Fitosociologia vol. 48 (2) suppl. 1: 75-82, 2011

Vegetation science and the ecoregional approach: a proposal for the ecological land classification of Italy.

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Abstract
This paper presents the context, methodology and preliminary results of an ecoregionalisation process applied at national scale. Ecoregion delineation was based on robust biophysical stratification and on vegetation data, particularly vegetation series. Synphytosociological information proved to be very effective as diagnostic or descriptive feature, promoting the role of synphytosociology as scientific reference point for ecoregional programmes.

Keywords: ecological land classification, vegetation series, ecoregions.

Riassunto
Questo lavoro presenta il contesto, la metodologia e i risultati preliminari di un processo di classificazione ecoregionale applicato a scala nazionale. Le ecoregioni sono state delimitate in base a fattori fisici e a dati di vegetazione, relativi in particolare alle serie. L'informazione sinfitosociologica si è dimostrata un valido attributo diagnostico e/o descrittivo per l'identificazione e la cartografia di unità ecologiche omogenee. La sinfitosociologia può pertanto assumere un ruolo di riferimento scientifico per i progetti di classificazione ecologica del territorio.

Parole chiave: classificazione ecologica del territorio, ecoregioni, serie di vegetazione.

Introduction

In connection with the concern on global change and the transition to ecosystem-based management (Convention on Biological Diversity, 1992; Millenium Ecosystem Assessment, 2005), in the last three decades the attention of ecologists from different fields progressively converged on environmental heterogeneity and shifted from individual ecosystems to the spatial pattern of habitats, communities, and land uses, under a new landscape perspective (Wu & Hobbs, 2002). In vegetation science, this supported the development of modern phytosociology, which is focused on the characterisation of individual plant communities and on their spatial relationships, either dynamic or purely topographical, with adjacent communities (Géhu, 1986; Rivas-Martinez, 2005; Lazare J.-J., 2009). From a more general perspective, the process of ecological land classification, which links ecology and geography for mapping ecological regions (ecoregions), received renewed attention. Ecological land classification defines areas that are homogeneous in terms of ecosystem patterns on spatial scales from global to local, and provides a consistent spatial framework within which ecosystems at various levels of generalisation can be described, monitored and assessed (Loveland & Merchant, 2004). The increased interest in ecoregion mapping has prompted scientific debates on all research aspects (Rowe & Sheard, 1981; Omernik, 2004; Makhdoum, 2008) and has driven several global (Bailey, 1996; Olson *et al*., 2001; FAO, 2000) to national and regional initiatives, especially in North America (Ecological Stratification Working Group, 1996; US Environmental Protection Agency, 2005; ECOMAP, 2007; Sayre *et al*., 2009).

Despite differences in nomenclature and scales, researchers working on ecoregionalisation largely agree on the basic factors that makes the hierarchy of nested units significant from ecological and management perspectives. In most cases vegetation represents crucial information at different levels of detail, owing to its indicator value of environmental conditions at a site. In particular, it is potential natural vegetation that helps delineate and characterise ecoregions: it represents a relatively stable factor in time and simplifies intricate patterns resulting from anthropic disturbance and secondary successional stages (Wright *et al*., 1998; Bailey, 2005).

Within this context, we present a proposal for identifying and mapping the ecoregions of Italy, drawn on climate, physiography, biogeography, potential natural vegetation, and vegetation series. The reasons underlying this research line are mainly two. Firstly, we believe that the experience gained with synphytosociology and, more generally, vegetation science can be very effective even at the ecoregion level, and that the integration of the ecoregional approach with synphytosociology would in turn allow detailed vegetation information to be interpreted more accurately from both ecological and chorological points of view. Secondly, Italy represents a hotspot of ecoregional diversity in Europe and needs a comprehensive and detailed system of ecoregions to make national and sub-national management strategies truly sustainable.

Background

Ecological land classification relies on a scale-independent concept of ecosystem: the homogeneity of biotic and abiotic components that separates an ecosystem from its surroundings depends upon the scale of observation (O'Neill *et al.*, 1986; Rowe, 1996). On this basis a hierarchical framework can be built that portrays ecosystems at different levels and scales and that enables the choice of detail most suitable for specific management and planning objectives (Cleland *et al.*, 1997).

The key point in building such a hierarchy is to establish the relative importance of diagnostic factors on determining the spatial pattern observed at each scale (Bailey, 1987; Klijn & Udo de Haes, 1994). Ideally differentiating criteria should also reflect a temporal hierarchy, and range from the most enduring components at the higher levels to factors that respond faster to, or most influence, change over time.

Although using single determining characteristics at each level would ease comprehension and replicability of the methodology, in most cases a multi-criteria approach is employed that integrates patterns and relationships of all factors and considers both diagnostic (controlling) and mapping (dependent) features (Klijn, 1994). This procedure ensures ecological significance of boundaries while accounting for the complex interactions among ecosystem components (Omernik, 2004; Bailey, 2005). In many proposed frameworks, the number and set of mapping characteristics vary from one ecological region to another, regardless of the level of generalisation, and the expert judgement on the relative importance of different data plays a crucial role in the strategy analysis (Loveland & Merchant, 2004).

There is common general agreement on the use of climate, landform, hydrology, vegetation, and soils for building ecoregions, whereas the inclusion of humans is still a matter of debate. In Europe, the long history of tight interactions between man and the natural environment made confusing or perhaps unnecessary the distinction between landscape and ecoregion classifications (Zonneveld, 1989; 1995; Bastian, 2000). However, a major difference between the two approaches, at least at the finer scales of observation, could indeed lie in the issue of including or excluding human factors in the procedure. The identification of ecological regions should emphasise relatively stable natural characteristics and their interconnections (Bailey, 2005), whereas landscape units should be based also on the spatial pattern of land uses and the underlying interactions between socio-economic and natural characteristics (Pinto-Correia *et al.*, 2003; Mucher *et al.*, 2010; van Eetvelde & Antrop, 2007). When based only on main natural features, ecological land classification depicts spatial units that are homogeneous in terms of biological and environmental potential. Therefore, it provides the best spatial reference framework for many conservation and sustainability tasks, such as sampling stratification, assessment of biodiversity and resource conditions, monitoring of change (Cleland *et al.*, 1997; Ricketts & Imhoff, 2003; Gallant et al., 2004). However, not all scientists working on ecoregionalisation share this view, and some proposals from Canada and North America explicitly include land use patterns among the classification components (Marshall & Schut, 1999; Omernik, 1987).

In the U.S. different resource management agencies developed their specific spatial framework at regional and national scales, and an attempt to create a standardised and nationally comprehensive map of ecological units has been ongoing since 1996 (McMahon *et al.*, 2001). In the meantime, the USDA Forest Service has issued its approximated official inventory of ecological units at the subregional and regional scales (ECOMAP, 2007), based on climate, physiography, geologic substrate, and vegetation. Recently, Sayre *et al.* (2009), from the United States Geological Service, proposed a new map of standardised, mesoscale terrestrial ecosystems based on biophysical stratification. The biophysical units drawn on biogeography, bioclimate, lithology, landform, and topographic moisture potential have finally been characterised in terms of ecosystem types using a hierarchical National Vegetation Classification system (US-NVC) that is based on recurrent patterns of plant communities (Comer *et al.*, 2003).

In Europe, ecological land classification developed particularly in the Netherlands. Klijn and collaborators

(1995, 1996) mapped different levels of ecological units using a case-by-case assessment of relative importance of components. They employed geology, geomorphology, groundwater and surface water, soil, vegetation, and fauna to develop the framework of ecoregions and ecodistricts, the two spatial scales most suitable for planning at the national level (Klijn *et al*., 1995). Soil classification and ground-water levels were then used as conditioning site factors for mapping more detailed ecoseries (Klijn *et al*., 1996). At European scale, the European Environment Agency promoted the development of a Digital Map of European Ecological Regions (DMEER) at 1:2,500,000 scale, based on cluster analysis of climatic, topographic, and potential vegetation data and on the judgement of a large team of biogeography experts (EEA, 2000). For this project vegetation data were extracted from the Map of Natural Vegetation of Europe (Bohn, 2003), which recognised 19 physiognomic-ecologic formations further differentiated into 650 units according to floristic, edaphic, climatic, and phytogeographical criteria. The continental scale of the work required ecoregions to be described in more general vegetation terms, in spite of the use of almost 500 zonal vegetation units in the automatic classification process. According to DMEER, Italy falls into six ecological distinct areas: Alps conifer and mixed forests, Po basin mixed forests, Italian sclerophyllous and semi-deciduous forests, Tyrrhenian-Adriatic sclerophyllous and mixed forests, Appennine deciduous montane forests, and South Appenine mixed montane forests.

A proposal for the ecoregions of Italy

Italy is characterised by a highly heterogeneous pattern of ecosystems that emerge at all scales and can be organised into ecologically significant spatial units only using a detailed biophysical stratification based on robust data integration.

As seen in the previous sections, it is widely acknowledged that vegetation data represent basic information for delineating or characterising ecoregions, either in terms of potential natural vegetation or as vegetation types based on combinations of plant communities. The concept of vegetation series contemporarily takes into account the potential vegetation and the pattern of dynamically related plant communities that recurs in similar biogeographical and environmental settings. By providing different levels of description, vegetation series represent indeed the best vegetation information for the ecoregionalisation process.

Recently, a large team of regional experts from several Italian Universities produced the National Map of Vegetation Series at scale 1:500,000 (Blasi ed., *in press*). This map confirms the potential for forest vegetation over more than 80% of the national territory and highlights an extraordinary diversity of vegetation types: as an example, beech forests fall into 41 different vegetation series, and deciduous oak woodlands into 85. Overall, the map depicts 240 vegetation series (sigmeta) and 39 geosigmeta, classified in the legend according to climatic region, bioclimatic type, and geographic area, and characterised by their Latin name and by geographical distribution, ecology, and physiognomy. We are integrating this large amount of information with data on bioclimate, biogeography, litho-structural units, and morpho-tectonics units (Table 1) to characterise and delineate different levels of ecological classification using a top-down approach. Hierarchical levels, diagnostic criteria, and scales broadly follow the North-American model (Cleland *et al*., 1997; ECOMAP, 2007), though significant changes have been made to adapt it to the complexity of the Italian territory. In particular, our classification scheme consists of four general levels that spans from European to national and subnational application scales (at the continental application scale, Italy is fully included in the Humid Temperate Domain according to global climatic and terrestrial ecoregion classifications). Each application scale is subdivided into ecological units or ecoregions *sensu latu*, which are delimited according to climatic, biogeographic, and physiographic criteria. These units are then described by the main characteristics of natural vegetation, ranging from vegetation formations to individual plant associations (Table 2). The local application

Biophysical attribute	**Sources**
Bioclimate	Bioclimatic map of Europe (Rivas-Martìnez *et al*., 2004) Updated Phytoclimatic map of Italy (Blasi & Michetti, 2005 and *unpublished data*)
Biogeography	Biogeographic map of Europe (Rivas-Martinez *et al*., 2004) modified according to recent national and local schemes (Biondi *et al*., 2006; Blasi *et al*., in press)
Geomorphology	Structural Model of Italy (Bigi *et al*., 1992) Geological sheets of the National Geological Service
Vegetation	Map of Natural Vegetation of Europe (Bohn *et al*., 2003) Map of Vegetation Series of Italy (Blasi ed., *in press*)

Tab. 1 - Basic data used for the ecoregionalisation process.

Application scale	Ecological unit (ecoregions *sensu latu*)	Main design criteria	Natural vegetation descriptors
European and National	**Division**	Macroclimatic zones Biogeographic regions/subregions	Structure and physiognomy of major zonal vegetation types
	Province	Orographic systems and biogeographic provinces	Dominant common and distinctive vegetation physiognomies
National and Regional	**Section**	Physiographic complexes (litho-structural regions) Biogeographic sectors Bioclimatic types	Characteristics combination of vegetation physiognomies
National and Regional	**Subsection**	Morpho-tectonic sectors Ombrotype and thermotype Characteristic combination of vegetation series	Prevalent vegetation series (*sigmeta*)
Local	**Land systems**	Lithology	Complete list of vegetation series (*sigmeta*)
	Land facets	Topography (altitude, slope and aspect)	
	Environmental units	Potential natural vegetation	Seral stages of vegetation series (*plant associations*)

Tab. 2 - Levels of generalisation with main design criteria and vegetation descriptors.

scale joins the ecological units already proposed for ecosystem classification and mapping by Blasi *et al*. (2000; 2005) with the higher levels of the newly proposed ecoregionalisation scheme.

As an example, in the next section we describe the classification scheme of the Cilento subsection by reporting the diagnostic features and natural vegetation descriptors of each level of interest.

Classification of the Cilento Subsection

MEDITERRANEAN DIVISION

21 Tyrrhenian Bordeland Province

21A Tuscan Section

21B Roman Section

21C Latium-Campanian Section

21Ca Volsci Range Subsection

21Cb Vesuviano-Flegrea Subsection

21Cc Lattari Mountains Subsection

21Cd Sele Plain Subsection

21Ce Cilento Subsection

21Cf Lucano-Calabrese Subsection

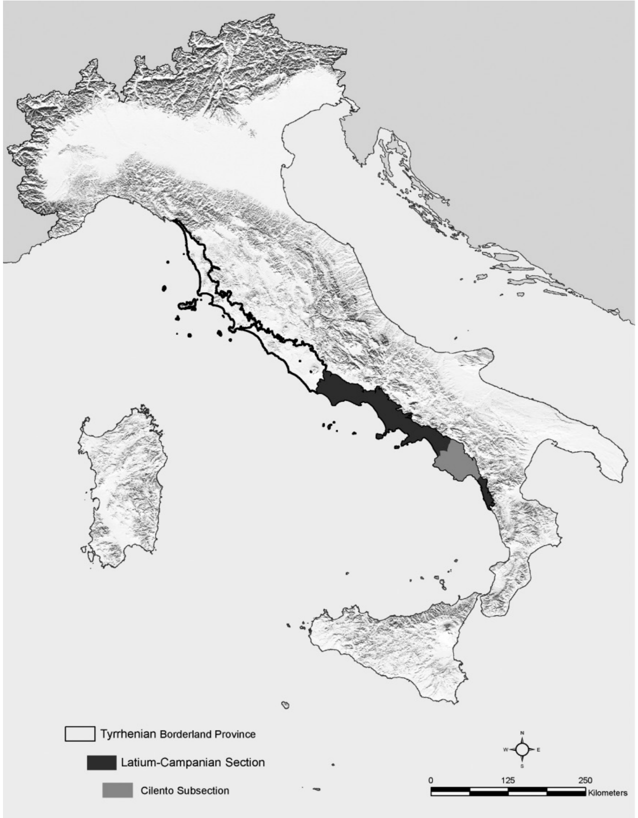

Fig. 1 - Delineation of the Cilento Subsection and of higher levels of generalization.

MEDITERRANEAN DIVISION

Mediterranean macroclimate, Mediterranean biogeographic region (with Western and Eastern Mediterranean subregions). Presence of summer aridity, precipitation concentrated during the autumn-winter period, and small difference between winter and summer temperatures. The mountain reliefs of the southern Apennines, Sicily and Sardinia represent an orographic variant with a temperate climate but low level of continentality (less than 17°C).

Potential natural vegetation prevalently consists of forests, with mixed woods of evergreen and deciduous *Quercus* species. Forests and shrublands consisting exclusively of evergreen sclerophyllous species characterise a narrow coastal strip along the peninsula and significantly penetrate inland areas only in Sardinia and in the Apulian plateau. The subdivision between the Western and Eastern Mediterranean biogeographic subregions results in a peculiar mixture of Mediterranean, Illyrian and Subatlantic elements. Reference orders: *Quercetalia pubescenti-petraeae* Klika 1933 corr. Moravec in Béguin et Theurrilat 1984, *Quercetalia ilicis* Br.-Bl. *ex* Molinier 1934, *Pistacio-Rhamnetalia alaterni* Rivas-Martinez 1975.

Tyrrhenian Borderland Province

Extensional belt of the inner Apennine platform due to the expansion of the Tyrrhenian Sea.

Italo-Tyrrhenian biogeographic province.

Dominant potential vegetation physiognomies: *Quercus cerris* forests; Riparian and hygrophilous forests

Additional widespread potential vegetation physiognomies: Other deciduous oak woods (prevalently *Quercus frainett*o and *Q. pubescens*); *Quercus ilex* forests

Distinctive vegetation physiognomies: Subcoastal plain forests with *Fraxinus oxycarpa* and *Quercus robur.*

Latium-Campanian Section

Sector of the Apennine chain formed by nappes from different paleogeographic domains (Tethyan oceanic environment, Apennine carbonatic platforms, siliceous-calcareous-marly continental basin) and characterised by coastal *graben*, volcanism (Roman comagmatic Province) and promontories.

Western coastal biogeographical sector of the Italo-Tyrrhenian biogeographic Province.

Bioclimate is Oceanic Mediterranean, with relatively higher precipitation than the Roman and Tuscany sections. The subcoastal mountain ranges of Volsci, Lattari and Cilento represent an orographic variant with transitional Temperate climate and significant oceanicity.

Mosaic of subacidophilous *Quercus frainett*o forests (17.5%), acidophilous *Quercus virgiliana* forests (13.5%), *Quercus cerris* forests (13.4%) and *Ostrya carpinifolia* forests (12.3%).

Cilento Subsection

Tyrrhenian promontory with several orographic features (from coasts to mountain massifs) and heterogeneous lithology (Cretacic limestones, clays, sandstones, Quaternary alluvial deposits).

Thermotype from Thermo-Mediterranean to lower Oro-Temperate. Ombrotype: from Subhumid to Hyperhumid.

Characteristic combination of vegetation series (dominant and distinctive):

- Neutral-basiphile *Quercus ilex* series of the southern Apennines (*Festuco exaltatae-Querco ilicis sigmetum*)

- Acidophilous *Quercus virgiliana* series of the Tyrrhenian side of the Southern Apennines *(Erico arboreae-Querco virgilianae sigmetum)*
- Neutral-basiphile *Ostrya carpinifolia* series of the Southern Apennines *(Seslerio autumnalis-Acero obtusati sigmetum)*
- Neutral subacidophilous *Quercus cerris* series of the Southern Apennines (*Lathyro digitati-Querco cerridis sigmetum*)
- Western neutral-basiphile *Quercus cerris* series of the southern Apennines (*Thalictro aquilegifolii-Querco cerridis* sigmetum), exclusive of Cilento
- Neutral-basiphile *Fagus sylvatica* series of the Southern Apennines: *Anemono apenninae-Fago sylvaticae sigmetum*; *Ranunculo brutii-Fago sylvaticae sigmetum* (this latter occurs in Campania only in the Cilento subsection)

Prevalent vegetation series:

- *Erico arboreae-Querco virgilianae sigmetu*m (29.8% of the subsection area)
- *Lathyro digitati-Querco cerridis sigmetum* (24.8%)
- *Seslerio autumnalis-Acero obtusati sigmetu*m (11.5%)

Conclusions

This paper illustrates the context and methodology of an ecoregionalisation process at national scale that is being carried out by integrating biophysical and vegetation data. In particular, information derived from vegetation series was used as diagnostic attribute at the finer levels of details and as descriptor for map units of higher levels. Synphytosociological data proved to be very effective in the delineation process, promoting the role of modern phytosociology as scientific reference point for ecoregional programmes.

Our research team is involved in this project since almost ten years. In 2000 we already proposed a hierarchical deductive land classification aimed at identifying areas with similar abiotic and vegetation features on progressively finer scales. This new proposal differs substantially, in that it includes all levels of generalisation from European to local scales and is being tested and implemented using updated and original maps of phytoclimate, geomorphology, and vegetation series at the national level.

The newly proposed ecoregionalisation procedure led so far to the identification of 2 Divisions, 13 Provinces, 33 Sections, and almost 80 Subsections. More detailed data on lithology and topography and on the ensemble of seral stages characterising vegetation series are needed in order to define the local levels.

This national ecological land classification, based on sound scientific data and robust interdisciplinary methodology, provides an appropriate spatial reference framework to effectively address national strategies for sustainability and to draw up national and regional plans of action based on the natural potential of ecological land units as opposed to administrative boundaries.

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