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The geosynphytosociological approach as a tool for agriculture innovation: the study case of saffron (*Crocus sativus* L.) cultivation suitability assessment in the Macerata district (central Italy)

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Abstract
The maintenance of open areas as grasslands and croplands has become a vital issue addressed to biodiversity conservation. For this purpose, innovation in agricultural activities may be a key factor. To achieve this goal, it is essential to identify the agronomic suitability and the most appropriate spatial pattern for the proposed cultivation. Therefore, the definition of land suitability classes and of their boundaries is a key step. For this purpose we used the phytosociological approach since it is based on an ecological definition and hierarchical classification of plant communities and landscapes and can be considered as an indirect way to assess the variation of the environmental conditions. Starting from the Marche Region vegetation geo-database, for each vegetation series a draft of the main ecological factors matching with the ecological needs of *Crocus sativus* L. was carried out. Afterwards, two intermediate maps were drawn: the "Climatic suitability map" and the "Soil suitability map". Finally, the "*Crocus sativus* cultivation suitability map" was drawn by overlapping these two maps. Results were tested by agronomic experimentations. The synphytosociological approach proved to be a very valuable method. In fact, the areas belonging to the highlighted different suitability classes (that is the different vegetation series) showed substantial differences in the saffron productivity. Moreover using the vegetation mapping procedures also the definition of the borders of each suitability class has been easily solved at the landscape scale.

Key words: Geographic Information Systems, landscape ecology, landscape homogenization, suitability map, vegetation series.

Introduction

The whole European mountain territory suffered in the last decades of strong demographic and economic decline (Antrop, 2004; Mazzoleni *et al*., 2004; Falcucci *et al*., 2007). In the Apennines the abandonment of agro-pastoral traditional activities led to the landscape homogenization (Agnoletti, 2007; Pezzi *et al*., 2008; Geri *et al*., 2010; Bracchetti *et al*., 2012), owing to the strong reforestation of the hilly and mountain territory (Catorci *et al*., 2012). These processes are leading to significant problems from the biodiversity conservation viewpoint, in that they drive to a decrease in landscape diversity and ecosystem services (Metzger *et al*., 2006; Falcuci *et al*., 2007; Vitasović Kosić *et al*., 2011). Thus, the maintenance of a wide number of open areas as grasslands and croplands has become a vital issue as also indicated by the European Landscape Conservation Directive (Biondi, 2012). Recently, the European policies have implemented strategies for the conservation and sustainable use of biodiversity in agriculture (Galdenzi *et al*., 2012). With this object in view, the European Strategy for Plant Conservation 2008-2014 and the Habitats Directive may be considered as some of the main drivers devoted to biodiversity conservation, since they give important tools and prospects in the field of environmental sustainability (Biondi *et al*., 2012b; Biondi, 2013).

However, to achieve the conservation of the open areas, it is relevant to detect new economic opportunities and livelihood for mountain inhabitants. For this purpose, innovation in agricultural activities may be a key factor. Nevertheless, aiming the introduction of new cultivations, it is essential to know the agronomic suitability of the considered territory (Pineda Jaimes *et al*., 2012), particularly when the cultivation start up needs a considerable economic investment, as that involved in the saffron production. On the other hand, *Crocus sativus* cultivation is potentially highly attractive because of its high economic profits (about 12/15 Euros/m^2) besides the need of small crop areas and of modest mechanization (basic factors for the mountain agriculture). Because of this, in 2003-2008 a project focused on saffron cultivation, supported by the European Union and local public bodies, has been developed in the Macerata district (central Italy). One of the main project goals was the realisation of the "Map of saffron cultivation suitability in the mountain sector of the Macerata district". This kind of ecological map is a key tool in understanding the possibilities of new cultivations for a certain territory and evaluating their potential economic benefits for the local social bodies. In fact, the land suitability assessment consists in a prediction of the potential of land for proposed land-use systems (Malczewski, 2004). Land-use suitability analysis aims at identifying the most appropriate spatial pattern for future land-uses, according to specific requirements, preferences, or predictors of

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some activity (Collins *et al*., 2001). Thus, the definition of the boundaries of the considered environmental factors is a key step in the land suitability assessment and in the consequent definition of boundaries among suitability classes. With this object in view, it was demonstrated that analysis of environmental features affecting the landscape ecology can be performed by their interpretation in terms of different hierarchically determined spatio-temporal intervals (Allen & Starr, 1982; King, 1977; O'Neill & King, 1998). Within this process, each element can be interpreted as part of a higher element or as a structure containing systems of lower rank (Farina, 2001). Thus, the multidimensional complexity of ecological systems can be broken down into many organizational levels, each containing only a small number of interacting factors, in which mutual relationships and links between the highest and lowest organizational levels can be modelled (Tainton *et al*., 1996), making also possible the spatial definition of the ecosystem units through a hierarchical approach (Blasi *et al*., 2000). In this context, application of methods and concepts of serial and catenal phytosociology (Géhu *et al*., 1991; Ozenda, 1982; Rivas-Martínez, 2005) is useful, since they are based on an ecological definition and hierarchical classification of plant communities and landscapes (Biondi, 2011). It follows that the phytosociological study of a plant landscape can be considered as an indirect way to assess the variation of the environmental conditions and permit to fix the boundaries of several environmental features at the landscape scale (Catorci *et al*., 2009). In fact, a vegetation series consists of all the associations (plant communities) linked by a dynamic relationship which highlights an area representing a homogeneous biogeographic and environmental unit (Biondi, 2011). Thus, both plant association and vegetation series may be used as bioindicator tools (Biondi *et al*., 2012a). These assumptions make it possible to map, in G.I.S. environment, families of polygons with environmental features that are most likely to present a reduced variability (Vitanzi *et al*., 2010) and that may be organized into a hierarchical scheme (Smiraglia *et al*., 2013), where the different information levels, based on hierarchical criteria, are simulated in multiple polygon segmentations (Blaschka, 2001).

Furthermore, following the phytosociological approach, any data carried out from experimental plots (punctual data), can be likely applied to the whole polygon and therefore to all polygons referring to the same phytosociological unit. This allows the drafting of maps showing the distribution of several landscapes attributes as the agronomic suitability for a certain cultivation type. Obviously, the scale used for the map elaboration is a key factor since it determines the type and the drawing details and patterns of the evaluated ecological factors. As regards the "Map of *C. sativus* cultivation suitability in the mountain sector of the Macerata district", the main aim of the research was the subdivision of the study area along a gradient of agronomic suitability, mainly based on the assessment of the pedo-climatic features of the territory and on agronomic experimentations addressed to test the cartographic results.

Materials and Methods

Crocus sativus agronomic features

In the agronomic cycle of saffron there are two different stages within one year: the activity period and the dormant one. The growing period lasts from September to May. During this period the plants activate their metabolism while root penetration, sprouting, flowering and leaf growth take place. During the dormant phase (May-September), the leaves die and the bulbs do not change in volume or weight because they are already fully formed (Catorci *et al*., 2007c).

Crocus sativus grows equally well in mild temperate climate as in Mediterranean areas with cool winters and dry summer conditions. The plant is resistant to extreme temperatures varying from 40 °C during summer, to -15 °C in winter. Instead, saffron is greatly affected by spring frosts and snow falls during the flowering period (October-November). It prefers well drained soils, rich in calcareous debris, with neutral or slightly alkaline pH. Moreover, it needs soils rich in nutrients and is favoured by abundant spring rainfall, while it can tolerate soil water shortage in summer, as the crop is resting during this period. Autumnal precipitations may be harmful if they are either too light or too heavy. Critical factors are connected with excessively clayey or not enough drained soils (conditions fostering parasitic diseases) (Cappelli *et al*., 1999), water scarcity in spring and autumn (because it gives raise to the production of a low number of flowers and a low growth rate of the new bulbs), stagnant soil and hot humid climate (conditions for parasitic diseases), mean winter temperature less than 3 °C (risk of bulb damage by frost) and mean temperature in spring (March, April) less than 6 °C (low growth rate of the new bulbs) (Sampathu *et al*., 1984; Behzad *et al*., 1992; Mc Gimpsey *et al*., 1997). Moreover, in the others Italian areas where saffron is traditionally cultivated the sum of autumn, winter and spring rainfalls generally do not exceed 700 ml/year (Catorci *et al*., 2007c).

It was argued that the economic sustainability of saffron cultivation mainly depends on the bulbs weight and dimension, because greater the bulb higher the number of flowers (bulbs lower than 2 cm in diameter do not produce flowers at all). Thus it is basic that agronomic practices and land features promote the best development of bulbs.

Fig. 1 - Location of the study area in the mountain sector of the Macerata district (Marche, Italy)

Study area

The study area is placed in the Marche Region (Macerata District), along the central Apennine chain. Its elevation ranges from 300 to more than 2,000 m a.s.l. and consists of about 100,000 hectares (Fig. 1). The land-use consists of: woodland (30%), grasslands and meadows (20%); arable lands (40%); urban areas (5%); other (5%). The inhabitants are approximately 40,000 people having a strong demographic decline in the last decades.

Geo-morphological and soil features

The land form of the study area is characterized by two calcareous mountain ridges separated by a hilly landscape constituted by pelitic, marly and arenaceous substrata (Regione Marche, 1991). The morphology of mountain ridges is defined by steep slopes and quite flat tops. The basal sectors of slopes are often constituted by calcareous debris and have a quite gentle angle. The steeper slopes are characterized by strongly eroded thin soil cover, with poorly differentiated profile and with high amount of calcareous skeleton (Lithic Xerorthents-Udorthents). The arable areas are limited at altitudes lower than 1,000 m a.s.l., and placed on the gently undulated summits of the minor ridges, the wider U shaped valleys, the gentler morphologies along the break-slopes and on the foot-slopes. Soils are thicker than those of slopes, mostly with well developed surface horizons and characterized by fine/coarse granular to fine/medium poliedric structure. They are usually subalkaline and very well drained, owing to the high amount of calcareous skeleton (Entic, Typic and Inceptic Rendolls, Entic and Typic Haploxerolls and Hapludolls) (ASSAM, 2006).

The hilly landscape is characterized by gentle slopes with many semi-flat areas. The bottoms of the valley, crossed by the main rivers (Nera, Chienti and Potenza), have a flat morphology and are constituted by alluvial debris (Regione Marche, 1991). The gentler topography of these landscapes, together with the softer substratum enhanced arability and therefore most of this landscape is agricultural. These landscapes are characterized by a wide range of soils usually showing difficult internal drainage due to the mainly clayey texture. Moreover they are characterized by low nutrient content and subacid (on sandstones) to alkaline pH (ASSAM, 2006).

Bioclimatic features

As far as the climatic features concern, the study area is mainly encompassed within the following bioclimatic belts (Biondi *et al*., 1995; Orsomando & Catorci, 2000; Catorci *et al*., 2007b): lower Mesotemperate; upper Mesotemperate; lower Supratemperate and upper Supratemperate. Moreover, the top of the highest peaks belong to the Orotemperate climatic belt. The main characteristics of the aforementioned bioclimatic units (particularly referred to the saffron requirement) are summarised in Table 1.

Tab. 1 - The main bioclimatic features of the bioclimatic belts of the study area. The variables affecting saffron cultivation (average temperature of winter months, average temperature of March and April, average precipitation of autumn, winter and spring) are reported as well.

Bioclimatic belt	Altitudinal range (m a.s.l.)	Average annual temp. (°C)	Average temperature of winter months (°C)	Average temperature of March and April (°C)	N of months with average T< 10 °C	N of months with t< 0°C	Average annual prec. (mm)	Average prec. autumn, winter and spring (mm)	Drought stress (N. of months)	Cold stress (N. of months)	Growing period (N. of days with t>6°C)
Lower Mesotemperate	100-450	13-15	> 3	> 6	04-mag	0	750-850	< 700	1	05-giu	210-240
Upper Mesotemperate	450-1000	nov-13	³ 3	> 6	05-giu	01-feb	850-1100	< 700	0	06-lug	180-210
Lower Supratemperate	1000-1450	09-nov	< 3	≤ 6	06-lug	02-mar	1100-1300	about 700	0	07-ago	150-180
Upper Supratemperate	1450-1900	07-set	< 3	< 6	07-ago	03-apr	1300-1500	> 700	0	08-set	120-150

Geosynphytosociological assessment

The landscape assessment of the study area, following the Rivas-Martìnez' methods (2005), made it possible to identify 11 geosigmeta and 31 series. Data, shown in the Table 2, are mainly based on Catorci & Orsomando (2001), Allegrezza (2003), Biondi *et al*. (2004), Catorci *et al*. (2003, 2007d, 2010), Taffetani *et al*. (2004), and on the Marche Region vegetation geodatabase (Pesaresi *et al*., 2007).

Experimental design and data collection

The landscape ecological assessment was based on the Marche Region vegetation geodatabase (Catorci *et al*., 2007a; Pesaresi *et al*., 2007). Starting from this cartographic document, a synphytosociological map of the study area (on the scale of 1: 50,000) was carried out, by integrating the vegetation database with field surveys. All the following cartographic elaborations were performed at the same scale (1: 50,000), since our aim was to assess the *Crocus sativus* cultivation suitability at the landscape scale in a wide territory.

For each vegetation series a draft of the main ecological factors matching with the ecological needs of *Crocus sativus* (whose understanding was deepened by assessing the pedo-climatic features of Italian areas where the saffron cultivation traditionally takes place) was carried out using: the vegetation database of the Marche Region (geo-morphological features); bibliographic data as the bioclimatic features concern (Biondi *et al*., 1995; Orsomando & Catorci, 2000; Catorci *et al*., 2007b; Amici & Spina, 2002); field surveys aimed to define the main soil features of arable lands.

A preliminary comparison among the ecological features of the considered vegetation series and those of *Crocus sativus* led to the exclusion of some landscape units because clearly falling out of the range of optimal climatic and pedologic conditions (i.e. those of oro-temperate bioclimatic belt, peaty soils; semi-rocky slopes). Vegetation series whose cultivated areas covered a small surface (less than 50 hectares), thus with low interest from an economic point of view, were excluded as well. In all the remaining vegetation series, two or more experimental fields (of about 50 x 50 m) were placed. In each of them a four years long agronomic experimental trial was carried out using the same agronomic techniques. In each year of experimentation, the dry weight of the saffron stigmas (g/kg of sowed bulbs) was assessed for each plot. Data on the *Crocus sativus* amount of flowers (autumn) and weight/dimension of bulbs (august) were collected as well.

Starting from the synphytosociological map and from the assessment of the main ecological features of each vegetation series (Table 3), two intermediate maps were drawn: the "Climatic suitability" map and the "Soil suitability" map.

Finally, the "*Crocus sativus* cultivation suitability map" was drawn by overlapping these two maps since the overlay procedures play a central role in many GIS applications, including techniques that are in the forefront of the advances in the land-use suitability analysis (O'Sullivan & Unwin, 2003). We assumed that the high level of suitability corresponds to areas where both the bioclimatic and soil features had the higher value of suitability, while the absence of suitability corresponds to areas where both bioclimatic and soil features are not fitting for saffron cultivation. Intermediate condition were assessed as well, and mapped as low and moderate suitability classes. Finally, the cartographic results were tested using the output of the agronomic experimentations.

Results

Climatic suitability map

The climatic assessment of the study area drove us to divide the territory into three classes.

Unsuitable areas. We included into this class the *Cardamino kitaibelii-Fago sylvaticae sigmetum*. The distribution of this vegetation series includes slopes located at altitudes higher than 1,200-1,300 m a.s.l. with average annual precipitation exceeding 1,000 ml. These slopes are also characterized by low temperatures, which preclude a normal growth of the vegetative apparatus and bulbs (winter mean temperature <3 °C and spring mean temperature <6 °C).

Low suitability areas. The *Lathyro veneti-Fago sylvaticae sigmetum*, the *Aceri obtusati-Querco cerridis fago sylvaticae sigmetosum*, the *Carici sylvaticae-Querco cerridis sigmetum*, and the *Cytiso sessilifolii-Querco pubescentis querco cerridis sigmetosum* are included in this suitability class. The distribution of these vegetation series includes slopes placed at altitudes ranging from 800/900 to 1,200 m a.s.l. The annual average temperatures are good, but those of spring are too low (<6 °C), and the average annual precipitation exceeds 900 ml, while the sum of autumn, winter, and spring precipitation exceeds 700 ml. Because of this, the growth of bulbs is not optimal and the development of fungal diseases might be favoured.

High suitability areas. The following vegetation series were included in this suitability class: *Scutellario columnae-Ostryo carpinifoliae violo reichenbachianae sigmetosum, Scutellario columnae-Ostryo carpinifoliae cytiso sessilifolii sigmetosum, Asparago acutifolii-Ostryo carpinifoliae corno maris sigmetosum, Roso sempervirentis-Querco pubescentis querco pubescentis sigmetosum, Roso sempervirentis-Querco pubescentis cotino coggygriae sigmetosum, Cytiso sessilifolii-Querco pubescentis sigmetum, Scutellario columnae-Ostryo carpinifoliae pruno avii sigmetosum, Peucedano cervariae-Querco pubescentis peucedano cervariae sigmetosum, Hieracio murori-Ostryo carpi-*

nifoliae hieracio murori sigmetosum, Erico arboreae-Querco pubescentis erico arboreae sigmetosum. The distribution of these vegetation series includes slopes located at altitudes ranging from 400/450 to 900/950 m a.s.l. with average annual rainfall lower than 900 ml. Moreover, the sum of autumn, winter and spring precipitation is lower than 700 ml, while the winter and spring average temperatures are higher then 3 °C and 6 °C respectively.

Soil suitability map

Mostly based on the soil drainage conditions and with regard to the rainfall regime of each considered vegetation series, the study area has been divided into four suitability classes.

Unsuitable areas. These areas include slopes placed over 1,200-1,300 m a.s.l. where low winter and spring temperatures do not permit the activity of nitrifying bacteria in spring, thus the organic substances are not exploitable by plants (Bonan, 2008), during the period of leaves and bulbs growth. Moreover the prolonged snow cover and the winter strong frost may damage the bulbs. We included in this category the *Cardamino kitaibelii-Fago sylvaticae sigmetum*.

Low suitability areas. We included in this class of suitability floodplains (S*alico albae sigmetum, Salico albae-Alno glutinosae sigmetum,* and *Salico albae-*

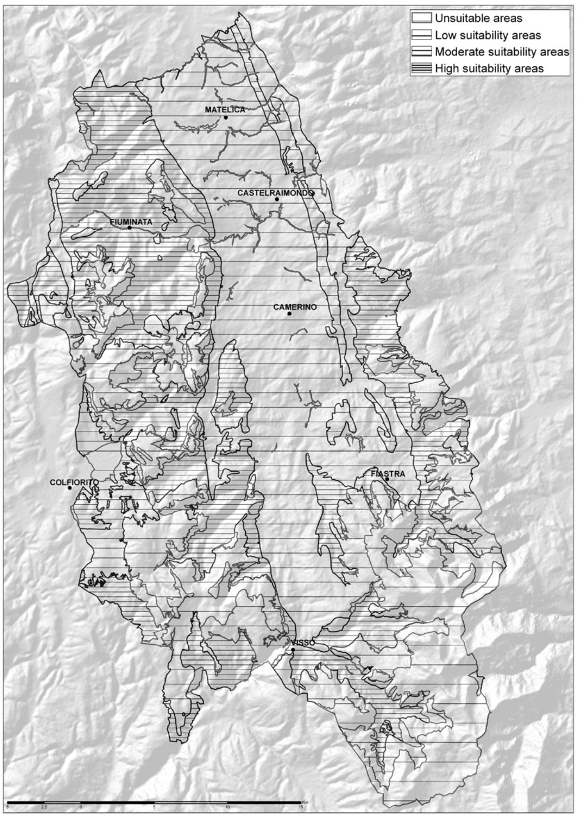

Fig. 2 - Map of *Crocus sativus* cultivation suitability in the mountain sector of the Macerata district

Populo nigrae populo nigrae sigmetosum) with clayey and hydromorphic soils because of the closeness to the groundwater table. In these conditions the bad soil drainage and the consequent water stagnation, foster the fungal disease and decay of bulbs. As a matter of fact, the good growth of new bulbs may be difficult and thus the saffron cultivation is not advisable. For the same reasons, we included in this category also landscapes overlying marly and clayey substrata which soils are on average deep and characterized by fine granular texture (*Scutellario columnae-Ostryo carpinifoliae pruno avii sigmetosum, Peucedano cervariae-Querco pubescentis peucedano cervariae sigmetosum*).

Moderate suitability areas. We included in this category landscapes overlying arenaceous substrata (*Hieracio murori-Ostryo carpinifoliae hieracio murori sigmetosum, Erico arboreae-Querco pubescentis erico arboreae sigmetosum*). Soils are on average deep and their drainage ability is quite good, nevertheless they are poor in nutrients; this may reflect in some difficulties to obtain a regular growth of bulbs.

High suitability areas. We included in this class the calcareous ridges with soil having a high capacity of drainage, since they have a high amount of calcareous debris, are of reduced thickness and poor in clay/loam content (*Roso sempervirentis-Querco pubescentis querco pubescentis sigmetosum, Roso sempervirentis-Querco pubescentis cotino coggygriae sigmetosum, Scutellario columnae-Ostryo carpinifoliae violo reichenbachianae sigmetosum, Scutellario columnae-Ostryo carpinifoliae cytiso sessilifolii sigmetosum, Asparago acutifolii-Ostryo carpinifoliae corno maris sigmetosum, Aceri obtusati-Querco cerridis fago sylvaticae sigmetosum, Carici sylvaticae-Querco cerridis sigmetum, Cytiso sessilifolii-Querco pubescentis sigmetum, Cytiso sessilifolii-Querco pubescentis querco cerridis sigmetosum*), *Lathyro veneti-Fago sylvaticae sigmetum*.

Agronomic results

The cropland of the hilly calcareous series (*Scutellario columnae-Ostryo carpinifoliae sigmetum, Scutellario columnae-Ostryo carpinifoliae cytiso sessilifolii sigmetosum and Cytiso sessilifolii-Querco pubescentis sigmetum*) emerged as the most productive ones, with productivity ranging from 0.6 to 0.8 g of dry stigmas/kg of bulbs. Intermediate levels of saffron production (0.3-0.6 g of dry stigmas/kg of bulbs) were obtained in the hilly sandy sites (*Hieracio murori-Ostryo carpinifoliae sigmetum* and *Erico arboreae-Querco pubescentis sigmetum*) and in experimental plots placed into the *Carici sylvaticae-Quercetum cerridis sigmetum*. Instead, very low levels of productivity (0.1-0.3 g of dry stigmas/kg of bulbs) were recorded on marly substrata (S*cutellario columnae-Ostryo carpinifoliae pruno avii sigmetum* and *Peucedano cervariae-Quer-*

Table 2 - Geosynphytosociological assessment of the plant landscape in the study area. Geosigmeta and their respective vegetation series are indicated

GEOSIGMETUM OF CALCAREOUS SUBSTRATES OF THE LOWER MESOTEMPERATE BIOCLIMATIC BELT
Climatophilous neutro-basophilous series, of *Ostrya carpinifolia*
Asparago acutifolii-Ostryetum carpinifoliae corno maris sigmetosum
Edapho-xerophilous neutro-basophilous series of semi-rocky slopes, of *Quercus ilex*
Cyclamino hederifolii-Querco ilicis cyclamino hederifolii sigmetosum
Edapho-xerophilous neutro-basophilous series, of *Quercus pubescens* s.l.
Roso sempervirentis-Querco pubescentis querco pubescentis sigmetosum
Edapho-xerophilous neutro-basophilous series of debris of foot-hill, of *Quercus pubescens* s.l.
Roso sempervirentis-Querco pubescentis cotino coggygriae sigmetosum

GEOSIGMETUM OF CALCAREOUS SUBSTRATES OF THE UPPER MESOTEMPERATE BIOCLIMATIC BELT
Climatophilous neutro-basophilous series of *Ostrya carpinifolia*
Scutellario columnae-Ostryo carpinifoliae violo reichenbachianae sigmetosum
Edapho-xerophilous neutro-basophilous series of semi-rocky north-facing slopes, of *Quercus ilex*
Cephalanthero longifoliae-Querco ilicis sigmetum
Edapho-xerophilous neutro-basophilous series of *Ostrya carpinifolia*
Scutellario columnae-Ostryo carpinifoliae cytiso sessilifolii sigmetosum
Edapho-xerophilous neutro-basophilous series of debris of foot-hill of *Quercus pubescens* s.l.
Cytiso sessilifolii-Querco pubescentis sigmetum
Edapho-xerophilous neutro-acidophilous series of south-facing slopes of *Quercus pubescens* s.l.
Cytiso sessilifolii-Querco pubescentis querco cerridis sigmetosum
Edapho-mesophilous sub-acidophilous series of *Quercus cerris*
Aceri obtusati-Querco cerridis fago sylvaticae sigmetosum
Edapho-mesophilous acidophilous series of *Quercus cerris*
Carici sylvaticae-Querco cerridis sigmetum

GEOSIGMETUM OF TECTONIC-KARSTIC DEPRESSIONS OF THE UPPER MESOTEMPERATE AND LOWER SUPRATEMPERATE BIOCLIMATIC BELTS
Edapho-hygrophilous neutrophilous series of tectonic-karstic depressions, of *Salix cinerea*
Salico cinereae sigmetum

GEOSIGMETUM OF CALCAREOUS SUBSTRATES OF THE LOWER SUPRATEMPERATE BIOCLIMATIC BELT
Climatophilous neutrophilous series of *Fagus sylvatica*
Lathyro veneti-Fago sylvaticae lathyro veneti sigmetosum
Edapho-xerophilous basophilous series of the steep rocky slopes, of *Ostrya carpinifolia*
Scutellario columnae-Ostryo carpinifoliae seslerio nitidae sigmetosum
Edapho-mesophilous neutro-basophilous series of *Acer pseudoplatanus*
Acero obtusati-pseudoplatani sigmetum

GEOSIGMETUM OF CALCAREOUS SUBSTRATES OF THE UPPER SUPRATEMPERATE BIOCLIMATIC BELT
Climatophilous sub-acidophilous series of *Fagus sylvatica*
Cardamino kitaibelii-Fago sylvaticae sigmetum
Edapho-xerophilous basophilous series of watershed lines of *Sesleria juncifolia*
Carici humilis-Seslerio apenninae sigmetum

GEOSIGMETUM OF CALCAREOUS SUBSTRATES OF THE OROTEMPERATE BIOCLIMATIC BELT
Climatophilous acidophilous series of *Salix retusa*
Carici kitaibelianae-Salico retusae sigmetum
Edapho-xerophilous neutro-basophilous series of watershed lines, of *Juniperus communis* var. *saxatilis*

Helianthemo grandiflori-Junipero alpinae sigmetum
Edapho-xerophilous basophilous series of watershed lines, of *Sesleria juncifolia*
Carici humilis-Seslerio apenninae dryado octopetalae sigmetosum
Edapho-mesophilous acidophilous series of *Vaccinium myrtillus*
Luzulo italicae-Vaccinio myrtilli sigmetum

GEOSIGMETUM OF MARLY AND MARLY CALCAREOUS SUBSTRATES OF THE LOWER MESOTEMPERATE BIOCLIMATIC BELT
Edapho-xerophilous neutro-basophilous series of *Quercus pubescens* s.l.
Roso sempervirentis-Querco pubescentis querco pubescentis sigmetosum

GEOSIGMETUM OF MARLY AND MARLY CALCAREOUS SUBSTRATES OF THE UPPER MESOTEMPERATE BIOCLIMATIC BELT
Climatophilous neutro-basophilous series of *Ostrya carpinifolia*
Scutellario columnae-Ostryo carpinifoliae pruno avii sigmetosum
Edapho-xerophilous neutro-basophilous series of *Quercus pubescens* s.l.
Peucedano cervariae-Querco pubescentis peucedano cervariae sigmetosum

GEOSIGMETUM OF ARENACEOUS SUBSTRATES OF THE UPPER MESOTEMPERATE BIOCLIMATIC BELT
Climatophilous sub-acidophilous series of *Ostrya carpinifolia*
Hieracio murori-Ostryo carpinifoliae hieracio murori sigmetosum
Edapho-xerophilous sub-acidophilous series of South-facing slopes of *Quercus pubescens* s.l.
Erico arboreae-Querco pubescentis erico arboreae sigmetosum

GEOSIGMETUM OF PELITIC SANDSTONE SUBSTRATES OF THE UPPER MESOTEMPERATE BIOCLIMATIC BELT
Climatophilous neutro-basophilous series of *Ostrya carpinifolia*
Scutellario columnae-Ostryo carpinifoliae pruno avii sigmetosum
Edapho-xerophilous neutro-basophilous series of South-facing slopes of *Quercus pubescens* s.l.
Peucedano cervariae-Querco pubescentis peucedano cervariae sigmetosum

GEOSIGMETUM OF PRESENT AND RECENT ALLUVIAL DEPOSITS OF RIVER COURSES
Edapho-hygrophilous neutrophilous series of *Salix alba*
Salico albae sigmetum, Salico albae alno glutinosae sigmetosum, and *Salico albae-Populo nigrae populo nigrae sigmetosum*

co pubescentis sigmetum) and in correspondence of the *Lathyro veneti-Fago sylvaticae sigmetum*.

With regard to bulbs, a decreasing trend of their dimension among the experimental trial (from about 4-5 to 2-3 cm in diameter) has been also observed in the low productivity sites (marly substrata and mountain slopes placed over 900-1,000 m a.s.l.). Within the riparian series we recorded a progressive decrease of both stigmas production and bulbs weight, and at the end of the experimental trial all the experimental plots were substantially out of production.

Suitability map for saffron cultivation

The overlapping of bioclimatic and soil landscape suitability maps allowed the definition of four suitability classes whose distribution is shown in Fig. 2. As mentioned before, the high level of suitability corresponds to areas where both the bioclimatic and soil features had the higher value of suitability, while the absence of suitability corresponds to areas where both bioclimatic and soil features are not fitting for saffron cultivation. Two intermediate suitability classes, including areas with moderate and low suitability, have been provided as well, the former associated to suboptimal climatic and/or pedologic conditions (precipitation higher than 900 mm/yr, quite low temperatures in spring; quite well drained but nutrient poor soils), and the latter to low suitability conditions with regard to climate or soil (too low temperatures and too high precipitation; clayey soils, with low organic matter content). The four suitability classes are shortly described hereafter.

Unsuitable areas. Substantially, in these areas no saffron production was obtained after the first/second year of experimentation, thus saffron cultivation is not possible, not even with the application of the best agronomical techniques. These areas encompass the alluvial floodplains and the mountain slopes placed at

Tab. 3 - Ecological features of the vegetation series in the study area, including macro-environmental variables (bedrock, altitudinal range, aspect, slope angle) and climatic features affecting saffron cultivation (average temperature of winter months, average temperature of March and April, average precipitation of autumn, winter and spring).

Geosigmeta	Vegetation series	Ecological features
Geosigmetum of calcareous substrates of the lower Mesotemperate bioclimatic belt	Climatophilous neutro-basophilous series, of *Ostrya carpinifolia, Asparago acutifolii-Ostryetum carpinifoliae corno maris sigmetosum*	Calcareous slightly to moderately steep south-facing slopes, at altitudes ranging from 250 to 400 m a.s.l. Average temperature of winter months > 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series of semi-rocky slopes, of *Quercus ilex, Cyclamino hederifolii-Querco ilicis cyclamino hederifolii sigmetosum*	Calcareous slightly to very steep or semi-rocky south-facing slopes, at altitudes ranging from 150-200 to 700-800 m a.s.l. Average temperature of winter months > 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series, of *Quercus pubescens* s.l., *Roso sempervirentis-Querco pubescentis querco pubescentis sigmetosum*	Calcareous slightly steep south-facing slopes, covered by calcareous debris at altitudes lower than 500 m a.s.l. Average temperature of winter months > 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series of debris, of *Quercus pubescens* s.l.,*Roso sempervirentis-Querco pubescentis cotino coggygriae sigmetosum*	Calcareous slightly to moderately steep south-facing slopes, covered by calcareous debris, at altitudes lower than 700 m a.s.l. Average temperature of winter months > 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
Geosigmetum of calcareous substrates of the upper Mesotemperate bioclimatic belt	Climatophilous neutro-basophilous series of *Ostrya carpinifolia, Scutellario columnae-Ostryo carpinifoliae violo reichenbachianae sigmetosum*	Calcareous slightly to moderately steep north-facing slopes, at altitudes ranging from 400 to 1000 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series of semi-rocky north-facing slopes, of *Quercus ilex, Cephalanthero longifoliae-Querco ilicis sigmetum*	Calcareous slightly to moderately steep or semi-rocky north-facing slopes, at altitudes ranging from 450-500 to 900-1000 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series of *Ostrya carpinifolia, Scutellario columnae-Ostryo carpinifoliae cytiso sessilifolii sigmetosum*	Calcareous slightly to moderately steep south-facing slopes, at altitudes lower than 900 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series of debris, of *Quercus pubescens* s.l., *Cytiso sessilifolii-Querco pubescentis sigmetum*	Calcareous slightly to moderately steep south-facing slopes, covered by calcareous debris, at altitudes ranging from 400 to 800 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-acidophilous series of south-facing slopes of *Quercus pubescens* s.l., *Cytiso sessilifolii-Querco pubescentis querco cerridis sigmetosum*	Calcareous moderately steep south-facing slopes, at altitudes ranging from 800 to 1100 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-mesophilous sub-acidophilous series of *Quercus cerris, Aceri obtusati-Querco cerridis fago sylvaticae sigmetosum*	Calcareous slightly steep or semi-flat north-facing slopes on sub-acid soil, at altitudes ranging from 700 to 1,000 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-mesophilous acidophilous series of *Quercus cerris, Carici sylvaticae-Querco cerridis sigmetum*	Calcareous slightly to moderately steep north-facing slopes, covered by fersiallitic paleosols, at altitudes ranging from 800 to 1,200 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
Geosigmetum of tectonic-karstic depressions of the upper Mesotemperate and lower Supratemperate bioclimatic belts	Edapho-hygrophilous neutrophilous series of tectonic-karstic depressions, of *Salix cinerea Salico cinereae sigmetum*	Flat and periodically flooded bottom of tectonic-karstic depressions, at altitudes ranging from 800 to 1,200 m a.s.l. Average temperature of winter months ³ 3 °C or < 3°C; average temperature of March and April > 6 °C or ≤ 6 °C; average precipitation of autumn, winter and spring ≤ 700 mm.
Geosigmetum of calcareous substrates of the lower Supratemperate bioclimatic belt	Climatophilous neutrophilous series of *Fagus sylvatica, Lathyro veneti-Fago sylvaticae lathyro veneti sigmetosum*	Calcareous slightly to moderately steep mainly north-facing slopes, at altitudes ranging from 900 to 1,400 m a.s.l. Average temperature of winter months < 3 °C; average temperature of March and April ≤ 6 °C; average precipitation of autumn, winter and spring of about 700 mm.
	Edapho-xerophilous basophilous series of the steep rocky slopes, of *Ostrya carpinifolia, Scutellario columnae-Ostryo carpinifoliae seslerio nitidae sigmetosum*	Calcareous steep rocky slopes. Average temperature of winter months < 3 °C; average temperature of March and April ≤ 6 °C; average precipitation of autumn, winter and spring of about 700 mm.
	Edapho-mesophilous neutro-basophilous series of *Acer pseudoplatanus, Acero obtusati-pseudoplatani sigmetum*	Calcareous very steep slopes of deep little valleys. Average temperature of winter months < 3 °C; average temperature of March and April ≤ 6 °C; average precipitation of autumn, winter and spring of about 700 mm.
Geosigmetum of calcareous substrates of the upper Supratemperate bioclimatic belt	Climatophilous sub-acidophilous series of *Fagus sylvatica, Cardamino kitaibelii-Fago sylvaticae sigmetum*	Calcareous moderately steep slopes, con esposizione variabile, at altitudes ranging from 1,400 to 1,800 m a.s.l. Average temperature of winter months < 3 °C; average temperature of March and April < 6 °C; average precipitation of autumn, winter and spring > 700 mm.
	Edapho-xerophilous basophilous series of watershed lines of *Sesleria juncifolia, Carici humilis-Seslerio apenninae sigmetum*	Calcareous watershed lines of relief tops. Average temperature of winter months < 3 °C; average temperature of March and April < 6 °C; average precipitation of autumn, winter and spring > 700 mm.

Geosigmetum of calcareous substrates of the Orotemperate bioclimatic belt	Climatophilous acidophilous series of *Salix retusa, Carici kitaibelianae-Salico retusae sigmetum*	Slopes on calcareous decarbonate substrates, at altitudes higher than 1800/1900 m a.s.l. Average temperature of winter months < 3 °C; average temperature of March and April < 6 °C; average precipitation of autumn, winter and spring > 700 mm.
	Edapho-xerophilous neutro-basophilous series of watershed lines, of *Juniperus communis* var. *saxatilis, Helianthemo grandiflori-Junipero alpinae sigmetum*	Calcareous watershed lines at altitudes higher than 1800/1900 m a.s.l.. Average temperature of winter months < 3 °C; average temperature of March and April < 6 °C; average precipitation of autumn, winter and spring > 700 mm.
	Edapho-xerophilous basophilous series of watershed lines, of *Sesleria juncifolia, Carici humilis-Seslerio apenninae dryado octopetalae sigmetosum*	Calcareous watershed lines of relief tops, at altitudes higher than 1800/1900 m a.s.l. Average temperature of winter months < 3 °C; average temperature of March and April < 6 °C; average precipitation of autumn, winter and spring > 700 mm.
	Edapho-mesophilous acidophilous series of *Vaccinium myrtillus, Luzulo italicae-Vaccinio myrtilli sigmetum*	Slopes on calcareous decarbonate substrates, at altitudes higher than 1800/1900 m a.s.l. Average temperature of winter months < 3 °C; average temperature of March and April < 6 °C; average precipitation of autumn, winter and spring > 700 mm.
Geosigmetum of marly and marly calcareous substrates of the lower Mesotemperate bioclimatic belt	Edapho-xerophilous neutro-basophilous series of *Quercus pubescens* s.l., *Roso sempervirentis-Querco pubescentis querco pubescentis sigmetosum*	Marly-calcareous slightly steep south-facing slopes, at altitudes lower than 450 m a.s.l. Average temperature of winter months > 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
Geosigmetum of marly and marly calcareous substrates of the upper Mesotemperate bioclimatic belt	Climatophilous neutro-basophilous series of *Ostrya carpinifolia, Scutellario columnae-Ostryo carpinifoliae pruno avii sigmetosum*	Marly-calcareous slightly to moderately steep north-facing slopes, at altitudes ranging from 400 to 800 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series of *Quercus pubescens* s.l., *Peucedano cervariae-Querco pubescentis peucedano cervariae sigmetosum*	Marly-calcareous slightly to moderately steep south-facing slopes, at altitudes ranging from 400 to 800 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
Geosigmetum of arenaceous substrates of the upper Mesotemperate bioclimatic belt	Climatophilous sub-acidophilous series of *Ostrya carpinifolia, Hieracio murori-Ostryo carpinifoliae hieracio murori sigmetosum*	Arenaceous slightly to moderately steep north-facing slopes, at altitudes ranging from 500 to 900 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous sub-acidophilous series *of South-facing slopes of* Quercus pubescens s.l., *Erico arboreae-Querco pubescentis erico arboreae sigmetosum*	Arenaceous slightly to very steep south-facing slopes, at altitudes ranging from 500 to 900 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
Geosigmetum of pelitic sandstone substrates of the upper Mesotemperate bioclimatic belt	Climatophilous neutro-basophilous series of *Ostrya carpinifolia, Scutellario columnae-Ostryo carpinifoliae pruno avii sigmetosum*	Pelitic sandstone slightly to moderately steep north-facing slopes, at altitudes ranging from 400 to 800 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
	Edapho-xerophilous neutro-basophilous series of South-facing slopes of *Quercus pubescens* s.l., *Peucedano cervariae-Querco pubescentis peucedano cervariae sigmetosum*	Pelitic sandstone slightly to moderately steep south-facing slopes, at altitudes ranging from 400 to 800 m a.s.l. Average temperature of winter months ³ 3 °C; average temperature of March and April > 6 °C; average precipitation of autumn, winter and spring < 700 mm.
Geosigmetum of present and recent alluvial deposits of river courses	Edapho-hygrophilous neutrophilous series of *Salix alba, Salico albae sigmetum Salico albae alno glutinosae sigmetosum Salico albae-Populo nigrae populo nigrae sigmetosum*	River banks and river beds.

altitudes higher than 1,100/1,200 m a.s.l. belonging to the following vegetation series: *Cardamino kitaibelii-Fago sylvaticae sigmetum, Salico albae sigmetum, Salico albae-alno glutinosae sigmetosum,* and *Salico albae-Populo nigrae populo nigrae sigmetosum*. The vegetation series excluded "a priori", because clearly falling out of the range of optimal environmental conditions, were included inside this suitability class (*Aceri obtusati-pseudoplatani sigmetum, Carici humilis-Seslerio apenninae sigmetum, Carici humilis-Seslerio apenninae dryado octopetalae sigmetosum, Carici kitaibelianae-Salico retusae sigmetum, Helianthemo grandiflori-Junipero alpinae sigmetum, Luzulo italicae-Vaccinio myrtilli sigmetum, Cephalanthero longifoliae-Querco ilicis sigmetum, Cyclamino hederifolii-Querco ilicis cyclamino hederifolii sigmetosum, Salico cinereae sigmetum, Scutellario columnae-Ostryo carpinifoliae seslerio nitidae sigmetosum*).

Low suitability areas. The agronomic experiment showed a very low saffron productivity (ranging from 0.1 to 0.3 g of dry stigmas/kg of bulbs). Moreover, the decrease of bulbs weight and dimension indicates that in these areas the saffron cultivation is not sustainable from an economic point of view. Only in minor cases and peculiar geomorphological settings, the cultivation may have success if coupled with the best agronomic practices. Falls into this suitability class the following vegetation series: *Lathyro veneti-Fago sylvaticae lathyro veneti sigmetosum, Scutellario columnae-Ostryo carpinifoliae pruno avii sigmetosum, Peucedano cervariae-Querco pubescentis peucedano cervariae sigmetosum*.

Moderate suitability areas. The agronomic experiment showed a saffron productivity ranging from 0.3 to 0.6 g of dry stigmas/kg of bulbs. This suitability class corresponds to the hilly landscapes with arenaceous bedrock and calcareous slopes placed between 800 and 1,100 m a.s.l. (*Hieracio murori-Ostryo carpinifoliae hieracio murori sigmetosum, Erico arboreae-Querco pubescentis sigmetum, Carici sylvaticae-Querco cerridis sigmetum, Aceri obtusati-Querco cerridis fago sylvaticae sigmetosum; Cytiso sessilifolii-Querco pubescentis querco ceridis sigmetosum*). In the first landscapes the main problems regard the nutrient poor amount of soil that should be addressed fertilizing abundantly with good manures. In the case of the calcareous ridges, the best sites are the south facing or well sheltered slopes.

High suitability areas. In sites encompassed within this suitability class an excellent productivity can be reached whether the optimal agronomic techniques are performed. Indeed, the agronomic experiment showed a saffron productivity ranging from 0.6 to 0.8 g of dry stigmas/kg of bulbs. These areas correspond to the hilly calcareous landscapes on slopes ranging from 400 to 800 m a.s.l. (*Scutellario columnae-Ostryo carpinifoliae violo reichenbachianae sigmetosum, Scutellario columnae-Ostryo carpinifoliae cytiso sessilifolii sigmetosum, Asparago acutifolii-Ostryo carpinifoliae corno maris sigmetosum, Cytiso sessilifolii-Querco pubescentis sigmetum*).

Discussion and Conclusion

In the context of land suitability analysis, the main aim is to identify the best sites for some activity given the set of potential (feasible) sites. The main general problem is to rank or rate the alternative sites and to define their boundaries (Malczewski, 2004). Moreover the characteristics of sites should be tested, so that the best environmental conditions (that are the best landscapes from a phytosociological point of view) can be identified. As regards these goals the synphytosociological approach proved to be a key tool and a very valuable method. Indeed, mapping in GIS environment, permits to establish correlations between the vegetation and other ecological factors (geological, geomorphological, bioclimatic, etc.), because this approach makes it possible to make correlations with other maps from specialised analyses. Therefore, this process evaluates the actual ecological complexity of the environment, and thus defines it in dimensional and ecological terms with remarkable precision (Biondi *et al*., 2011). A core problem is the choice of the correct mapping scale that is reflected in the mapping details and correctness of the considered ecological factors. This obstacle may be avoided by making more maps in finer details of limited areas that represent significant samples of the plant landscape (Biondi *et al*., 2011). In the present study we chose a low detailed scale (1: 50,000) because our aim was to evaluate a large territory from a geologic and bioclimatic point of view, which are two ecological factors acting on a broad scale. Obviously the responses of the study in terms of *Crocus sativus* cultivation suitability do not permit to know if the territory of a particular farm is certainly placed in a good or not good territory for the saffron cultivation point of view due to the ecological variability acting at the detailed scale; instead, they may support the socio-economic planning.

However, the general correctness of the vegetation assessment and adopted scale is confirmed by the fact that the areas belonging to the highlighted different suitability classes (that is group of different vegetation series) showed substantial differences in the saffron stigmas productivity and bulbs dimension maintenance, consequently in the potential economic interest of this kind of new cultivation. Moreover using the vegetation mapping procedures also the definition of the borders of each suitability class has been easily solved at the landscape scale. Moreover the adopted method permitted to know the potential vegetation series within which it has been possible, with further detailed analyses, to identify the surfaces suitable for the saffron cultivation and thus to understand its potential economic interest. In turn, it induced the local public bodies to continue the efforts to foster this kind of cultivation.

The adopted methodological process showed how the hierarchical organisation of a database enables the progressive gathering of knowledge, both in qualitative and quantitative terms. This avoids long periods of research prior to making management decisions, and may be followed by more detailed management strategies based on improved knowledge. Obviously, the phytosociological assessment of the considered territory has been useful as well as that based on the agronomic research. Nevertheless, the latter kind of approach cannot be sufficient by itself to understand the territorial importance from an economic point of view. Thus it can be stated that only the combination of these two types of approaches permits to draw up aware development plans.

Nowadays in the Macerata district there are more than 40 farms including the saffron cultivation in their activities and that two farmer associations have been founded in the last years, each of them organising events including saffron as a flag-product. Moreover, it has to be noticed that the saffron cultivation suitability map was used by the stakeholders with the aim to define the border of the area devoted to saffron production, characterized by a certificate of origin.

Actually, we can state that the phytosociological approach may be very useful, not only for the vegetation knowledge and management or the biodiversity conservation, but also for the agronomic and economic development of a territory, especially in complex landscapes as those of the mountain areas.

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