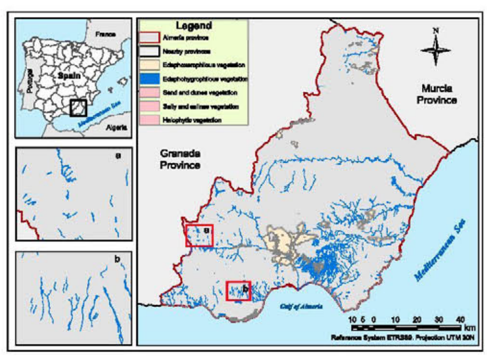
Islands of biogeodiversity in arid lands on a polygons map study: Detecting scale invariance patterns from natural resources maps

J.J. Ibáñez , R. Pérez-Gómez , Eric C. Brevik , A. Cerdà



ABSTRACT

Many maps (geology, hydrology, soil, vegetation, etc.) are created to inventory natural resources. Each of these resources is mapped using a unique set of criteria, including scales and taxonomies. Past research indicates that comparing results of related maps (e.g., soil and geology maps) may aid in identifying mapping deficiencies. Therefore, this study was undertaken in Almeria Province, Spain to (i) compare the underlying map structures of soil and vegetation maps and (ii) investigate if a vegetation map can provide useful soil information that was not shown on a soil map. Soil and vegetation maps were imported into ArcGIS 10.1 for spatial analysis, and results then exported to Microsoft Excel worksheets for statistical analyses to evaluate fits to linear and power law regression models. Vegetative units were grouped according to the driving forces that determined their presence or absence: (i) climatophilous (ii) lithologic-climate; and (iii) edaphophylous. The rank abundance plots for both the soil and vegetation maps conformed to Willis or Hollow Curves, meaning the underlying structures of both maps were the same. Edaphophylous map units, which represent 58.5% of the vegetation units in the study area, did not show a good correlation with the soil map. Further investigation revealed that 87% of the edaphohygrophilous units were found in ramblas, ephemeral riverbeds that are not typically classified and mapped as soils in modern systems, even though they meet the definition of soil given by the most commonly used and most modern soil taxonomic systems. Furthermore, these edaphophylous map units tend to be islands of biodiversity that are threatened by anthropogenic activity in the region. Therefore, this study revealed areas that need to be revisited and studied pedologically. The vegetation mapped in these areas and the soils that support it are key components of the earth's critical zone that must be studied, understood, and preserved.

1. Introduction

The inventory of many natural resources is based on georeferenced databases and maps showing the spatial distribution of resources such as soils, geology, vegetation, and hydrology. However, the underlying structure of cartographic products has not received as much interest from the scientific community as many other areas of research (e.g. Ibáñez et al., 2009), despite some interesting spatial patterns that can be detected, and as also occurs in the taxonomies used to create these maps (Ibáñez and Montanarella, 2013; Bockheim et al., 2014; Miller and Schaetzl, 2016; and references therein). At the same time the spatial information regarding a particular natural resource can be enhanced by analysing the maps of other natural bodies (e.g. vegetation maps in soilscapes studies or soil maps in geologic studies) (Brevik and Fenton, 1999; Juilleret et al., 2012; Miller and Burras, 2015), an approach that takes advantage of the interdisciplinary nature of soil science (Brevik et al., 2015; Brevik et al., 2016a). This approach also permits the user to detect if different cartographic products follow the same or similar mathematical structures.

The use of mapping contributes to our knowledge and understanding of landscapes and ecosystems, better planning, sustainable use of resources, the conservation of biodiversity, and assists in risk management (Soulard et al., 2016; Oinam et al., 2014; Xu et al., 2015; Brevik et al., 2016a). Maps can also be used as a tool for scientific research that allows further understanding of the Earth System. Biodiversity is usually studied by counting the numbers of species (Berendse et al., 2015; de Hedo et al., 2015; Taguas et al., 2015) but the combination of species diversity and mapping can shed light on ecosystem functioning. To this end, several studies on geodiversity have been conducted (e.g., Ibáñez et al., 1994; Parks and Mulligan, 2010; Brilha, 2016) and geodiversity studies represent a promising area of growth in soil science.

From some perspectives the soil associations of a soil map legend may be considered as natural units. However, the cartographic representations of soil surveys must meet certain conditions such as i) matching the hierarchic taxonomic level used to the scale of mapping; ii) a minimum polygon size that fits soil functions to the map scale; and iii) the boundary density–scale map relationship, among others (Dent and Young, 1981; USDA-Soil Survey Division Staff, 1993). These conditions limit the ability of soil mappers to represent the reality as seen in the field on their maps, being in part a product of conventions as well as cognitive bias (Ibáñez et al., 2009). Thus the map legend is in part natural but in part artificial.

In Spain, as in other countries of Continental Europe, the use of the phytosociological and syntaxonomic approaches is common in order to create national and regional potential vegetation maps (e.g. Rivas-Martínez, 2005; Loidi and Fernández-González, 2012) utilizing an International Code of Phytosociological Nomenclature (Weber et al., 2000). Sinphytosociological analysis is based on conceptual plant associations termed 'syntaxa' (singular 'syntaxon') and the resultant hierarchical taxonomy is called "synsystem" or syntaxonomic system. This approach permits an empirical mapping of the potential vegetation in a given territory (e.g. Loidi and Fernández-González, 2012). The syntaxonomic system (e.g. Mirkin, 1989; Rivas-Martínez, 2005) discerns between plant communities that are climatically, lithologic-climatically, and soil dependant. Thus this geobotanical approach permits identification of phytocenoses whose presence depends on soil conditions. In this respect it is notable that in the vegetation map the polygons show single syntaxonomical taxa instead of the pedotaxa associations shown in the soil map. The main problem with this methodology for scientists unaware of the syntaxonomic system lies in the number of unusual terms that are created, a problem that is shared by soil taxonomic nomenclature (Smith, 1986). Plant landscape descriptions are based on the concept of "potential natural vegetation" (PNV), dynamic-catenal phytosociology, etc. (see Loidi and Fernández-González, 2012). For example, tesela and microtesela correspond to land units where the same PNV is present. Climatophilous vegetation corresponds to those plant communities that are only dependent on climatic factors. PNV could consist of one or several plant associations that converge along its trajectories (ecological succession) at a final stage with the same (predictable) or similar floristic composition. A single PNV could currently consist of different serial stages of the same ecological succession.

Thus it could be interesting to analyse the size-frequency distribution polygons of both soil and vegetation maps, as well as analyse the "Potential Natural Vegetation" or PNV associated with soils in order to detect if PNV maps can inform us of certain soil features that were not detected in traditional soil maps (Ibáñez and Pérez-Gómez, 2016). The spatial distribution of soilscape patterns in Almería was studied by Ibáñez et al. (2015). Pedodiversity, lithologic associations and the "potential natural vegetation" (PNV) diversity types were analysed by Ibáñez and Pérez-Gómez (2016) and showed similar trends by watersheds. The objectives of this study were to: (i) compare the structure of a soil map and a vegetation map in order to analyse their similarities and differences, and (ii) investigate the additional information that vegetation maps can provide on the studied spatial patterns of soil. However, it should be noted that not all natural resource maps are made with the same standards. For example, in many vegetation maps at detailed scales polygons represent single plant communities whereas soil map polygons show combinations of soil types and pedotaxa following certain rules agreed upon by experts.

2. Material and methods

The study area is part of the Almeria Province located in the southeastern Iberian Peninsula (Fig. 1). This region is one of the most arid areas of Europe (Puigdefábregas and Mendizabal, 1998). The physiography of the study area is very steep, reaching elevations near 3000 m above sea level over short distances (Simón et al., 2005). The climate is arid, with precipitation increasing from 800 m to the mountain tops. The soilscapes are typical of arid lands and deserts from the coast up to 1000–1200 m above sea level. At higher altitudes precipitation increases, and the arid soils and vegetation are replaced by pedotaxa and PNV representative of Mediterranean xeric environments (Ibáñez et al., 2015). At the mountain tops plant communities and soilscapes receive higher amounts of precipitation, creating an ecosystem of pastures and meadows.

The river networks of the Almeria arid lands are called the ramblas. Ramblas is the term used in Spain to indicate the semi-arid, arid and desertic ephemeral water courses that are called wadi in Africa, are similar to the arroyos in the western USA, and are also called dry rivers (see Aliat et al., 2015, and references therein). These drainage networks are generally dry year round, except after rains with intensities higher than 30 mm day^{-1}. Arid and desertic lands are characterized by sudden but infrequent heavy rainfall, often resulting in flash floods (Alonso-Sarría et al., 2015; Ibáñez et al., 2015 and references therein). In the study area the ramblas are dry most of the year and often for several consecutive years (Villalobos-Megía, 2007). During periods of

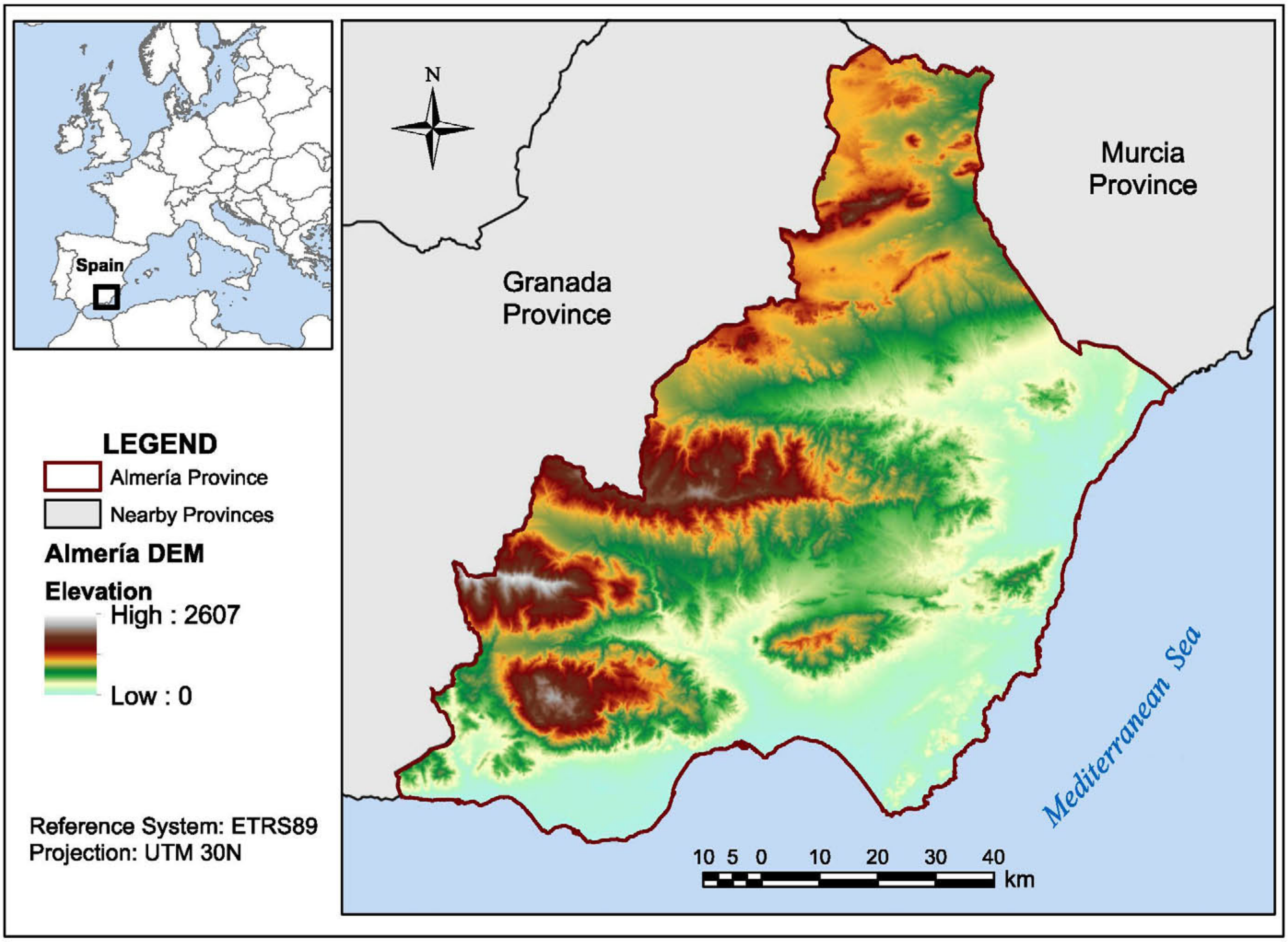


Fig. 1. Digital elevation model of the study area (Almería, Spain).

normal rains in this environment, after showers where a small amount of water falls, water flows through some sections, the ramblas become waterlogged in other sections, and water may disappear completely when it reaches a permeable subsoil. However, dry sections remain the most extensive part of the ramblas system even after normal rains. In fact, many sections of the ramblas are used as arable land, roads, and for housing construction. At the landscape level, hydrological and sediment connectivity in ramblas and wadis are very complex (Marchamalo et al., 2015), whereas the ecosystem dynamics are not well understood (Dahlberg, 2000).

Most rainfall occurs during stormy periods, which might only occur once every few years to decades (there are no gauging stations). These events can generate huge floods and environmental disasters, eroding riverbeds and much of the vegetation that grows in them and that began to recover from previous flash floods during the dry normal years, although some plants are adapted to survive the turbulent flows as shown by their huge root biomass (i.e. *Nerium oleander*). Moreover, these disastrous floods recharge aquifers, raising the local water table.

In this study we used a vegetation map and a soil map of the Almería Province in the SE of Spain (Table 1). The soil map was created using

Table 1
Properties of georeferenced databases analysed in this study.

Georeferenced data bases	Richness	Scale map	N° polygons
Potential Vegetation Analysis	40	1:10.000	5864
Soil associations	302	1:100.000	2448

international standard rules (FAO, 1991; http://www.uni-koeln.de/sfb389/e/e1/download/boeden/notes.txt) and the WRB classification (FAO, 1998). FAO (1998) was used rather than more recent versions of the WRB classification because all soil mapping was competed prior to the release of more recent versions. In the mapping of vegetation no cartographic rules or taxonomies are universally accepted. For this reason we made use of a taxonomic system that is very popular in many countries of continental Europe termed the syntaxonomic system, as shown below.

The potential vegetation information used in this study was downloaded from the IDEA Andalucía Portal as a georeferenced layer at the scale 1:10,000 (IDEA, Andalucía). The soil data set used was the digital soil map of Almeria at the scale 1:100,000 (Aguilar-Ruiz et al., 2004), according to the pedological classification of the WRB (FAO, 1998). Statistical analysis was conducted on the digitized soil map using GIS tools. All data were introduced in a spatial geodatabase using ArcGIS 10.1 software. Afterwards, the polygons of each PNV type and soil association units (40 PNV units and 302 soil association files) were exported to Excel spreadsheets for statistical analyses of their respective fits to linear and power law regression models. In all cases the data were sorted by decreasing number or spatial extent of its polygons, obtaining the so termed rank-abundance plots (Fig. 2). The fragmentation index is the inverse value of the average polygon size. A particular spatial distribution is more fragmented whenever its average polygon size is small or the fragmentation index is larger in comparison with other types.

PNV units were grouped according to the driving forces that determined their presence or absence (P/A): (i) climatophilous (climate is

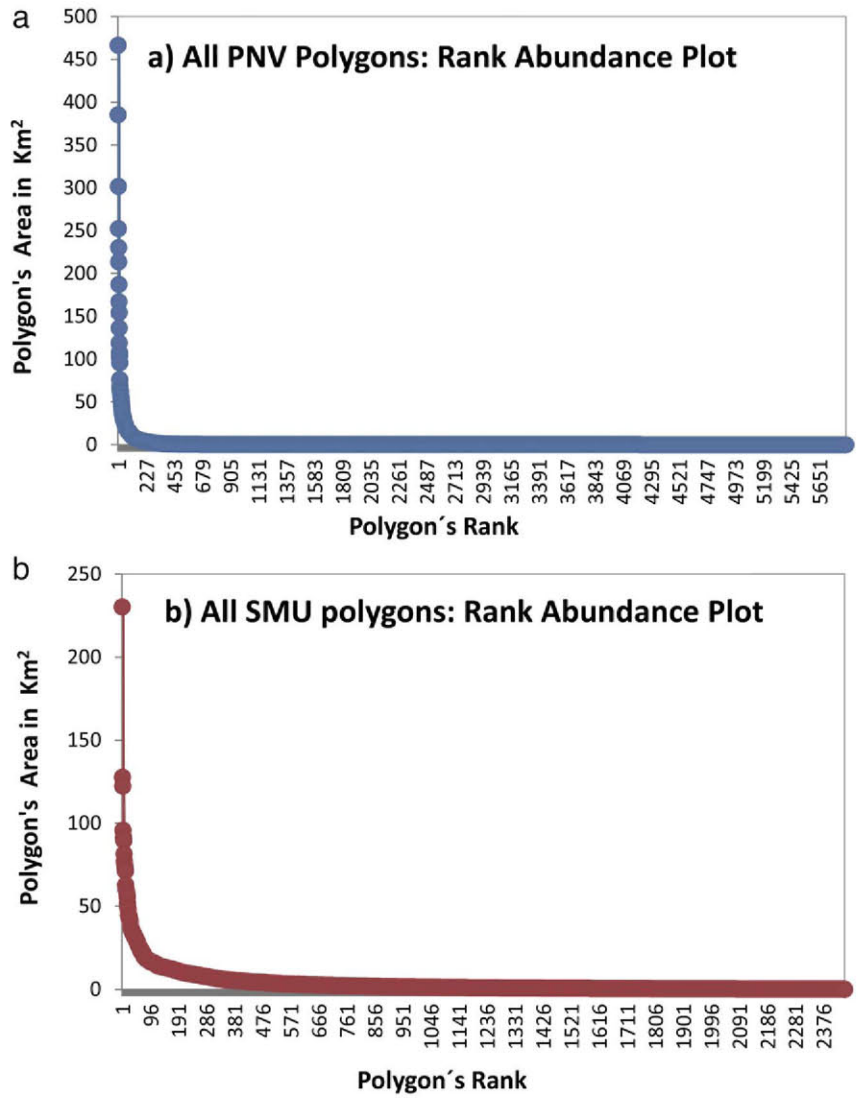


Fig. 2. Rank abundance plots of (a) all the PNV polygons, and (b) all soil associations (or soil map units -SMU-) polygons.

the only determinant of P/A) (ii); lithologic-climate (climate and parent material determine PNV P/A); and (iii) edaphophylous (soil features determine PNV P/A). Other terms are applied to the denomination of phytocenoses conditioned by the properties of the soils and/or rocks such as i) basophilous (plants that grow on pedotaxa rich in nutrients), ii) edaphohygrophilous (plant species associated with pedotaxa that have permanent or seasonal waterlogging), iii) edaphoxerophilous (plants adapted to xericity that grow in a tesela or microtesela on pedotaxa that store very little water), etc. These concepts, among others, are further explained by Rivas-Martínez (2005). But such words in this article will be modified to create a more intelligible text for the readers. Soil types will be described using the universal classification well known by pedologists as the World Reference Base for Soil Resources (WRB) (FAO, 1998).

3. Results and discussion

3.1. Analysing soil and vegetation maps

Both rank abundance plots (Fig. 2) conformed to Willis or Hollow Curves (Willis and Yule, 1922), the most frequently detected in pedodiversity and biodiversity inventories (Magurran, 2004; Ibáñez et al., 1995). Thus, polygon size-number distribution of both PNV units

Table 2
Larger and smaller Plant Potential Vegetation Units polygons for each of the groups classified according to the abiotic factors that determine their presence.

	Area m²	Rates per thousand of study area
PNV larger polygons		
Climatophilous	466,495,705.50	53.198000
Lithological	301,636,684.55	34.397891
Climatophilous	252,097,306.51	28.748545
Lithological	229,981,735.95	26.226540
Lithological	213,517,556.40	24.349007
Lithological	186,887,649.82	21.312199
Lithological	166,817,685.22	19.023470
Climatophilous	154,407,521.41	17.608247
Lithological	135,989,448.09	15.507896
PNV smaller polygons		
Sands and sands dunes	4.04	0.000000
Sands and sands dunes	3.74	0.000000
Sands and sands dunes	3.56	0.000000
Sands and sands dunes	3.13	0.000000
Sands and sands dunes	2.75	0.000000
Sands and sands dunes	1.41	0.000000
Sands and sands dunes	1.20	0.000000
Sands and sands dunes	0.61	0.000000
Sands and sands dunes	0.22	0.000000
Sands and sands dunes	0.01	0.000000

and soil associations follow the same trend: there are few very large polygons where as their numbers increase with decreases in their size.

In both maps the size of the polygons ranged over several orders of magnitude. Table 2 shows the major and minor vegetation map polygons, indicating the nature of the plant communities (PNV) as previously explained. Note that this statement is maintained in all the PNV groups. When these data fit well to a power law across three or more orders of magnitude it is possible to conclude that the data are indicative of underlying or fingerprint fractal structures (Schroeder, 1992; Brown et al., 2002).

In order to investigate the existence of underlying mathematical patterns both datasets were analysed to detect if they fit linear or power regression models. PNV with less than five polygons and SMU with <11 polygons were not taken into account. The results are shown in Table 3. It is clear that both datasets fit power laws better than a linear model (see Fig. 3 for SMU units). The degree of statistical fitting (R^2 values) of soil associations (SMU) with >11 polygons to a power law distribution is shown in Table 4. In other words, when thousands of PNV and SMU polygons are fitted to linear and power distributions the best fits appear with the power abundance distribution model as is the rule in biodiversity and pedodiversity studies for taxa-area relationships.

Likewise the size-polygons number for each type of PNV and SMU were fitted to power laws. For all the types of PNV number-frequency distributions fit a power law well, with an average R^2 value of 0.89. In a similar way, most of the SMU units (93%) fit a power law well, the exception being SMUs with a small amount of data (<11 polygons). The average R^2 statistic for all the SMUs was 0.88. Thus, both datasets as well as the corresponding classes of PNV and SMU conformed to power laws with similar R^2 values, showing that the spatial distribution of the number of polygons of each PNV and most of the SMUs followed a scale invariance distribution along several orders of magnitude, the fingerprint (identifying character) of fractal structures.

The reason for this prevalent pattern in biodiversity and pedodiversity as well as many other natural patterns is not well known. However, several researchers have reported the existence of these relationships over many years and indicate that it may be due to the non-linear dynamic nature of the biological and earth surface systems (e.g. Korvin, 1992; Schroeder, 1992; Turcotte, 1997; Ibáñez and De-Alba, 2000; Brown et al., 2002).

3.2. Soil information that can be extracted from the vegetation maps

As described in Section 1, the syntaxonomical nomenclature specifies syntaxa (plant communities) in which P/A is conditioned by climate and other environmental factors such as soil. For example, the term basophilous is applied to PNV where growth occurs on pedotaxa rich in nutrients (eutric in pedologic terms) whereas acidophilous is applied to PNV that are found growing on siliceous soils and parent materials (dystric ionic environments in pedological terms). In the study area dystric and eutric soil properties, which correspond to acidophilous and basophilous PNV, occur on parent materials poor and rich in nutrients respectively. Lithology in association with climate are the driving forces creating the P/A. The rest of the PNV were labelled as climatophilous or edaphophylous. Edaphophylous PNV were subsequently classified according to the main soil features that conditioned the nature of these plant communities with terms such as edaphohygrophilous, edaphoxerophilous, halophytic (meso-halophytic, hyper-halophytic for saline environments), gypsiferous (soils and parent material rich in gypsum), riparian (bordering water courses), brackish waters, sand deposits, dunes, salt marshes, salinas, etc. In addition other PNV growth only occurs on specific parent materials and thus terms such as limestone, dolomite, and subsaline marls, among others, are also frequent in the syntaxonomic nomenclature. Obviously some PNV occur in sites that are conditioned by more than one soil feature. For example, a PNV could be named "Subsaline marls polyteselar edaphoxerophilous vegetation complex" or "Upper-Meso-Mediterranean dry-sub-humid on siliceous soils edaphohygrophilous series" or "Meso-Upper-Mediterranean-Low limestone-dolomitic edaphoxerophilous series".

In this study we grouped PNV classes. After that the area-number of polygons as well as statistical average of polygon sizes and the respective fragmentation index of each class classified in the study area (Table 5) were fitted to a power law as shown in Table 6.

Table 5 shows the grouping of the PNV in the study area into classes based on the abiotic factors that determine their presence/absence. Climatophilous PNV cover the largest portion of the landscape, whereas edaphophylous PNV only cover a small fraction of the study area. However, the number of edaphophylous polygons is comparatively high.

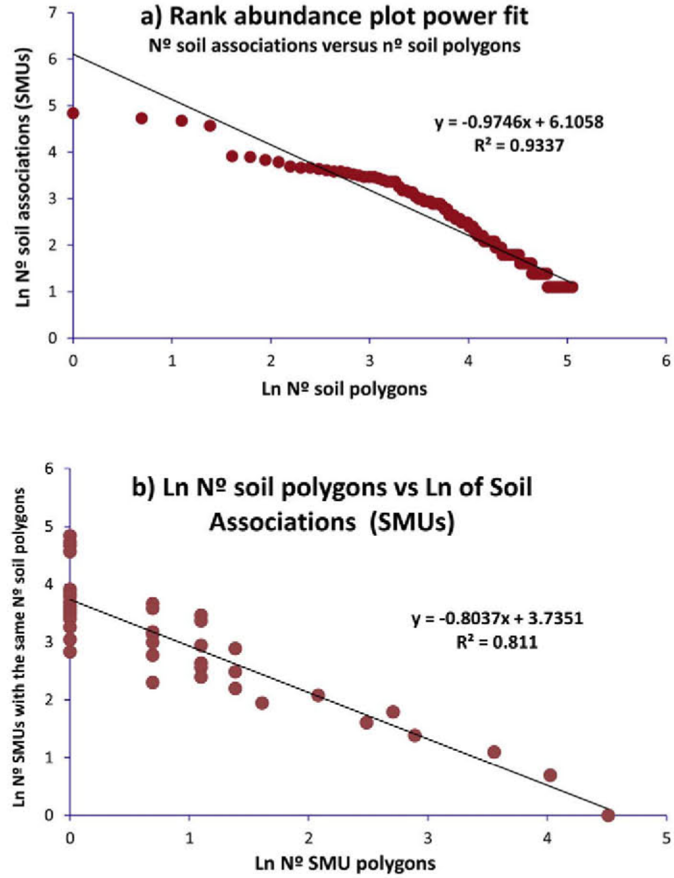


Fig. 3. Power fit for the number of soil polygons per soil map unit (SMU).

Table 3
R^2 values for the fit of map polygons (PNV for vegetation and SMU for soil associations) to linear and power law regression models.

	R^2 linear model	R^2 power model
PNV polygons (size-number)	0.27	0.85
SMU Polygons (size-number)	0.23	0.80

Table 4
R^2 values for the power fit of soil map units that have more than eleven polygons.

R^2 values	N° SMU
>0.95	8
0.90–0.95	10
0.80–0.90	35
0.70–0.80	24
0.60–0.70	7
0.50–0.60	4

Table 5
Select statistics for the studied PNV grouped by types according to the driving forces that determine their presence/absence.

PNV groups	Area km^2	N° polygons	Polygons statistical average	Fragmentation index
Climatophilous	3463.81475	2819	2.03	0.89
Lithologic-climatophilous	2980.36288	1335	2.99	11.36
Edaphophylous	488.063895	1710	0.12	20.33
Total	6932.24153	5864	1.48	14.69
Edaphophylous types				
Sand & salts PNV	259.179742	628	1.77	6.37
Edaphoxerophilous	86.791292	76	1.54	0.74
Edaphohygrophilous	488.063895	1710	0.12	20.33

Furthermore, the trend of the fragmentation index is inversed with respect to the area covered by each class, indicating that the ratio area/number of polygons increases according to the area each group occupies. Thus edaphophylous PNV appear in small plots given that the edaphohygrophilous plant communities are, in general, the smallest of the plant communities.

As shown in Table 6 the best power law fit was obtained by edaphohygrophilous PNV that are dependent on an excess of soil water with respect to the surrounding arid soil cover. It is notable that edaphoxerophilous PNV are mainly associated with rocky outcrops and debris from certain types of rocks such as hard limestones and dolomites (rocky flora), and could be considered to be a plant community that is lithologic-climate dependant. Generally edaphoxerophilous polygons are larger than edaphohygrophilous ones (Fig. 4). The same is true with gypsiferous and subsaline PNV that occur on gypsum deposits and subsaline marls. Thus the best fit to a power law occurs in edaphophylous vegetation on wetter, saline soils and sandy soils. The rest of the PNV depend mainly of climate and/or lithologic factors, but not on the soil-landform conditions. In Fig. 4 it is not possible to identify the many very small polygons dispersed in the landscape because of their very small size.

From a syntaxonomic point of view most of the PNV in the study area are dependent on or associated with specific soil properties and features (58.5%). This figure decreases for PNV whose presence depends on lithology-climate (24.5%) and even more for those that are exclusively climate dependant (17%). Thus most of the diversity of plant communities in the arid study area is at least partially dependant on soil conditions, and mainly on the temporal abundance of water. There were 23 edaphophylous PNV in the study area, whereas there were 10 lithology-climate dependant PNV and only 7 climate dependent PNV. Among the edaphophylous PNV there were 16 edaphohygrophilous, four edaphoxerophilous, and three sandy and salty soils PNV. Therefore, edaphohygrophilous plant communities represent 40% of the PNV richness of the study area. Two (12.5%) of the edaphohygrophilous PNV were riparian or associated with watercourse margins with high flow rates that are seasonally dry. This association with water occurred despite, or perhaps because, of the study area's aridity and the small overall area covered by this vegetation type. (Figs. 4 and 5).

Table 6
Power law fit of the polygons by number of PNV groups.

Area-number polygons	R^2
Edaphohygrophilous	0.87
Salt series	0.79
Sand & dunes series	0.50
Salinas series	0.47
Edaphoxerophilous series	0.0002
Lithologic-climate (basophilous series)	0.05
Lithologic-climate (acidophilous series)	0.04
Gypsiferous series	0.07
Subsaline marls series	0.06
Climatophilous series	0.004

Matching the soil map to the PNV map does not clearly show the expected association between soil and vegetation units, especially with respect to the relationships between edaphohygrophilous PNV and pedotaxa nomenclature indicative of an abundance or surplus of water in the soil or their growth on rocks and rock debris. Thus it is necessary to understand why this discrepancy exists. In this respect the syntaxonomical nomenclature is very informative. The non-riparian edaphohygrophilous PNV (87%) are located in the dry ramblas riverbeds that are rich in pebbles with layers of finer materials. However, these fluvial "sediments" are not considered soils in most soil taxonomies. This is the reason why the presence of these numerous plant communities does not align with information on the soil maps. The same is true for most of the edaphoxerophilous PNV classes.

The vegetation at these sites will send its root systems several meters deep to reach water in the subsoil and can grow luxuriantly, as is described in Section 2. For this and other reasons, the "sediments" of the ramblas meet the main points of the commonly accepted modern definition of soil (Ibáñez and Boixadera, 2002; Brevik and Arnold, 2015). Not including this type of soil in pedological taxonomies undermines the usefulness of soil maps in studies on plant-soil relations, as well as in those concerning the protection of nature (Ibáñez et al., 2008; Haslmayr et al., 2016). Such is the case in WRB (FAO, 1998). Notice that only 2 edaphohygrophilous PNV are riparian units, although in Fig. 4 these vegetation types conspicuously border the margins of the largest and wetter ramblas courses, with the rest of the PNV types only being represented by small elongated spots. Furthermore, the vegetation maps were at a more detailed scale (1:10,000) than the soil maps (1:100,000). Several studies comparing soil and geology maps have indicated that soil maps can provide important information that is missing on the geology maps when the soil maps are at a larger scale than the geology maps (Brevik and Miller, 2015 and references therein). This study gives another example of a case where a larger scale map (vegetation) provided important information that was missing from a smaller scale map (soil), allowing knowledge to be extended about a related natural resource.

According to the 2014 version of WRB (IUSS Working Group WRB, 2014, pp. 4): "(...) *the object classified in the WRB is: any material within 2 m of the Earth's surface that is in contact with the atmosphere, excluding living organisms, areas with continuous ice not covered by other material, and water bodies deeper than 2 m. If explicitly stated, the object classified in the WRB includes layers deeper than 2 m. The definition includes continuous rock, (...) cave soils as well as subaqueous soils (...)*". Thus, the classification does not seem to exclude the ramblas riverbeds as a type of soil.

3.3. Should we consider ramblas riverbeds as soils?

Ramblas or wadi riverbeds are occasionally covered by a sheet of running water, but most of the time they are exposed to atmospheric conditions, support plant and other life, and thus soil-forming factors are usually active. It seems logical that the "sediments" of these edaphohygrophilous PNV should be considered to be types of soils.

Several studies of the of soil/sediment biology of temporary watercourse streambeds in Spanish ramblas support the idea that they are a habitat that is several meters deep and rich in soil organisms (Zaballos, 1997; Ortuño et al., 2013). Thus, considering widely accepted definitions of soil (Soil Survey Staff, 1999; IUSS Working Group WRB, 2014; Brevik and Arnold, 2015), current findings suggest that these media should be considered to be soils.

As far as we know there are no pedological studies of the above mentioned sites. However, depending of the nature and texture of the layers under the riverbeds a variety of pedotaxa could be present. Riverbed soils often contain a significant amount of large boulders and gravel which would lead to classification as a Leptosol if the coarse fragments

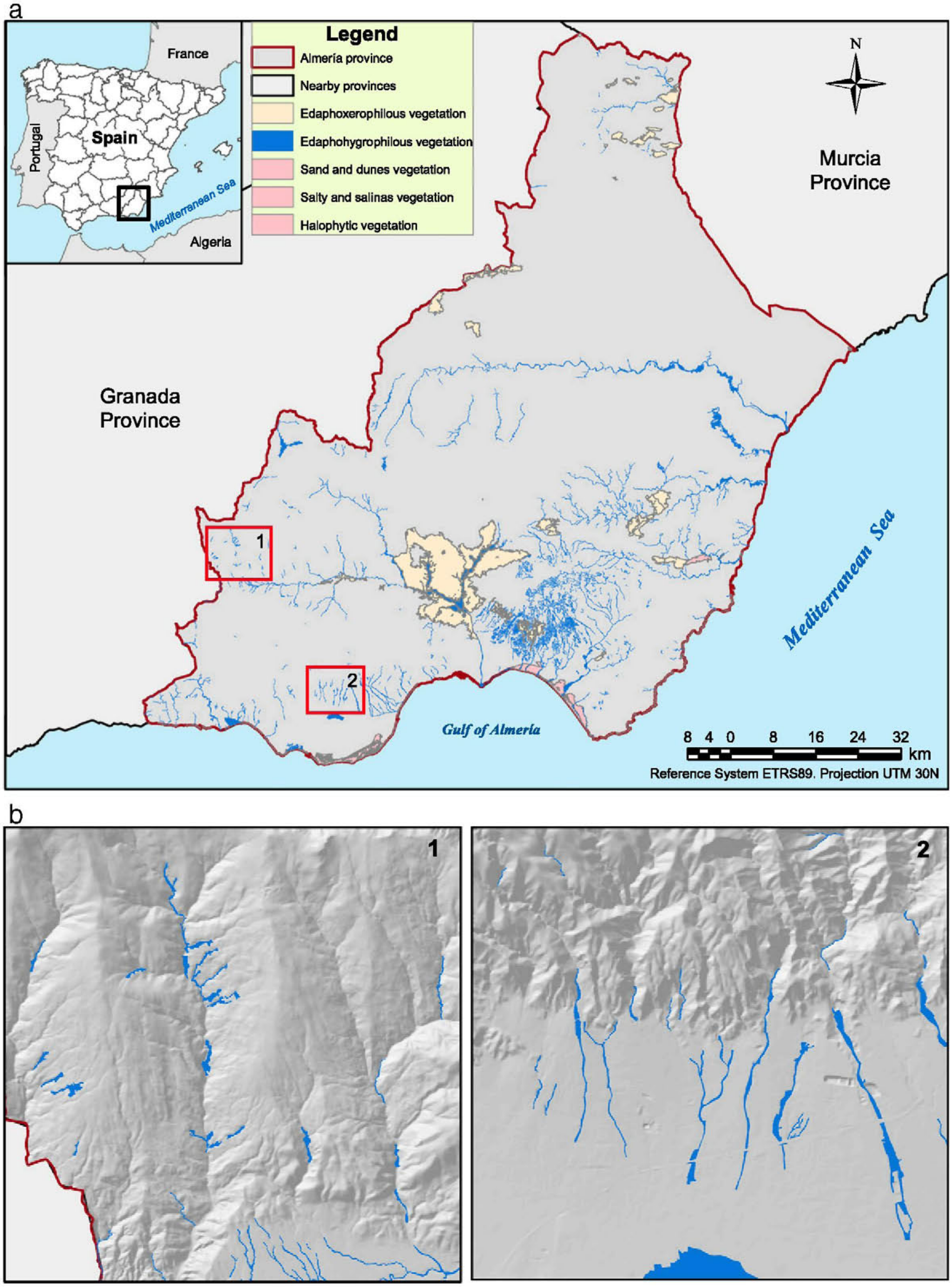


Fig. 4. a) Distribution of edaphophylous and other related vegetation types in Almería. b) Detailed view of two selected areas.

occupied a volume >80% in the upper 75 cm. Otherwise most of the riverbed soils in the ramblas would probably classify as Regosols. Furthermore, aridic properties (defined on pp. 59 in WRB 2014) could also be present. In the case of Leptosols this would lead to a very tentative classification as a Hyperskeletic Leptosol (aridic) (Freddy Nachtergaele, pers. com.). However, the origin and formation of these potential "wet Leptosols in arid environments" are not reflected in the WRB 2014 (pp. 154–155).

In arid lands the ramblas stream bed channels are hot spots of biodiversity because they serve as a water source within the framework of the Earth's Critical Zone (CZ). According to Lin (2010): "*The Critical Zone (CZ) is a holistic framework for integrated studies of water with soil,*

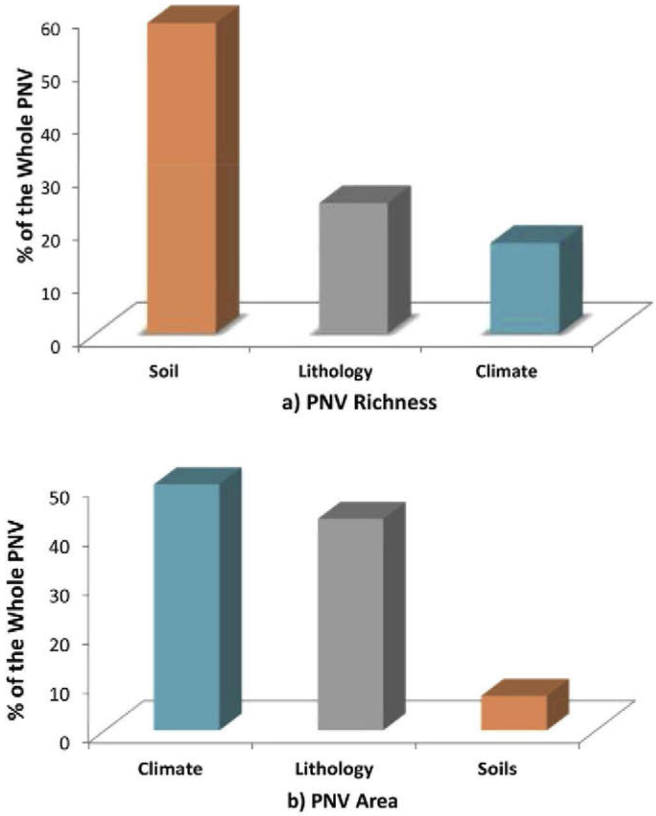


Fig. 5. a) The number of PNV types associated with each abiotic factor and b) % PNV area covered by PNV that are dependent on abiotic factors.

rock, air, and biotic resources in terrestrial environments. This is consistent with the recognition of water as a unifying theme for research on complex environmental systems. The CZ ranges from the top of the vegetation down to the bottom of the aquifer, with a highly variable thickness (from <0.001 to >10 km). The pedosphere is the foundation of the CZ, which represents a geomembrance across which water and solutes, as well as energy, gases, solids, and organisms are actively exchanged with the atmosphere, biosphere, hydrosphere, and lithosphere to create a life-sustaining environment". This description fits the ramblas environment well, making them a critical system to study to better understand CZ, including pedosphere, functioning in arid environments.

3.4. The spatial distribution of edaphohygrophilous PNV in the landscape

The green oases of the edaphohygrophilous PNV only occur along some sections of the channels of the ramblas within a larger sea of arid land. As shown in Section 3.2 and Fig. 4, these plant communities are distributed as spots that dot the landscape in general as very small polygons. Depending on their properties, subsurface soil layers, regoliths and underlying rocks they may behave as aquifers, aquitards or aquifuges (aquicludes). Given that the entire population of edaphohygrophilous PNV polygons have a distribution that conforms to power laws with sizes that exceed three orders of magnitude, they can be considered as a fractal structure (Hastings and Sugihara, 1993; Harte et al., 2001; Ibáñez et al., 2005): islands of biogeodiversity. Therefore, the syntaxonomic approach provided soil information important for environmental purposes that is currently lacking in most soil classifications and soil maps. This information is also very useful to biodiversity conservation purposes as proposed by Ibáñez and Pérez-Gómez (2016). From a landscape ecology perspective called the "patch-corridor-matrix model", climate and climate-lithological dependant PNV should be considered as matrices or, in some instances, patches (as also occurs with edaphoxerophilous plant associations), whereas riparian vegetation could be labelled as corridors and edaphohygrophilous communities as small patches or spots (Forman and Godron, 1981, 1986). A high heterogeneity of soils in these habitats in arid lands has also been demonstrated in other arid and semi-arid lands, such as Algeria (Aliat et al., 2015).

3.5. Plant communities at risk of extinction and soils

Depending on the area and number of polygons certain PNV are possibly at risk of extinction within Almería province (Table 7), an event that would have negative implications for ecosystem functions (de Graaff et al., 2015). In this study our estimations of such risk include 14 PNV units: 8 edaphohygrophilous, 2 edaphoxerophilous, 3 lithologic-climatic dependents and 1 climatically dependant. Therefore 71.4% of the plant communities at risk of disappearing in the study area are edaphophylous.

The rare but devastating flash floods that occur in the ramblas have forced mankind to build water control structures in many channels. However, such construction projects threaten to devastate many riverbeds with consequent risk of extinction to plant species and the ecological communities that depend on them (Sprenger, 1999; Allen, 2003; Kudray and Schemm, 2008). Likewise, the fast expansion of tourism residences and greenhouse crops in Almería are additional serious threats to the habitat's vegetation and to vascular plants near coastal lands (e.g. sands, dunes, some halophytic PNV and saltmarshes) (Allen, 2003; Castro et al., 2011; Domínguez-Beisiegel et al., 2013). Both habitats cover small areas within the study area, but host a considerable part of the area's biodiversity.

3.6. Reinvigoration of mapping data

In the current research environment funding to conduct soil research can be difficult to obtain, with shrinking budgets in many parts of the world since about the 1980s (Hartemink and McBratney, 2008; Brevik et al., 2016b). This situation makes it very important to make the best possible use of all information that is available to us, particularly when it involves little additional expense. This has led to the increasing use of proximal and remote sensing, advanced statistical methods, and pedotransfer functions within soil science in recent years (Brevik et al., 2016a,b; Khaledian et al., 2016; Reidy et al., 2016). This study, along with past studies that have looked at the relationships between soil and geology maps (Brevik and Miller, 2015), show that there is no reason that we should not also utilize maps of related natural resources (geology, hydrology, vegetation, etc.) to extract important soil information. Such use would represent a reinvigoration of mapping data that has the potential to provide high additional value from field work that has already been conducted.

4. Conclusions

Soil and vegetation maps are created following different traditions and standards. However, when the number-size polygons of soil and vegetation maps are analysed they both fit well to power laws across several orders of magnitude, showing that both exhibit a scale invariance pattern. In a rank-abundance plot these distributions are termed Hollow or Willis curves, being ubiquitous in biodiversity and pedodiversity studies. Thus there are few very large polygons and the total number of polygons increased rapidly as the typical size of the polygons in any given group decreased. This may result from the nonlinear nature of earth surface systems.

Vegetation maps are based on the systems of various geobotanical schools, such as the syntaxonomic system, and may be very useful to increase the information available for the study of classical pedology. Using the cartography of plant communities in the study area we were able to analyse spatial distribution of biodiversity related to

Table 7
PNV at risk of extinction in the study area.

PNV in risk of extinction	N° polygons	Conservation	Max km^2	Min km^2	Min m^2
Gypsiferous edaphoxerophilous vegetation complex	3	Minority	7.289	0.004	4099
Brackish waters edaphohygrophilous geoseries	1	Endemic	0.058		58,082
Thermo-Mediterranean semiarid riparian geoseries	3	Minority	0.299	0.158	157,791
Oro-Mediterranean basophilous edaphohygrophilous microgeoseries	2	Minority	0.005	0.005	4774
Thermo-Mediterranean meso-halophytic edaphohygrophilous microgeoseries	7	Risk	2.399	0.002	1521
Meso-Thermo-Mediterranean meso-halophytic edaphohygrophilous series	9	Risk	0.198	0.011	9886
Meso-Upper-Mediterranean subhumid & humid basophilous edaphohygrophilous series	9	Risk	0.076	0.019	19,020
Upper-Meso-Mediterranean dry- sub-humid on acidophilous edaphohygrophilous series	3	Minority	0.041	0.022	22,251
Meso-Upper-Mediterranean-Low limestone-dolomitic edaphoxerophilous series	5		6.657	0.051	50,618
Upper-Mediterranean on nutrients rich soils series	8		2.294	0.003	3295
Upper-Meso-Mediterranean limestone series	1	Endemic	0.02		20,799
Upper-Meso-Mediterranean sub-humid & humid on nutrients rich soils series	3	Minority	0.024	0.01	10,461
Thermo-Meso-Mediterranean series	4		6.406	0.519	518,558
Halophytic coastal vegetation	1	Endemic	4.155		4,155,390

vegetation. A considerable part of the biodiversity in Almería lies in the beds of the streams. The streambed sediments are not considered soils in most pedological classifications and during mapping. However, in some novel classifications such as the WRB version of 2014, these sediments are considered soils. Because the vegetation that grows in these sites is mainly terrestrial, hosting a microfauna of edaphic origin, the underlying materials should be considered soils reaching from the surface to the water table. The vegetation mapped in these areas, termed edaphohygrophilous ("soil water lovers"), is distributed in small plots over several magnitude orders across the Almería landscape following a scale invariance pattern. Thus, they seem to be islands of biodiversity in the arid landscape. These islands of biodiversity are a key component of the earth's critical zone within this arid environment that must be preserved.

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