sets for the Mediterranean Region, (2) to improve the current bioclimatic maps for Sicily, and (3) to test whether this approach can be used for landscape diagnosis. Sicily is ideal for our study, because of its central position in the Mediterranean and because its vegetation has been thoroughly investigated (*see* Brullo *et al*. 2002 for details). Moreover, the bioclimatic indices proposed by Rivas-Martínez (1994) have already been applied for Sicily by Brullo *et al*. (1996), and a fairly good number of weather stations and related bioclimatic data are available for the whole island (Duro *et al*. 1996, Cartabellotta *et al*. 2000, Bazan *et al*. 2006).

Material and methods

Study area

Sicily and its surrounding islets are recognized as one of the Mediterranean biodiversity hotspots (Médail & Quézel 1997, 1999). The richness of the Sicilian flora is due to a great variety of habitats and to a complex paleo-geographic history (Brullo *et al*. 1995). The current vascular plant flora includes over 13% of endemic taxa (Raimondo & Di Gristina 2007, Raimondo & Spadaro 2008, Troia & Raimondo 2010, Raimondo *et al*. 2010, 2012, Castellano *et al*. 2012, Marino *et al*. 2012, 2014, Guarino *et al*. 2013) and most of the typical Mediterranean vegetation can be found on the island (Guarino 2011). The total area of Sicily is about 25 700 km^2, of which approximately 61.4% is hilly, 24.5% is mountainous and 14.1% consists of alluvial plains (Fig. 1).

Vegetation mapping

In order to outline the existing woody vegetation, a detailed physiognomic map of the Sicilian woody vegetation was used (available as digital data at http://www.sitr.regione.sicilia.it/webgisportal/default.aspx). The reasons for choosing the woody vegetation are its relative stability and easy recognisability from aerial photographs. A geographical information system was used to map 10 342 patches of woody vegetation larger than 10 ha (ArcGIS Desktop Release 9, ESRI, Redlands, CA).

Vegetation types were classified on the basis of phytosociological literature and field surveys. The Sicilian woody vegetation has been thoroughly investigated by phytosociologists. In recent years, detailed syntaxonomical schemes have been published by Brullo *et al*. (2002, 2008, 2012). The patches (homogeneous areas larger than 1000 m^2) that include phytosocio-

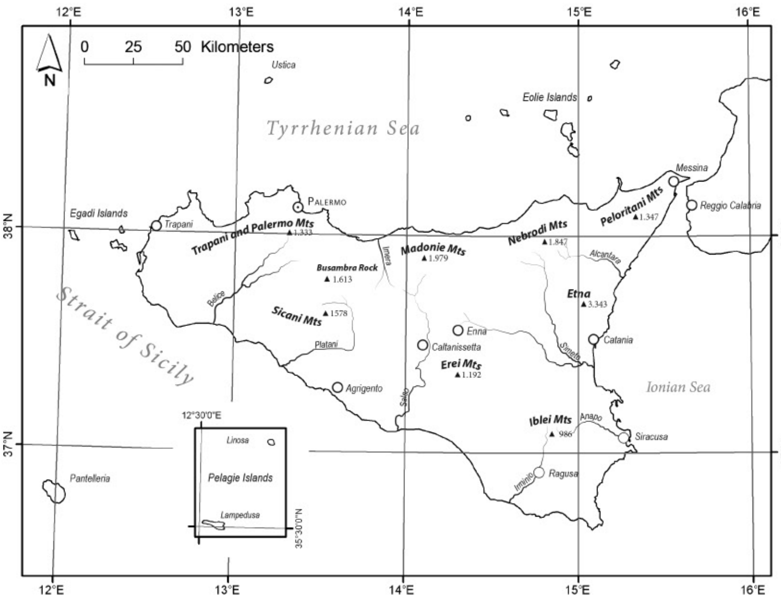

Fig. 1. Toponymic map of Sicily.

logical plots (surface about 100 m^2) were used as 'spectral fingerprints' of each vegetation unit. All the other patches were classified using supervised multispectral analysis associated with overlaying a soil map of Sicily (Fierotti *et al*. 1998), based on the assumption that neighbouring patches belonging to the same multispectral group, occurring on the same soil unit and at similar altitudes should belong in the same vegetation unit. Boundaries of the patches were verified in the field. Each patch of the considered phytosociological units was further associated with a climatic variable. Sources and use of the climatic data and bioclimatic classification are specified in the following paragraph.

Climatic data and bioclimatic classification

This study is based on the WorldClim data (Hijmans *et al*. 2005) from the period 1950–2000. The WorldClim data (temperature and rainfall) consist of climate grids with a resolution of 1 km^2 and a net of 38 600 grid cells, with an interval of 30´´, which in Sicily corresponds to 734 m (long.) × 926 m (lat.).

The bioclimatic classification of Sicily follows Rivas-Martínez (1994). That classification is based on formulas calculating temperature and rainfall ranges and distributions, which are used to define the values for respective bioclimatic belts: thermotype and ombrotype (Table 1). Each of them is expressed by a characteristic group of plant communities (*biocoenoses* of Rivas-Martínez 2002). The thermotype indices used in this study are: (1) thermicity index [It = $(T + M + m) \times 10$, where T is the yearly average temperature, m is the average minimum temperature of the coldest months of the years, and M is the average maximum temperature of the coldest months of the years; (2) continentality index (Ic = Tmax – Tmin, where Tmax is the average temperature of the warmest month, and Tmin is the average temperature of the coldest month); (3) compensated thermicity index (Itc = It + Ci), where Ci is the compensation value based on the continentality index (Ic), used to compensate the peak of low temperature in areas with continental climate; according to Rivas-Martínez (1994) if $18 < \text{Ic} \leq 21$, then $\text{Ci} = 5 \times (\text{Ic} - 18)$; (4) positive temperature index (Tp, expressed with one decimal accuracy, resulting from the annual sum of the monthly average temperatures higher than 0 °C).

Ombrotypes were defined using the ombrothermic index [$\text{Io} = 10 \times \text{Pp}/\text{Tp}$, where Pp is the annual precipitation (mm)]; as recommended by Rivas-Martínez (1994), only precipitation of the months with average temperature higher than 0 °C is used in the formula.

Thermotype and ombrotype grids were processed at the resolution of 1 km^2.

Geostatistical and correlation analysis

The fidelity of each vegetation unit to a given bioclimate (defined through the combination of thermotypes and ombrotypes) was evaluated as a percentage of the total surface it occupies within a given bioclimatic unit (Table 2). Bioclimatic maps were obtained through the application of the above mentioned Rivas-Martínez's indices to the WorldClim grids.

In order to test the usefulness of the WorldClim interpolation as a predictive tool, and its correspodence with the vegetation units, the centroid coordinates of the vegetation patches were divided into two independent sets: calibration and validation. Grouping was done in order to ensure that the statistical properties of the altitude, i.e. mean, variance, minimum and maximum values were most similar in each group. The calibration set was used to establish average (U) and variance (σ^2) of the WorldClim variables (mean temperature: T_{mean}; average annual rainfall: P) associated with each considered vegetation unit.

Distance-based redundancy analysis (Legendre & Anderson 1999) was carried out using the *VEGAN* package in R (Oksanen *et al*. 2009), to calculate the variances of the calibration and validation sets and to score the centroid coordinates of the vegetation units. The goodness of fit (expressed here as percentage of accuracy) was calculated as $R = (V_0 - V)^2/(V_0)^2$ (Taylor

Table 1. Threshold values for bioclimates, thermotypes and ombrotypes according to Rivas-Martìnez (1994): Ic = continentality index, Io = ombrothermic index, It = thermicity index, Ict = compensated thermicity index, Tp = positive temperature index.

Bioclimate	Ic	Io
Mediterranean pluviseasonal oceanic	≤ 21	> 2.0
Mediterranean xeric oceanic	≤ 21	1.0–2.0
Thermotype	**It, Ict**	**Tp**
Lower cryoromediterranean (LCme)	–	150–450
Upper oromediterranean (UOme)	–	450–675
Lower oromediterranean (LOme)	–	675–900
Upper supramediterranean (USme)	120–150	900–1200
Lower supramediterranean (LSme)	150–220	1200–1500
Upper mesomediterranean (UMme)	220–285	1500–1825
Lower mesomediterranean (LMme)	285–350	1825–2150
Upper thermomediterranean (UTme)	350–400	2150–2300
Lower thermomediterranean (LTme)	400-450	2300–2450
Upper inframediterranean (UIme)	450–515	2450–2650
Ombrotype		**Io**
Upper hyperhumid (UHh)		18.0–24.0
Lower hyperhumid (LHh)		12.0–18.0
Upper humid (UHu)		9.0–12.0
Lower humid (LHu)		6.0–9.0
Upper subhumid (USh)		4.8–6.0
Lower subhumid (LSh)		3.6–4.8
Upper dry (UDry)		2.8–3.6
Lower dry (LDry)		2.0–2.8
Upper semiarid (USa)		1.5–2.0
Lower semiarid (LSa)		1.0–1.5

Table 2. Percentages of the vegetation series of Sicily in the bioclimatic belts obtained by means of the WorldClim variables; the highest values are set in boldface. Values smaller than 0.5% were ignored. *R* = percentage of accuracy of the WorldClim maps. For the explanation of bioclimatic unit abbreviations, *see* Table 1.

Vegetation head series	LCme UHh	UOme LHh	LOme UHu	LOme LHu	USme LHu	USme USh	USme LSh	LSme LSh	LSme Udry	UMme USh	UMme LSh	UMme UDry	UMme LDry	LMme LSh	LMme UDry	LMme LDry	UTme LSh	UTme UDry	UTme LDry	UTme USa	LTme LSh	LTme UDry	LTme LDry	LTme USa	UIme LSa	*R* (%)
Rumici-Astragalion siculi	17.099	18.743	**22.225**	16.162	6.054																					99.08
Epipactido-Fagetum			4.746	7.199	**71.048**	16.026	0.771																			91.37
Luzulo-Fagetum					28.712	**60.368**		6.893																		88.40
Junipero-Abetum nebrodense					14.411	**78.161**		4.891																		94.42
Anemono -Fagetum					8.796	**41.775**	22.090	24.928	0.696																	90.51
Geranio-Quercetum ilicis						**50.500**		28.738	4.755			14.397														85.33
Agropyro-Quercetum congestae					6.065	18.035	**28.752**	19.078			19.749			1.600	6.721											95.31
Arrhenathero-Quercetum cerridis						2.436	10.780	**56.87**	3.122		11.884	13.053			1.085											92.70
Ilici-Quercetum austrotyrrhenicae								**42.193**	3.717			40.431			4.267	5.910										87.36
Arabido-Quercetum congestae						4.059	13.204	33.362			**41.818**	2.827			4.704											81.78
Teucrio-Quercetum ilicis								23.435	19.391			**42.587**			8.358	4.846										93.93
Quercetum gussonei								14.53	1.670		15.287	**41.211**			24.292	0.507		2.503								94.96
Aceri-Quercetum ilicis					0.813	3.867		13.576	1.001		4.931	**39.882**			29.128	1.225		4.349								83.18
Festuco-Quercetum congestae						1.713	1.668	8.822	2.249		11.101	**50.896**			15.724	6.874			0.680							84.46
Sorbo-Quercetum virgilianae								14.654	2.422		1.852	**66.335**			10.563	3.845										95.05
Mespilo-Quercetum virgilianae												**57.698**			33.882	8.421										99.83
Quercetum leptobalanae								4.619			1.303	33.677			**43.762**	10.621			5.582							80.23
Erico-Quercetum virgilianae							0.611	1.303	0.756	0.565	14.21	9.780		14.676	13.083	**15.263**	5.715	10.811	8.801			3.131				92.67
Doronico-Quercetum ilicis															31.237	**49.761**			18.757							88.49
Oleo-Quercetum virgilianae											0.618	5.150	1.639		11.029	**37.377**		2.993	36.192				3.455	0.599		84.23
Erico-Quercetum ilicis																**100.00**										95.04
Thymo-Pinetum halepensis															1.046	**56.30**			33.260	1.140			7.792			85.29
Genisto-Quercetum suberis											0.843	5.334			26.173	6.352		10.35	**37.303**				13.048			94.89
Pistacio-Quercetum ilicis												8.934			23.735	15.264		9.84	**34.889**			1.596	5.527			82.27
Rhamno-Quercetum ilicis												3.899			16.884	3.386		4.135	**33.645**			4.534	33.396			99.82
Stipo-Quercetum suberis													0.904			24.072			**71.085**	2.839			1.048			95.55
Junipero-Quercetum calliprini															1.140			6.393	**32.769**	20.315		0.780	19.893	18.240		89.02
Cisto-Pinetum pineae														1.797			40.260	0.767			**42.548**	14.628				95.14
Oleo-Euphorbietum dendroidis															1.916			11.143	15.249	2.631	3.463	**44.554**	12.125	7.563		89.08
Calicotomo-Rhoetum tripartitae																			32.384				**58.381**	8.792		89.37
Chamaeropo-Quercetum calliprini																			21.438				**78.509**			88.40
Myrto-Pistacietum lentisci																			9.198			1.295	**89.12**			94.42
Pistacio-Chamaeropetum humilis																			4.174	0.615			**87.715**	6.680		91.51
Ephedro-Juniperetum macrocarpae																			6.655	4.838			16.581	**63.851**		85.33
Periploco-Juniperetum turbinatae																									**100.00**	**95.31**

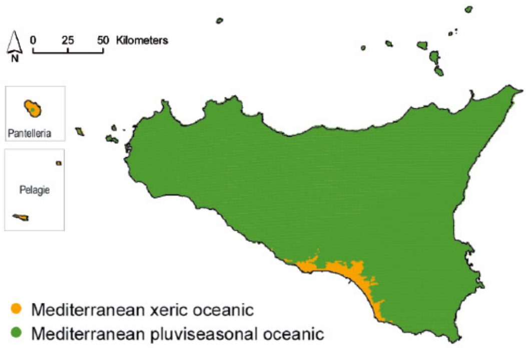

Fig. 2. Bioclimates in Sicily.

1997, Guarino *et al*. 2005), where V_0 is the variance of the calibration set and V is the residual variance of the validation set. The predictive power ("accuracy") of the WorldClim variables was then evaluated through the percentage of fit of the centroid coordinates of the validation set to the potential distribution areas obtained by means of WorldClim. The procedure was repeated for each vegetation unit in the data set.

Nomenclature and terms used

The taxonomic nomenclature follows Giardina *et al*. (2007) and the syntaxonomical nomenclature follows Brullo *et al*. (2008) for the vegetation units ascribed to the class *Quercetea ilicis*, and Brullo *et al*. 2012 for those ascribed to the class *Querco-Fagetea*. Phytosociological terms follow the definitions by Gèhu and Rivas Martínez (1994), Poldini and Sburlino (2005), Pedrotti (2013). Since those terms are not commonly used, a short explanation of the essential phytosociological terminology most frequently used in the present paper is given below.

"Climatophilous vegetation" is the vegetation which best characterizes a given bioclimatic unit and can be used to outline its territorial extension. The term is often juxtaposed with "edapho-hygrophilous vegetation" and/or "edaphoxerophilous vegetation", both referring to vegetation units that, under the same climatic conditions, colonize wet (the former) or dry (the latter) soils. "Vegetation series" is the process of change in the species composition and structure of plant communities over time; succession. In phytosociology, it is defined by all plant associations and their dynamic relationships (progressive as well as regressive) found within the same land unit. "Sigmetum" is the nomenclatural term comprising all successional stages of a vegetation series. "Head vegetation" is the most mature community in a vegetation series; i.e., climax community. It corresponds to the "Potential Natural Vegetation" (*sensu* Tüxen 1956).

Results

According to our results, Sicily encompasses the following Rivas-Martínez's bioclimatic units: one macrobioclimate (Mediterranean); two bioclimates: Mediterranean pluviseasonal oceanic (CI ≤ 21, OI > 2.0) and Mediterranean xeric oceanic (CI ≤ 21, 1.0 < OI < 2.0), and 25 bioclimatic units (Figs. 2–4). The percentages of accuracy (*R*) of the vegetation series in the bioclimatic belts are given in Table 2. Based on the distribution analysis of bioclimates (Table 2) and the edaphic preferences of each vegetation unit, a synoptic key was obtained (Table 3).

Each vegetation unit mentioned here corresponds to the most mature stage of a vegetation series, for which syndynamic information and catenal contacts (cf. Rivas-Martínez 2002) can be easily obtained from literature (Bazan *et al*. 2010, Brullo *et al*. 2008, 2012). All the bioclimatic units found in Sicily are briefly commented in Appendix, with reference to the related vegetation series.

Discussion

Information on ecosystems and practical methods to delimit habitats and biotopes are needed for all kinds of studies at landscape scale. Spatial planning requires knowledge of the landscape that does not rely on purely perceptual, but also on objective and quantifiable data. In this respect, landscape ecology for about 30 years has come up with theories, methods and tools necessary for the analysis and interpretation of the land mosaic (Forman & Godron 1986, Ingegnoli 2004). Among the most topical issues of this discipline is identification of homogeneous land

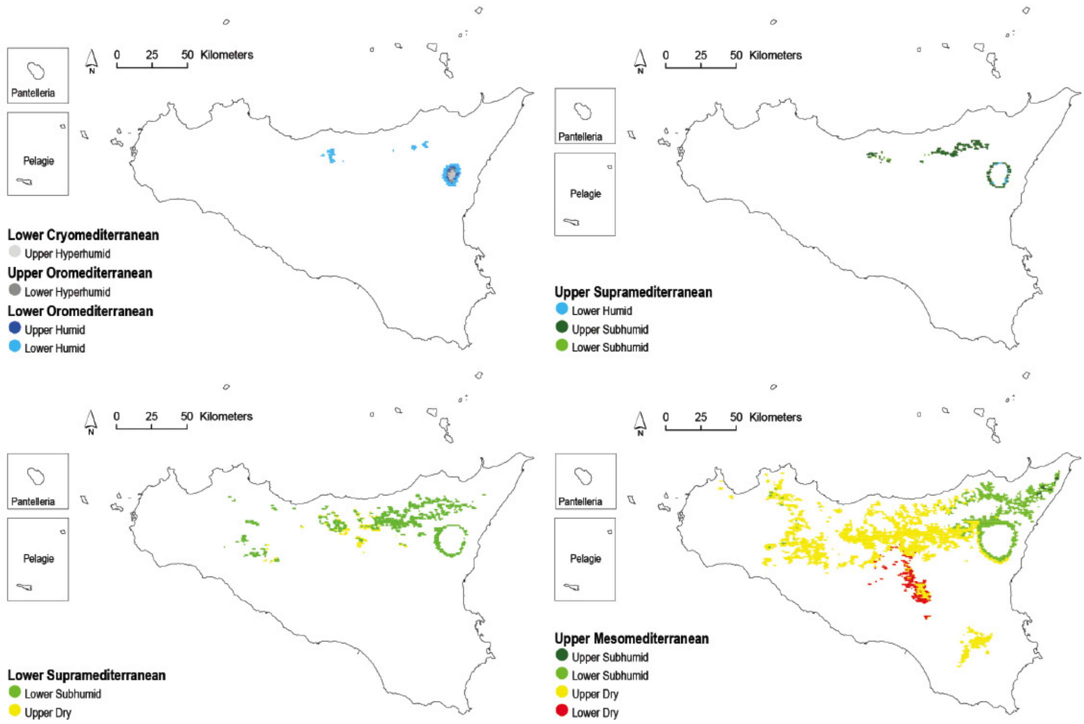

Fig. 3. Bioclimatic belts in Sicily (Lower Cryomediterranean to Upper Mesomediterranean).

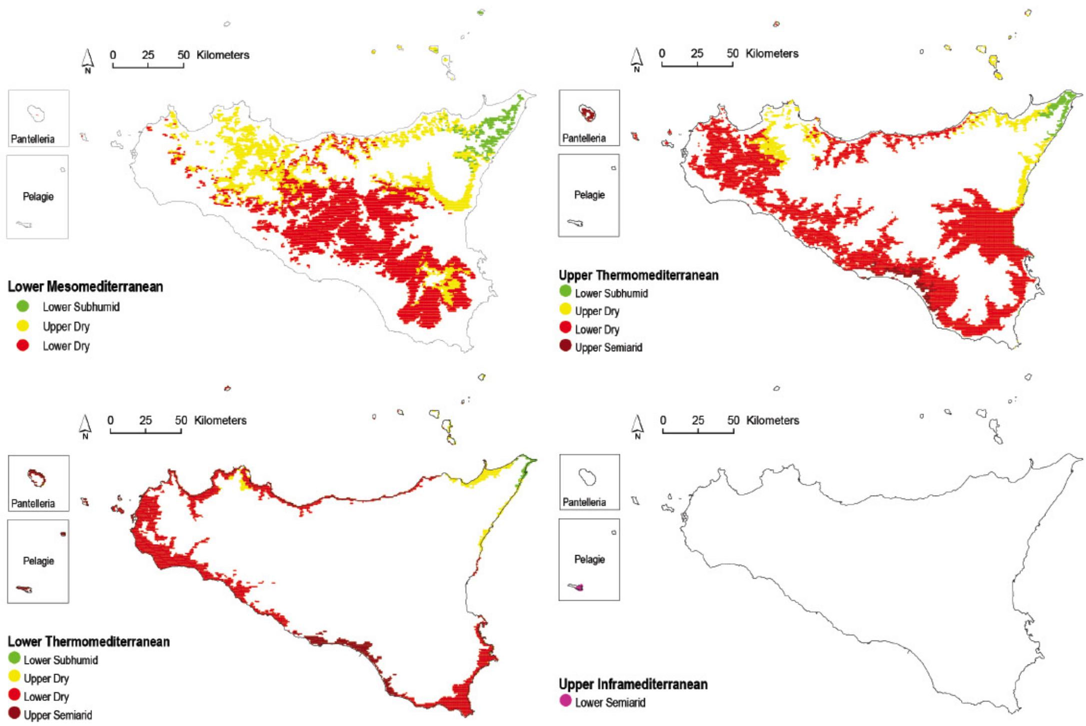

Fig. 4. Bioclimatic belts in Sicily (Lower Mesomediterranean to Upper Inframediterranean).

Table 3. Diagnostic key to define vegetation series according to bioclimatic belts. The vegetation units corresponding to the optimal bioclimatic units (defined as the highest value of the respective percentage distributions reported in Table 2) are given in boldface; other vegetation units frequently found within the considered bioclimatic unit are given in regular face; extrazonal vegetation units are given in italics. For the explanation of bioclimatic unit abbreviations, *see* Table 1.

Thermotypes	Ombrotypes	Basiphilous head vegetation series	Acidophilous head vegetation series
LCme	UHh		Rumici aetnensis-Astragalion siculi
UOme	LHh		**Rumici aetnensis-Astragalion siculi**
LOme	UHu		Rumici aetnensis-Astragalion siculi
	LHu		Rumici aetnensis-Astragalion siculi
USme	LHu	Luzulo siculae-Fagetum	**Epipactido meridionalis-Fagetum**
			Cephalanthero longifoliae-Betuletum aetnensis
			Junipero-Abetum nebrodense
	USh	**Luzulo siculae-Fagetum**	**Junipero-Abetum nebrodense**
		Hieracio madoniensis-Fagetum sylvaticae	*Junipero hemisphaericae-Pinetum calabricae*
			Anemono apenninae-Fagetum
			Ilici aquifolii-Taxetum baccatae
			Epipactido meridionalis-Fagetum
			Agropyro panormitani-Quercetum congestae
			Geranio versicoloris-Qeurcetum ilicis
	LSh		Anemono apenninae-Fagetum
			Agropyro panormitani-Quercetum congestae
			Agropyro panormitani-Populetum tremulae
			Daphno laureolae-Pinetum calabricae
			Arabido turritae-Quercetum congestae
			Arrhenathero nebrodensis-Quercetum cerridis
			Vicio cassubicae-Quercetum cerridis
			Rubo aetnici-Fagetum sylvaticae
			Geranio versicoloris-Qeurcetum ilicis
LSme	LSh	Sorbo torminalis-Quercetum virgilianae	Anemono apenninae-Fagetum
		Aceri campestris-Quercetum ilicis	Agropyro panormitani-Quercetum congestae
		Sorbo graecae-Aceretum pseudoplatani	**Arrhenathero nebrodensis-Quercetum cerridis**
			Melitto albidae-Fagetum sylvaticae
			Ilici aquifolii-Quercetum cerridis
			Arabido turritae-Quercetum congestae
			Quercetum gussonei
			Ilici-Quercetum austrotyrrhenicae
			Ilici aquifolii-Quercetum leptobalani
			Geranio versicoloris-Quercetum ilicis
			Teucrio siculi-Quercetum ilicis
	Udry		Teucrio siculi-Quercetum ilicis
UMme	USh		Erico arboreae-Quercetum virgilianae
	LSh		Agropyro panormitani-Quercetum congestae
			Arrhenathero nebrodensis-Quercetum cerridis
			Arabido turritae-Quercetum congestae
			Aceri obtusati-Ostryetum carpinifoliae
			Doronico orientalis-Castanetum sativae
			Quercetum gussonei
			Festuco heterophyllae-Quercetum congestae
			Erico arboreae-Quercetum virgilianae
	UDry	**Sorbo torminalis-Quercetum virgilianae**	Arrhenathero nebrodensis-Quercetum cerridis
		Aceri campestris-Quercetum ilicis	Ilici-Quercetum austrotyrrhenicae
		Ostryo carpinifoliae-Quercetum ilicis	**Quercetum gussonei**
			Festuco heterophyllae-Quercetum congestae
			Mespilo germanice-Quercetum virgilianae
			Lauro nobilis-Quercetum virgilianae
			Quercetum leptobalanae
			Geranio versicoloris-Quercetum ilicis
			Teucrio siculi-Quercetum ilicis
	LDry	Oleo sylvestris-Quercetum virgilianae	

continued

Table 3. Continued.

Thermotypes	Ombrotypes	Basiphilous head vegetation series	Acidophilous head vegetation series
LMme	LSh		Erico arboreae-Quercetum virgilianae
	UDry	Sorbo torminalis-Quercetum virgilianae	Quercetum gussonei
		Oleo sylvestris-Quercetum virgilianae	Festuco heterophyllae-Quercetum congestae
		Aceri campestris-Quercetum ilicis	Mespilo germanice-Quercetum virgilianae
		Pistacio lentisci-Quercetum ilicis	**Quercetum leptobalanae**
		Doronico orientalis-Quercetum ilicis	Erico arboreae-Quercetum virgilianae
		Rhamno alaterni-Quercetum ilicis	Genisto aristate-Quercetum suberis
	LDry	**Oleo sylvestris-Quercetum virgilianae**	Quercetum leptobalanae
		Celtido aetnensis-Quercetum virgilianae	**Erico arboreae-Quercetum virgilianae**
		Thymo capitati-Pinetum halepensis	Stipo bromoidis-Quercetum suberis
		Pistacio lentisci-Quercetum ilicis	**Erico arboreae-Quercetum ilicis**
		Doronico orientalis-Quercetum ilicis	
UTme	LSh		Cisto crispi-Pinetum pineae
	UDry	Oleo sylvestris-Euphorbietum dendroidis	Erico arboreae-Quercetum virgilianae
			Genisto aristate-Quercetum suberis
	LDry	Oleo sylvestris-Quercetum virgilianae	**Genisto aristate-Quercetum suberis**
		Calicotomo infestae-Rhoetum tripartitae	Thymo capitati-Pinetum halepensis
		Chamaeropo humilis-Quercetum calliprini	**Junipero turbinatae-Quercetum calliprini**
		Doronico orientalis-Quercetum ilicis	**Stipo bromoidis-Quercetum suberis**
		Pistacio lentisci-Quercetum ilicis	
		Rhamno alaterni-Quercetum ilicis	
		Oleo sylvestris-Euphorbietum dendroidis	
	USa		Junipero turbinatae-Quercetum calliprini
LTme	LSh		**Cisto crispi-Pinetum pineae**
	UDry	**Oleo sylvestris-Euphorbietum dendroidis**	Cisto crispi-Pinetum pineae
	LDry	**Calicotomo infestae-Rhoetum tripartitae**	Genisto aristate-Quercetum suberis
		Chamaeropo humilis-Quercetum calliprini	Junipero turbinatae-Quercetum calliprini
		Myrto-Pistacietum lentisci	
		Pistacio lentisci-Chamaeropetum humilis	
		Doronico orientalis-Quercetum ilicis	
		Rhamno alaterni-Quercetum ilicis	
		Ephedro fragilis-Pistacietum lentisci	
		Calicotomo infestae-Juniperetum turbinatae	
	USa	**Ephedro fragilis-Juniperetum macrocarpae**	Junipero turbinatae-Quercetum calliprini
UIme	LSa	**Periploco angustifoliae-Juniperetum turbinatae**	
		Periploco angustifoliae-Euphorbietum dendroidis	

areas, to which individual actions of management should be applied (Blasi *et al.* 2000).

The geobotanical approach in vegetation analysis is well suited not only to understanding natural and anthropogenic processes in progress, but also to identifying and mapping areas corresponding to homogeneous vegetation series. The visual aspect and the structure of vegetation are a result of complex interactions, in which climate, edaphic conditions and orography are the most significant variables. Nevertheless, there are some issues worth discussing when analysing the correspondence between phytosociological and bioclimatic units.

Bioclimatic units and geostatistical climate models

Bioclimatic indices took their origin in a time when sophisticated numerical models and technical tools with computational capabilities on grid and DTMs were not available. It was therefore useful, in that time, to propose 'simple' numerical approaches and threshold values to compare and possibly relate flora to vegetation. The classical application of bioclimatic indices was biased by the spatio-temporal heterogeneity of data, due to the scattered distribution of thermo-pluviometric monitoring stations and to the discontinuity of historic climate data. For that reason, until recent years, bioclimatic maps were based on the distribution range of the vegetation units and/or series, with which a given bioclimatic unit was empirically associated.

Currently, the problem of the uneven geographic distribution of climatic records can be overcome through the development of sophisticated climate models based on statistical prediction, so it is possible to obtain reasonably precise bioclimatic maps without considering the observable distribution of vegetation units. In this way, the distribution range of vegetation units can be used to check the validity of the discrete bioclimatic units. In our test (Table 2), the applicability of the WorldClim maps as predictive models for the distribution of the considered vegetation units was good. In particular, the bioclimatic indices calculated using the WorldClim data set turned out to depend mainly on altitude and thermotypes, while ombrotypes were linked to latitude, longitude and exposure. Such evidence is coherent with field observations and literature data, so the WordClim interpolation procedure seems to be applicable also at local scales.

Bioclimatic units and vegetation

In recent years, the most widely adopted bioclimatic indices in the Mediterranean phytosociological literature are those proposed by Rivas-Martìnez, whose uneven threshold values (Table 1) are used in the whole Mediterranean region, even if they were a result of a trial–error-adjustment procedure firstly based on the vegetation of the Iberian Peninsula (Rivas-Martìnez 1981).

In our work, Rivas-Martínez's bioclimatic units were adopted as working hypotheses, and their correspondence with the vegetation units was verified only after producing the bioclimatic maps through the application of Rivas-Martínez's algorithms to a high-resolution WorldClim grid. The result was that few of the vegetation units sharply overlapped with a given bioclimatic unit, while many units showed a more blurred bioclimatic assemblage (Table 2). This could be due to a mix of the following reasons and consequences:

1. All vegetation units do not have the same ecological amplitude. Fidelity (i.e., the more or less exclusive occurrence of certain species in a given community) and/or a recurrent combination of constant and dominant species is a satisfactory basis for the diagnosis and classification of plant communities, but certainly not all diagnostic species have similar ecological amplitudes. For this reason, the bioclimatic thresholds established through the distribution range of vegetation units occurring in a given territory should be checked and eventually adjusted when moving to another territory. If we assume that bioclimatic units are an empirical tool to express in a synthetic way the climatic preferences of a given vegetation type, the adjustment of bioclimatic thresholds should be allowed if necessary, when applying bioclimatic indices to different territories. Expressions like "Thermomediterranean" or "Oromediterranean" (the accuracy of which cannot be known beforehand) should represent a complement of bioclimatic indices and thermometric/pluviometric average measurements.
2. Bioclimatic indices exclusively based on thermometric and pluviometric data are not always good descriptors of the ecological amplitude of vegetation units and series, because they neglect important local factors, such as, e.g., moisture condensation, wind, and water availability. These factors are particularly important in the geologically and morphologically heterogeneous Sicily. A way to sharpen the discriminative character of bioclimatic indices is to include in their formulas additional algorithms that consider the influence of local factors. This was done, for instance, in the method for estimating how slope gradient and exposure, altitude and distance from the sea may influence the Mitrakos' Winter Cold Stress and Summer Drought Stress indices (Guarino 2001).
3. Resolution of the WorldClim model may be not good enough for applications at local scales. This assumption is in contrast with our results and with many other studies aimed at checking the usefulness of the model at different scales (e.g. Hijmans *et al.* 2005). An accurate prediction of a dynamic

phenomenon such as vegetation cover range is very difficult. However, the use of numerical predictive modelling methods like WorldClim, together with the analysis of aerial photographs and field surveys, allows us to produce a reasonably good geographical representation of the vegetation and, most importantly, it provides a useful basis for measuring applicability of any kind of bioclimatic index.

A more general criticism of the patterns obtained by the application of bioclimatic indices is that the whole approach may be an artefact imposed by clever shuffling of data and as such not mirroring nature. This is a valid objection, although, even without any adjustment, it has been demonstrated in this paper that higher syntaxononomical units turn out to overlap well with the Rivas-Martínez bioclimatic units: the correspondence of the Sicilian *Querco-Fagetea* vegetation with the Supramediterranean thermotype and the *Quercetea ilicis* vegetation with the Meso- and Thermomediterranean was very strong, as well as the correspondence of the *Quercion calliprini* vegetation with the Lower Thermomediterranean thermotype.

Conclusions

Bioclimatic models, integrated with the indubitable value of species distribution as an ecological indicator, can be useful tools for exploring the responses of living organisms to current and future climates (Grabherr *et al*. 1994, Pignatti *et al*. 2001, Walther *et al*. 2002, Moser *et al*. 2005). A geobotanical approach to spatial vegetation analysis, including bioclimatic indexation and mapping, is a practical way to describe natural vegetation dynamics, even when mature vegetation stands are missing. This approach can be useful in management of protected areas, biodiversity conservation and environmental restoration, taking into consideration that: (1) any kind of numerical threshold used to define bioclimatic units is not valid *a priori*, but only after it has been adapted to the territory and to the spatial scale used to set the developed model; (2) bioclimatic indices being an empirical tool, the model can be adjusted when applied to different territories; (3) the fidelity of any vegetation unit to a given bioclimatic unit is highly variable; (4) the mechanistic pitfall that climatophilous vegetation has to be necessarily linked to a single bioclimatic unit should be avoided. Instead, multifactorial hypotheses are required for the investigation of climatophilous vegetation, for which a strong correspondence to bioclimatic units can be true, but mechanistic understanding is always limited, because of long causal chains and indirect effects.

Climate can be described by a very large number of variables and indices. The bioclimatic approach, particularly when driven by the use of statistical climatic models, can be used for exploratory analyses that can be useful in predicting vegetation units. Climate research can generate hypotheses worth be tested further, even if ecological research has demonstrated that, sometimes, highly predictable vegetation dynamics under given climatic data are invalidated by subsequent investigation (e.g. Myers 1998, Carrión & Fernández 2009, Chiarucci *et al*. 2010).

At best, we can use the bioclimatic descriptors to develop hypotheses in an inductive framework. Difficulties will arise if we accept these hypotheses without critical testing by means of appropriate, in-depth investigations. Too often a model of vegetation series and its correspondence with bioclimatic units has been proposed as a universally informative system that can be adopted to forecast and eventually design natural vegetation dynamics.

Even if the bioclimatic approach can be used to explore the current distribution of vegetation units, its use to draft predictive scenarios should involve careful judgement. The key question concerns habitat changes in plant community composition and structure, and the changes this will entail for single plant species, animal populations and ultimately for species interactions. How communities shifted and changed in the past may give some indications, but the rates of future changes may be too different to make that analogy very useful. More importantly, habitat fragmentation has increased dramatically during the last centuries, which further complicates the usefulness of historical analogies.

Acknowledgements

Thanks are due to Prof. Francesco M. Raimondo (Botanical Garden, University of Palermo) for his useful suggestions during preparation of this manuscript.

References

Arriaga L., Castellanos V., Moreno E. & Alarcón J. 2004: Potential ecological distribution of alien invasive species and risk assessment: a case study of buffel grass in arid regions of Mexico. — *Conservation Biology* 18: 1504–1514.

Austin M.P. 1985: Continuum concept, ordination methods, and niche theory. — *Annual Review of Ecology and Systematics* 16: 3961.

Bartolo G. & Brullo S. & Pulvirenti S. 1994: Considerazioni fitosociologiche sulla vegetazione a Cistus crispus del territorio di Messina (Sicilia nord-orientale). — *Bollettino Accademia Gioenia di Scienze Naturali Catania* 27(346): 409–414.

Bazan G. & Brullo S. Raimondo F.M. & Schicchi R. 2010: Le serie di vegetazione della Regione Sicilia. — In: Blasi C. (ed.), *La vegetazione d'Italia*: 429–470. Palombi Editori, Roma.

Bazan G., Marino P., Schicchi R. & Surano N. 2006: Analisi geostatistica integrata come metodo per la conoscenza del bioclima della Sicilia. — *10ª Conferenza nazionale ASITA, Bolzano* 1: 253–258.

Blasi C. 2010: *La vegetazione d'Italia*. — Palombi Editori, Roma.

Blasi C., Carranza M.L., Frondoni R. & Rosati L. 2000: Ecosystem classification and mapping: a proposal for Italian landscapes. — *Applied Vegetation Science* 3: 233–242.

Bohn U. & Neuhäusl R. 2003: *Karte der natürlichen Vegetation Europas. Maßstab 1:2500000*. — Landwirtschaftsverlag, Münster.

Braun-Blanquet J. 1951: *Pflanzensoziologie*. — Springer, Wien.

Brullo S., Giusso del Galdo G. & Guarino R. 2001: The orophilous communities of the Pino-Juniperetea class in the Central and Eastern Mediterranean area. — *Feddes Repertorium* 112: 261–308.

Brullo S., Minissale P. & Spampinato G. 1995: Considerazioni fitogeografiche sulla flora della Sicilia. — *Ecologia Mediterranea* 21: 99–117.

Brullo S., Gianguzzi L., La Mantia A. & Siracusa G. 2008: La classe *Quercetea ilicis* in Sicilia. — *Bollettino Accademia Gioenia di Scienze Naturali Catania* 41: 1–124.

Brullo S., Giusso del Galdo G., Minissale P., Siracusa G. & Spampinato G. 2002: Considerazioni sintassonomiche e fitogeografiche sulla vegetazione della Sicilia. — *Bollettino Accademia Gioenia di Scienze Naturali Catania* 35: 325–359.

Brullo S., Scelsi F., Siracusa G. & Spampinato G. 1996: Caratteristiche bioclimatiche della Sicilia. — *Giornale Botanico Italiano* 130: 177–185.

Brullo C., Brullo S., Giusso del Galdo G., Guarino R., Siracusa G. & Sciandrello S. 2012: The class *Querco-fagetea sylvaticae* in Sicily: an example of boreo-temperate vegetation in the central mediterranean region. — *Annali di Botanica (Roma)* 2: 19–38.

Brullo S., Cormaci A., Giusso del Galdo G., Guarino R., Minissale P., Siracusa G. & Spampinato G. 2006: A syntaxonomical survey of the Sicilian dwarf shrub vegetation belonging to the class *Rumici-Astragaletea siculi*. — *Annali di Botanica (Roma)* 5: 103–149.

Bryan B., Connor J. & Ward J. 2005: *Systematic regional planning for multiple objective natural resource management. A case study in the South Australian River Murray Corridor*. — Natural Resource Management Economics, Policy and Economic Research Unit, CSIRO Land and Water, Adelaide.

Carrión J.S. & Fernández S. 2009: The survival of the 'natural potential vegetation' concept (or the power of tradition). — *Journal of Biogeography* 36: 2202–2203.

Cartabellotta D., Drago A., Lo Bianco B. & Lombardo M. 2000: *Atlante climatologico della Sicilia*. — Regione Sicilia, Ass. Agricoltura e Foreste, Palermo.

Castellano G., Marino P., Raimondo F.M. & Spadaro V. 2012: *Sorbus busambarensis* (*Rosaceae*), a new endemic species of Sicily. — *Plant Biosystems* 146 (Supplement): 338–344.

Chiarucci A., Araùjo M.B., Decocq G., Beierkuhnlein C. & Fernández-Palacios J.M. 2010: The concept of potential natural vegetation: an epitaph? — *Journal of Vegetation Science* 21: 1172–1178.

Del Arco-Aguilar M., Rodríguez-Delgado O.R., Acebes J., García-Gallo A., Pérez-de-Paz P.L., González-Mancebo J.M., González-González R. & Garzón-Machado V. 2009: Bioclimatology and climatophilous vegetation of Gomera (Canary Islands). — *Annales Botanici Fennici* 46: 161–191.

Duro A., Piccione V., Scalia C. & Zampino D. 1996: *Precipitazioni e temperature medie mensili in Sicilia relative al sessantennio 1926–1985*. — In: Guerriani A. (ed.),*5° Workshop Progetto Strategico Clima, Ambiente e Territorio nel Mezzogiorno C.N.R.*: 17–103. Consiglio Nazionale delle Ricerche, Palermo.

Fierotti G., Dazzi C. & Raimondi S. 1988: *Commento alla Carta dei Suoli della Sicilia*. — Assessorato Territorio e Ambiente Regione Sicilia, Università degli studi di Palermo.

Forman R.T.T. & Godron M. 1986: *Landscape ecology*. — John Wiley & Sons, New York.

Franklin J. 1995. Predictive vegetation mapping: geographic modelling of biospatial patterns in relation to environmental gradients. — *Progress in Physical Geography* 19: 474–499.

Gèhu J.-M. & Rivas-Martínez S. 1981: Notions fondamentales de phytosociologie. — In: Dierschke H. (ed.), *Syntaxonomie*: 5–35. J. Cramer, Vaduz.

Giardina G., Raimondo F.M. & Spadaro V. 2007: A catalogue of plants growing in Sicily. — *Bocconea* 20: 1–582.

Gleason H.A. 1926: The individualistic concept of the plant association. — *Bulletin of the Torrey Botanical Club* 53: 7–26.

Grabherr G., Gottfried M. & Pauli H. 1994: Climate effects on mountain plants. — *Nature* 369: 448.

Guarino R. 2001: Proposta per una parametrizzazione dei fattori stazionali nell'indice di Mitrakos. — *Ecologia Mediterranea* 27: 33–54.

Guarino R. 2011: Green landscapes of Sicily. — *Bulletin of the European Dry Grassland Group* 13: 16–25.

Guarino R., Ferrario E. & Mossa L. 2005: A stochastic model of seed dispersal pattern to assess seed predation by ants in annual dry grasslands. — *Plant Ecology* 178: 225–235.

Guarino R., Raimondo F.M. & Domina G. 2013: A new species of *Anthemis sect. Hiorthia* (Asteraceae) from SE Sicily. — *Plant Biosystems* 147: 821–825.

Hijmans R.J., Cameron S.E., Parra J.L., Jone P.G. & Jarvis A. 2005: Very high resolution interpolated climate surfaces for global land areas. — *International Journal of Climatology* 25: 1965–1978.

Ingegnoli V. 2004: *Landscape ecology: a widening foundation*. — Springer, Berlin, Heidelberg, New York.

Legendre P. & Anderson M. J. 1999: Distance-based redundancy analysis: testing multi-species responses in multifactorial ecological experiments. — *Ecological Monographs* 69: 1–24.

Marino A., Castellano G., Raimondo F.M. & Spadaro V. 2012: *Pyrus ciancioi* (*Rosaceae*), a new species from Sicily. — *Plant Biosystems* 146: 654–657.

Marino P., Castiglia G., Bazan G., Domina G. & Guarino R. 2014: Tertiary relict laurophyll vegetation in the Madonie mountains (Sicily). — *Acta Botanica Gallica* 161: 47–61.

Marino P., Guarino G. & Bazan G. 2012: The Sicilian taxa of *Genista* sect. *Voglera* and their phytosociological framework. — *Flora Mediterranea* 22: 169–190.

Médail F. & Quézel P. 1997: Hot-spots analysis for conservation of plant biodiversity in the Mediterranean Basin. — *Annals of the Missouri Botanical Garden* 84: 112–127.

Médail F. & Quézel P. 1999: Biodiversity hotspots in the Mediterranean Basin: setting global conservation priorities. — *Conservation Biology* 13: 1510–1513.

Mesquita S. & Sousa A.J. 2009: Bioclimatic mapping using geostatistical approaches: application to mainland Portugal. — *International Journal of Climatology* 29: 2156–2170.

Metzger M.J., Bunce R.G.H., Jongman R.H.G., Sayre R., Trabucco A. & Zomer R. 2013: A high-resolution bioclimate map of the world: a unifying framework for global biodiversity research and monitoring. — *Global Ecology and Biogeography* 22: 630–638.

Moser D., Dullinger S., Englisch T., Niklfeld H., Plutzar C., Sauberer N., Zechmeister H. G. & Grabherr G. 2005: Environmental determinants of vascular plant species richness in the Austrian Alps. — *Journal of Biogeography* 32: 1117–1127.

Myers R.A. 1998: When do environment-recruitment correlations work? — *Reviews in Fish Biology and Fisheries* 8: 285–305.

Oksanen J., Kindt R. & O'Hara R.B. 2009: *VEGAN: community ecology package*. — R package version 1.15-4. [Available at http://cc.oulu.fi/~jarioksa/softhelp/vegan.html].

Pedrotti F. 2013: *Plant and vegetation mapping*. — Springer, Dordrecht.

Peng C. 2000: From static biogeographical model to dynamic global vegetation model: a global perspective on modelling vegetation dynamics. — *Ecological Modelling* 135: 33–54.

Pignatti S., Bianco P.M., Fanelli G., Guarino R., Petersen L. & Tescarollo P. 2001: Reliability and effectiveness of Ellenberg's indices in checking flora and vegetation changes induced by climatic variations. — In: Walther J.R., Burga C.A. & Edwards P.J. (eds.), *Fingerprints of climate changes: adapted behaviour and shifting species ranges*: 281–304. Kluwer Academic Plenum Publishers, New York & London.

Poldini L. & Sburlino G. 2005: Terminologia fitosociologica essenziale. — *Fitosociologia* 42: 57–69.

Raimondo F.M. & Di Gristina E. 2007: *Hieracium madoniense* (Asteraceae) — a new species from Sicily. — *Plant Biosystems* 141: 86–92.

Raimondo F.M. & Spadaro V. 2008: A new species of *Centaurea* (Asteraceae) from Sicily. — *Botanical Journal of the Linnean Society* 157: 785–788.

Raimondo F.M., Domina G. & Spadaro V. 2010: Checklist of the vascular flora in Sicily. — *Quaderni di Botanica Ambientale e Applicata* 21: 189–252.

Raimondo F.M., Castellano G., Bazan G. & Schicchi R. 2012: *Sorbus madoniensis* (Rosaceae), a new species from Sicily. — *Plant Biosystems* 146 (Supplement): 345–351.

Rivas-Martínez S. 1981: Les étages bioclimatiques de la végétation de la Péninsule Ibérique. — *Anales del Jardín Botánico de Madrid* 37: 251–268.

Rivas Martinez S. 1994: Bioclimatic classification system of the Earth. — *Folia Botanica Matritensis* 12: 1–23.

Rivas-Martínez, S. 2002: Review of definitions (Dec. 2002). — Available at http://www.globalbioclimatics.org/book/review.htm.

Rivas-Martínez S. (ed.) 2007: Mapa de series, geoseries y geopermaseries de vegetazión de España. — *Itinera Geobotanica* 17: 5–436.

Sykes M.T., Prentice I.C. & Cramer W. 1996: A bioclimatic model for the potential distributions of north European tree species under present and future climates. — *Journal of Biogeography* 23: 203–233.

Taylor J. 1997: *Introduction to error analysis, the study of uncertainties in physical measurements*. — University Science Books, New York.

Troia A. & Raimondo F.M. 2010: *Isoëtes todaroana* (Isoëtaceae, Lycopodiophyta), a new species from Sicily (Italy). — *American Fern Journal* 99: 238–243.

Tüxen R. 1956: Die heutige potentielle natürliche Vegetation als Gegenstan der Vegetationskartierung. — *Angew Pflanzensozio (Stolzenau)* 13: 5–42.

Walther G.R., Post E., Convey P., Menzel A., Parmesan C., Beebee T.J., Fromentin J.M., Hoegh-Guldberg O. & Bairlein F. 2002: Ecological responses to recent climate change. — *Nature* 416: 389–395.

Whittaker R.H. 1951: A criticism of the plant association and climatic climax concepts. — *Northwest Science* 25: 17–31.

Appendix. Bioclimatic belts and their characterization in Sicily. Tp = Positive Temperature Index, It = Thermicity Index, Io = Ombrothermic Index.

1. Upper Cryomediterranean (UCme), Tp = 1–150

Distribution: Mt. Etna, at altitudes above 3000 m a.s.l.

Ombrotypes: Upper Hyperhumid (UHh), 18 < Io < 24.0

Vegetation series: Volcanic desert, without any visible vascular vegetation.

2. Lower Cryomediterranean (LCme), Tp = 150–450

Distribution: Mt. Etna, between 2400 and 3000 m a.s.l.

Ombrotypes: Lower Hyperhumid (UHh), 12.0 < Io < 18.0

Vegetation series: Volcanic desert and recent lava flows with scattered pioneer vegetation of *Rumici-Anthemidetum aetnensis* (Brullo *et al.* 2006).

3. Upper Oromediterranean (UOme), Tp = 450–675

Distribution: Mt. Etna, between 2000 and 2400 m a.s.l.

Ombrotypes: Lower Hyperhumid (LHh), 12.0 < Io < 18.0

Vegetation series: The vegetation is characterized by pulvinate shrubby communities of *Astragaletum siculi* (*Rumici-Astragalion siculi*). It forms a discontinuous formation of high phytogeographic interest with a set of endemic and rare species. *Astragaletum siculi* is physiognomically differentiated by the thorny pulvinate *Astragalus siculus*, growing together with *Senecio aethnensis*, *Galium aetnicum*, *Festuca circummediterranea*, *Robertia taraxacoides*, *Tanacetum siculum* and *Viola aetnensis* (Brullo *et al.* 2006).

4. Lower Oromediterranean (LOme), Tp = 675–900

Distribution: Madonie, Nebrodi, Mt. Etna between 1550 and 2000 m a.s.l.

Ombrotypes: Upper Humid (UHu), 9.0 < Io < 12.0; Lower Humid (LHu), 6.0 < Io < 9.0

Vegetation series: Orophilous shrubby communities of highest peaks adapted to cold environmental conditions. The occurrence of several rare taxa with relict distribution has high phytogeographical and ecological significance. On Mt. Etna, *Astragaletum siculi* becomes progressively denser and rich in taxa. In the Nebrodi and Madonie Mts. the vegetation has a similar structure, but different floristic settlement, which is ascribed to the alliance *Cerastio-Astragalion nebrodensis* (Brullo *et al.* 2006).

5. Upper supramediterranean (USme), It = (120)–150

Distribution: Madonie Mts., Nebrodi Mts., Mt. Etna between 1370 and 1550 m a.s.l.

Ombrotypes: Lower Humid (LHu) 6.0 < Io < 9.00; Upper Subhumid (USh), 4.8 < Io < 6.0; Lower Subhumid (LSh), 3.6 < Io < 4.8. The Upper Subhumid is widespread within this thermotypic horizon.

Vegetation series: The USme thermotype is characterized by beech forests, floristically distinguished by different edaphic conditions. On Mt. Etna, in the LHu horizon, the mature stage of vegetation is represented by *Epipactido meridionalis-Fagetum*, floristically very poor and with a scarce shrub layer. Under the same ombrotype, the Etnean birch woods (*Cephalanthero longifoliae-Betuletum aetnensis*) are also occurring, as edapho-xerophilous replacement of *Epipactido meridionalis-Fagetum sylvaticae* (Brullo *et al.* 2012).

In the Sicilian Apennines, USh is the most prevalent ombrotype. On carbonatic substrata of the Madonie, beech woods are represented by *Luzulo siculae-Fagetum*, while on siliceous substrata of the Madonie and Nebrodi Mts., the mature stage of vegetation series is *Anemono-Apenninae-Fagetum*. In the climatophilous belt of *Luzulo siculae-Fagetum*, narrow gorges with a microclimate characterized by a high degree of atmospheric moisture, on dolomites, are settled by *Hieracio madoniensis-Fagetum sylvaticae.* Additionally, *Junipero hemisphaericae-Abietetum nebrodensis* represents the edapho-xerophilous vegetation type, with a remarkable pioneer character, occurring in the Madonie Mts. within the area potentially occupied by the acidophilous beech forest (Brullo *et al.* 2001).

On the northern slopes of the Nebrodi Mts., the beech forests of *Anemono apenninae-Fagetum sylvaticae* are replaced by *Taxus baccata* forests (*Ilici aquifolii-Taxetum baccatae*) in stands characterized by colder and more humid and oceanic conditions. On rocky substrata, slightly acidic and well humified of the Madonie, Nebrodi and Peloritani Mts., the acidophilous holm oak forest named *Geranio versicoloris-Quercetum ilicis* is also found (Bazan *et al.* 2010).

The Lsh ombrotype, on the north-eastern slopes of Mt. Etna, is characterized by mesophilous *Quercus congesta* woods (*Agropyro panormitani-Quercetum congestae*). This association in more xeric conditions is replaced by *Daphno laureolae-Pinetum calabricae*, and on the eastern slopes of Mt. Etna at higher altitudes by *Vicio cassubicae-Quercetum cerridis*. In the sheltered and shady valleys, linked to more mesic conditions in comparison with the previous two associations, *Agropyro panormitani-Populetum tremulae* is occurring.

6. Lower supramediterranean (LSme), It = 150–220

Distribution: Sicani Mts., Busambra Rock, Palermo Mts., San Calogero, Favara and Granza, Madonie Mts., Nebrodi Mts., Peloritani Mts., Mt. Etna, between 960 and 1400 m a.s.l.

Ombrotypes: Lower subhumid (LSh), 3.6 < Io < 4.8; Upper dry (Udry), 2.8 < Io < 3.6.

Vegetation series: Within the Lsh ombrotype, in the mountain ridges of the Nebrodi Mts., the most widespread type of wood is *Arrhenathero nebrodensis-Quercetum cerridis*. This association represents the mature stage of a vegetation series made up by the shrubby vegetation of *Pruno-Rubion ulmifolii* and mesophilous meadows of *Plantaginion cupanii*.

Arrhenathero nebrodensis-Quercetum cerridis is floristically well differentiated from other Turkey oak woods of the Southern Apennines for the occurrence of several endemic species such as *Arrhenatherum nebrodense*, *Aristolochia sicula*, and *A. clusii*.

On the northern slopes of the Nebrodi Mts., with a remarkably oceanic mesoclimate caused by the exposure to moisture condensation from the sea, *Arrhenathero nebrodensis-Quercetum cerridis* is replaced by *Ilici aquifolii-Quercetum cerridis*. This association is well differentiated from the floristic, ecological and syndynamic viewpoint.

Within the *Arrhenathero nebrodensis-Quercetum cerridis* distribution area, in the north-facing slopes of the valleys of the Peloritani Mts., with remarkably humid microclimatic conditions, the turkey oak vegetation is replaced by *Melitto albidae-Fagetum sylvaticae*, which has to be regarded as an extrazonal community (Brullo *et al.* 2012).

In the Madonie Mts., on quartz sandstones and flysch, under oceanic mesoclimatic conditions, *Ilici aquifolii-Quercetum austrothyrrenicae* is occurring. Within the same bioclimatic belt, on gently slopes less humid, this association is replaced by *Ilici aquifolii-Quercetum leptobalani*. Its physiognomy is given by the occurrence of many different oak species, such as *Quercus leptobalanos*, *Q. congesta*, *Q. dalechampii* and sometimes *Q. ilex*.

LSme Udry is quite a rare bioclimatic combination in Sicily, well identified by the series of *Teucrio siculi-Quercetum ilicis*, limited to restricted areas of the Madonie and western Nebrodi Mts.

7. Upper mesomediterranean (UMme), It = 220–285

Distribution: Mountain areas between 620 and 1030 m a.s.l. This termotype is widespread on the mountain areas of Sicily: Palermo Mts., High Belice Corleonese, Sicani Mts., Madonie Mts., Upper Valley of the Salso River, Nebrodi Mts., highest hills of Enna, Peloritani Mts., Erei Mts., Etna and Hybalean Mts.

Ombrotypes: Lower dry (Ldry), Io = 2.0–2.8; Upper dry (Udry), Io = 2.8–3.6; Lower subhumid (Lsh), Io = 3.6–4.8; Upper subhumid (Ush), Io = 4.8–6.00.

Vegetation series: The subhumid ombrotype, occurring in the Peloritani Mts. and Mt. Etna areas is linked to acidophilous vegetation series. On Mt. Etna, it is outlined by *Agropyro panormitani-Quercetum congestae* and by *Arabido turritae-Quercetum congestae*. The last one is a basiphilous forest physiognomically characterized by the dominance of southern oaks, such as *Quercus congesta*, *Q. dalechampii* and *Q. ilex*. In narrow impluvia, where there are particular environmental conditions, represented by elevated atmospheric moisture, the series of *Aceri obtusati-Ostryetum carpinifoliae* is found. On the eastern slopes of Mt. Etna, *Doronico orientalis-Castanetum sativae* is occurring: a chestnut wood that appears floristically and ecologically quite natural.

The Udry ombrotype is localized on the southern and western slopes of Mt. Etna, on the southern slopes of the Nebrodi and Madonie Mts. The vegetation series is called *Festuco heterophyllae-Querceto congestae sigmetum*, whose stationary state is a wood physiognomized by dominant *Quercus congesta* which grows together with other oaks, such as *Q. dalechampii*, *Q. ilex* and *Q. amplifolia* (Guarino *et al.* 2013).

The *Arrhenathero nebrodensis-Querco cerridis sigmetum*, mainly linked to supramediterranean termotype, is gradually replaced by the *Querco gussonei sigmetum* in the Upper mesomediterranean belt, on siliceous sandy soils resulting from the weathering of quartz sandstones and flysch. The stands of *Quercus gussonei* are widespread along the northern slopes of the Nebrodi Mts. and Mt. Busambra, at the elevations between 600 and 900 m a.s.l.

At the highest elevations of the Hybalean Mts. (600–900 m a.s.l.), this bioclimatic belt is correlated to *Mespilo germanicae-Querco virgilianae sigmetum*. The *Quercus virgiliana* forest represents a mesophilous plant community, strictly linked to basaltic substrata, differentiated from the other thermophilous oak woods by the occurrence of *Mespilus germanica*. Within this series, in localities characterized by a high degree of soil moisture, *Mespilo germanicae-Quercetum virgilianae* is replaced by the edaphophilous vegetation of *Lauro nobilis-Quercetum virgilianae*.

The vegetation series of *Teucrio siculi-Quercetum ilicis* is widespread along the valleys and north-facing slopes of the Sicilian mountains, on siliceous substrata (schists, granites, gneiss, vulcanites, quartz sandstones and flysch). This association is an acidophilous holm oak forest, characterized by the occurrence of calcifuge species such as *Cytisus villosus*, *Erica arborea*, *Pulicaria odora*, *Festuca exaltata* and *Teucrium siculum*.

In the Sicani and Palermo Mts., the *Sorbo torminalis-Querco ilicis sigmetum* is occurring. The vegetation head series is physiognomically characterized by the dominance *Quercus virgiliana* and other rare species in Sicily such as *Sorbus torminalis*, *Physospermum verticillatum* and *Geocaryum cynapioides*. Frequent trees in this vegetation are: *Quercus ilex*, *Q. amplifolia*, *Fraxinus ornus*, *Acer campestre* and *Ostrya carpinifolia*.

On calcareous and dolomitic rocks, stable screes and immature soils, the woody vegetation is usually represented by *Aceri campestris-Quercetum ilicis*. It is an orophilous wood, characterized by *Ilex aquifolium*, *Acer campestre*, *A. monspessulanum*, *Sorbus graeca* and *Ulmus glabra*, floristically well differentiated from the other *Quercus ilex* woods of the Mediterranean Region.

8. Lower mesomediterranean (LMme), It = 285–350

Distribution: Palermo Mts, Sicani Mts., Erei Mts., uplands of the Gypsum-Sulphur Outcrops and Hybalean Mts. between 250 and 700 m a.s.l. It is the most widespread termotype of Sicily and covers the 33.9% of the regional surface.

Ombrotypes: Lower dry (Ldry), Io = 2.0–2.8; Upper dry (Udry), Io = 2.8–3.6; Lower subhumid (Lsh), Io = 3.6–4.8; The distribution follows a geographical gradient, increasing from west to east and from south to north.

Vegetation series: The mature stands of vegetation are climatophilous forests ascribed to the order *Quercetea ilicis*.

The Lsh ombrotype is localized in the Peloritani Mts. This thermotypic horizon is linked to the vegetation series of *Erico arboreae-Quercetum virgilianae*. The head of series is a forest physiognomically dominated by *Quercus virgiliana* with a dense shrubby layer characterized by many calcifuge species, such as *Erica arborea*, *Cytisus villosus*, *Arbutus unedo*, *Teline monspessulana*, etc. The *Erico arboreae-Querco virgilianae sigmetum* occurs in all ombrotypes of the LMme vegetation belt, on siliceous substrata with deep and well humified soils, and is also widespread in the Nebrodi Mts., Madonie Mts. and Eolie Islands.

The vegetation series most closely related to the Udry ombrotype is *Querco leptobalanae sigmetum*. It is acidophilous vegetation characterized by *Quercus leptobalanos*, together with *Q. dalechampii*, *Q. congesta*, *Q. amplifolia*.

On marl formation, in the Ldry ombrotype, the *Pinus halepensis* series is occurring. The mature stand of the series is *Thymo capitati-Pinetum halepensis*, a pine wood with a rich shrubby layer, containing *Thymus capitatus* and other sclerophyllous species such as *Pistacia lentiscus*, *Chamaerops humilis*, *Phillyrea latifolia*, and *Teucrium fruticans*.

Within deep and mature soils on calcareous substrata, the most widespread vegetation series is the *Oleo sylvestris-Querco virgilianae sigmetum* that characterizes whole LMme and Upper Thermomediterranean (UTme). The different aspects of the series are connected by a catenal contact with series of *Pistacio-Rhamno alaterni* sigmion and *Querco-Fago* sigmetea.

The potential natural vegetation is a *Quercus virgiliana* forest which includes other tree species, such as *Q. amplifolia Q. ilex*, *Fraxinus ornus,* and *Acer campestre*. This vegetation has more xeric requirements, as shown by the occurrence of Mediterranean species such as *Olea europaea* var. *sylvestris*, *Pistacia lentiscus*, *Teucrium fruticans*, *Prasium majus*, and *Asparagus albus*.

The oak woods of *Oleo sylvestris-Querco virgilianae sigmetum* are quite rare, in relation to their potential distribution, due the human settlements. The growing settlements had agricultural and pastoral activities dating back at least to the 2nd century BC. The residual well preserved patches occur in areas owned by the church, or in private hunting reserves.

The LMme and UTme thermotypes occur in 68.6% of the regional area. This large surface

could be probably not only linked to the *Oleo sylvestris-Quercetum virgilianae*. This association, and the related sigmetum should be considered *sensu lato*, because of the lack of knowledge on other vegetation types.
In the deep canyons of the Hyblean Plateau (Cave), *Doronico orientalis-Quercetum ilicis* is found. This is a mesophilous association characterized by the dominance of *Quercus ilex* and sporadic deciduous oaks, such as *Q. virgiliana* and *Q. amplifolia*.

9. Upper thermomediterranean (UTme), It = 350–400

Distribution: Hills between 0 and 450 m a.s.l. This thermotype characterizes the hilly landscape of southern Sicily, the alluvial plains of Catania and along the Tyrrhenian coast, from Cape Zafferano to Cape of Orlando. It is a very representative bioclimatic belt of Sicily, covering 32.8% of the regional surface.

Ombrotypes: Upper semiarid (Usa), Io = 1.5–2.0; Lower dry (Ldry), Io = 2.0–2.8; Upper dry (Udry), Io = 2.8–3.6; Lower subhumid (Lsh), Io = 3.6–4.8; The values of the Ombrothermic Index (Io) are increasing from south to north-east. The lowest values (Semiarid) are located in the Plain of Gela.

Vegetation series: The Ldry ombrotype is linked either to cork oak and holm oak woodlands. On the Tyrrhenian slopes of the Madonie and Nebrodi Mts., on siliceous sandy substrata, the most mature vegetation stand is represented by *Genisto aristatae-Quercetum suberis*. It is a cork-oak wood dominated by *Quercus suber* and *Q. congesta*, *Q. dalechampii*, *Q. amplifolia*, *Q. ilex*, *Q. gussonei*, and *Q.* × *fontanesii* (Marino *et al.* 2012).
In southern Sicily cork oak woods are ascribed to *Stipo bromoides-Quercetum suberis.* The vegetation series is widespread in the Caltagirone, Niscemi, Mazzarino territories (SE Sicily), Menfi and Castelvetrano territories (SW-Sicily). *Stipo bromoidis-Quercetum suberis* is a xerophilous association, localized on Pleistocenic sand deposits. On sandy soil of fossil dunes in SE Sicily, the *Junipero turbinatae-Querco calliprini sigmetum* is occurring. The series is localized between Gela and Marina di Ragusa, and around the Gulf of Castellammare.
The *Junipero-Quercetum calliprini* association represents a maquis with small trees of *Quercus calliprinos* and *Juniperus turbinata* growing together with *Pistacia lentiscus*, *Phillyrea latifolia* and *Rhamnus alaternus*.
On carbonatic substrata in this thermotype, the *Pistacio lentisci-Querco ilicis sigmetum* and the *Rhamno alaterni-Querco ilicis sigmetum* occur. Both are *Quercus ilex* stands, rich in thermophilous species featuring the order *Quercetalia calliprini* such as *Pistacia lentiscus Rhamnus alaternus Pistacia terebinthus.* The series of *Pistacio lentisci-Quercetum ilicis* is localized on shallow and rocky soils, widespread everywhere in the Island, *Rhamno alaterni-Quercetum ilicis* is localized on humid costal slopes in northwestern Sicily. This association is rich of lauriphylls such as *Rhamnus alaternus*, *Viburnum tinus*, *Laurus nobilis* and climbers like *Hedera helix*, *Smilax aspera*, *Rosa sempervirens*, *Rubia peregrina*, etc. The more humid microclimatic conditions, due to sea breeze, determines the presence of this extrazonal vegetation linked to subhumid condition within the Ldry ombrotype horizon (Marino *et al.* 2013).

10. **Lower thermomediterranean** (LTme), It = 400–450

Distribution: Costal areas between 0 and 220 m a.s.l. The termotype unit characterizes the coastal area of the whole region and covers 11.5% of its surface.

Ombrotypes: Upper semiarid (Usa), Io = 1.5–2.0; Lower dry (Ldry), Io = 2.0–2.8; Upper dry (Udry), Io = 2.8–3.6; Lower subhumid (Lsh), Io = 3.6–4.8. The values of the Ombrothermic Index (Io) are increasing from south to northeast. The lowest values (Semiarid) are located in the Plain of Gela; the most humid (subhumid) along the coast of the Strait of Messina.

Vegetation series: The vegetation of Lsh is characterized by *Pinus pinea* woodlands, with a shrub layer rich in acidophilus species belonging to *Cisto-Lavanduletea* such as *Cistus crispus*, *C. salvifolius*, *Tuberaria guttata*, and *Erica arborea*. The vegetion series of *Cisto crispi-Pino pineae sigmetum* is linked to sandy schistose soils of NE Peloritani, near Messina (Bartolo *et al.* 1994).
The Udry ombrotype is characterized by the occurrence of *Oleo-Euphorbio dendroidis sigmetum*. The head vegetation series, *Oleo-Euphorbietum dendroidis*, in most of the Island has to be considered an azonal community linked to the steepest rocky slopes. However, within the coastland of Etna and Peloritani, the coastland of Agrigento and the islands of Lipari, Vulcano, Ustica, this association represents a climatophilous community.
Lower dry ombrotype is characterized by the occurrence of shrubland/maquis communities, chiefly dominated by evergreen sclerophyll and summer-deciduous shrub, belonging to

the alliance *Oleo-Ceratonion siliquae*. The mature stands of the vegetation series are *Chamaeropo humilis-Quercetum calliprini*, *Pistacio lentisci-Chamaeropetum humilis*, *Myrto communis-Pistacietum lentisci* and *Calicotomo infestae-Rhoetum tripartitae*. These associations are widespread especially along the coastland of Sicily and are related to different substrata. These vegetation series are in catenal contact with the climatophilous series of *Querco ilicis sigmetalia* and halophilous communites of *Chritmo-Limonietea*.

11. **Upper Inframediterranean** (UIme), It = 450–515
Distribution: Lampedusa at from 0 to 30 m a.s.l.
Ombrotypes: Lower Semiarid (Sar), Io = 1.0–1.5. Localized on the eastern part of Lampedusa Island.
Vegetation series: *Periploco-Juniperetum turbinatae sigmetum.* The head of vegetation series is a termo-xerophilous maquis dominated by *Juniperus turbinata* and *Periploca angustifolia*. Some shrubs of *Quercetalia calliprini* are abundant: *Pistacia lentiscus*, *Prasium majus*, *Olea europaea* var. *sylvestris*, *Teucrium fruticans*, *Asparagus albus*, etc.