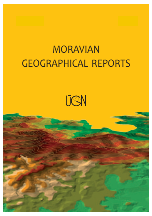

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Landform values for rural sustainability: Recognition and assessment in a Spanish–Portuguese border region case study

Elena DE UÑA-ÁLVAREZ [a*], Miguel Ángel ÁLVAREZ-VÁZQUEZ [a], María del Carmen CUQUEJO-BELLO [a]

Abstract

Landform assemblages may be used to define sites of geomorphological interest which are resources for rural sustainability. This paper focuses on the valuation and significance of such sites in the context of one European internal border region, illustrated using a case study from the inland mountains of the Spanish-Portuguese border: the Serra do Larouco. The theoretical and methodological approach used includes the recognition, inventory and assessment of a preliminary list of twenty-eight sites. They comprise diverse granitic landforms which characterise the rural inland landscapes in the North West of the Iberian Peninsula. The results from the qualitative and quantitative assessments were the basis for a final selection of nine sites as significant land resources. An analysis of their key values supports the proposal of different use and management options to promote rural sustainability. A review of the methodology applied and the consideration of other case studies provide a means to interpret and discuss the regional and local significance of the selected sites. The conclusions emphasise the crucial role that values linked to landforms can play in little-known mountainous and rural border regions, suggesting a future research agenda.

Keywords: *landforms; geomorphological site; rural sustainability; European border region; Serra do Larouco; Galicia (North West Spain); North of Portugal Mountains*

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1. Introduction

The Europe 2020 strategy focuses on smart, sustainable and inclusive growth across European regions. This approach demands territorial processes of change to face the global crisis, involving regional and local actors (European Commission, 2015). Current challenges for the European regions, however, depend on specific conditions that affect the possibilities of growth. After the 2008 global crisis, regional trends in Europe exhibit a core continental territory – where the impacts have been low or moderately low – surrounded by peripheral areas where the impacts have been high or very high (Crescenzi et al., 2016). Most of the border internal regions of the European Union (EU) are included within the lagging areas, often predominantly rural and mountainous territories (European Commission, 2010). They comprise more limited access to services, higher unemployment and lesser Gross Domestic Product (GDP) per head than the EU average. Following Capello and Caragliu (2016), a place-based scenario focused on the preservation and creative exploitation of local territorial assets, is the best option to decrease these regional disparities in the EU. This development proposal agrees with the new foundations for rural development (Ambrosio-Albalá and Bastiaensen, 2010; OECD, 2006), which emphasise the necessary recognition of the values of territorial assets by authorities, social partners and civil society in order to conceive successful strategies for development.

These perspectives incorporate a region's natural and cultural assets as key resources for the transformation and improvement of the territory. Such processes must have fruitful effects on the whole territorial components and also depend on the rediscovery of the places where distinctive use and management options arise. Moreover, the necessary creation of synergies between socio-economic growth and environmental protection (Naldi et al., 2015) implies the sustainable use and management of the natural and cultural assets, linking regional and place-based strategies. In rural and mountainous areas, the features and quality of the natural assets are defined as important factors for sustainability (Sánchez-Zamora et al., 2014); landforms and landscapes are essential components of their configuration, having a strong influence on their development trajectories.

[a] Research group for studies on Archaeology, Antiquity and Territory (GEAAT), Department of History, Art and Geography, University of Vigo, Spain (*corresponding author: E. De Uña-Álvarez, e-mail: *edeuna@uvigo.es*)

Around the northern Spanish-Portuguese border (Fig. 1), the Galicia-North Portugal Euroregion identifies a territory with powerful economic, social and cultural relationships (García-Álvarez and Trillo-Santamaría, 2013). The main conditions as regards the current territorial dynamics are its peripheral position both in the Iberian Peninsula and Europe, population decline and the structural imbalances between coastal and inland areas (Baltà Portolés, 2015). The European programs, especially through INTERREG projects, had more influence on the improvement of the road infrastructures than on the creation of local and regional initiatives for rural development (Domínguez et al., 2013). In this region, the landscape of the inland boundary is characterised by the presence of cross-border mountains. The case study of the Serra do Larouco, one of these mountains, was selected for its particular interest in the framework of peripheral European and Iberian border regions. It represents a rural inland area, affected by severe processes of depopulation.

The Larouco Mountain contains plentiful landforms although they are little known and lack protection. The aim of this study is to enhance the recognition, knowledge and visibility of landforms as key resources for the sustainability of this inland and rural area. There are three specific objectives: (i) to identify and characterise the landforms with highest interest and territorial significance; (ii) to analyse their current conditions in the regional and local context; and (iii) to carry out a study of their values assessment to create sustainable use/management strategies, furnishing significant information for the territorial authorities, stakeholders, residents and visitors.

The paper begins with an explanation of the theoretical and methodological approach. Then the methods applied for the inventory and assessments are described, the results are presented and their significance is explained. Finally, the conclusions synthesise the territorial and policy implications for future development and demonstrate lines of further research.

2. Theoretical background

The recognition and valuation of interest in landforms provide a significant knowledge base to define the priorities of territorial planning towards sustainable growth. This interest of landforms is related to multiple dimensions. Scientific knowledge of them, their conservation degree, uses and management reflect the values conferred on them by human communities through time. When landforms are components of the World Heritage Sites (UNESCO, 2016), the World Protected Areas (IUCN, 2013) or the Global Geosites (IUGS, 2015), a set of outstanding universal values are enhanced. Migoń (2014) summarises landform values at the global scale by their strong significance (as archives of the Earth's history, milestones in geomorphologic research and examples of specific features or processes) and their wider significance, linked to diverse socio-cultural meanings. Outside of these and other protected areas (e.g. Natura 2000 in Europe), landforms also have a set of interests which can provide helpful values for sustainable development.

Besides recording the legacy of the Earth's systems evolution, landforms interests for society include their functions as the physical basis of landscapes and life support. Landforms are a part of the geodiversity (Gray, 2011; Serrano and Ruiz-Flaño, 2007), and may be considered as specific features of a territory at regional or local scales (Panizza, 2009). The main values afforded by society to these geodiversity components are associated with their potential as resources for education, knowledge, recreation, tourism or cultural inspiration (Hjort et al., 2015). Landform assemblages having those scientific, educational, aesthetic, socioeconomic and cultural values define geomorphological sites or geomorphosites (Panizza, 2001; Panizza and Piacente, 2003; Reynard, 2009). These terms involve landforms in the common heritage of a territory, and the recognition of those sites is the first step to promote knowledge of their values, and to become aware of them. Landform identification and characterisation report the sites of geomorphological interest in a territorial context. The assessment procedures guide understanding and promotion of landforms as geomorphosites, which are "forms du relief ayant acquis une valeur scientifique, culturelle et historique, esthétique ou socio-économique, en raison de leur perception ou de leur exploitation par l'homme", being their values "généralement peu connue du grand public et des scientifiques d'autres disciplines" (Reynard and Panizza, 2005, p. 177).

Granitic landforms characterise the landscapes of the North West Iberian Peninsula. Their origin and evolution are related to several geomorphic processes (Migoń, 2006; Twidale and Vidal-Romaní, 2005). During the magma intrusion, cracks with diverse geometry patterns (for instance, polygonal or orthogonal) and systems of discontinuities (pseudo-bedding, sheets and joints) are generated. When the consolidated rock is located in less deep levels, the water flow across the discontinuities guides the sub-superficial processes (rock weathering). Thus, the rock platforms, bornhardts, inselbergs, castle rocks, tors, blocks or cavities (e.g. gnammas, tafoni) would be formed, whose final morphology on the Earth surface reflects the weathering/erosion balance. Once these landforms come into contact with sub-aerial agents (air, water, wind) their diversification and degeneration processes take place. In exogenous environments, other landforms (rills, gutters or potholes in bedrock channels) can be generated. All these landforms are usually identified with respect to their dimensional assortment. The inventory of the geomorphological sites in the study area counted the characteristic landforms in the North of Portugal and Galicia (Pereira et al., 2015; Vidal-Romaní et al., 2014); here the local denominations in the following dimensional categories are added in italics to ease their understanding and comparison:

i. Dimension variable: vein rock; cracking; pseudo-bedding (*pseudo-estratificación*, *pseudo-estratificaçao*); sheet (*laxe*, *laje*); weathering profile, grus (*xiabre*, *jiabre*);
ii. Micro dimension (from cm to m): rock basin, gnamma (*pía*); tafone, cavernous weathering (*cachola*, *cacheira*); rill, runnel (*fendas*, *sulcos*); gutter (*canelura*); block (*bloco*); boulder (*bolo*); block field (*pedregais*); logging stone (*pedra bolideira*) and pedestal rock (*rocha pedestal*); and
iii. Meso-Macro dimension (from m to km): tor, nubbin, castle kopje (*pedra*, *pena*, *penedo*, *outeiro*); dome, bornhardt (*moa*); alveole (*alveolo*); plain (*aplanamento*, *chao*, *chaira*); bedrock river (*cauce rochoso*).

The granitic landforms often inspire much awe in onlookers and they present undeniable scenic and aesthetic values. They receive singular names related to viewers' singular experiences, legends or myths from the local culture. Thus, these components of the territorial system integrate natural and cultural significances, gathering aesthetic, scientific, educational, symbolic, iconographic and socio-economic values (Pena dos Reis and Henriques, 2009). These tangible and intangible values, connected to the assets that comprise the geomorphological sites, keep track of human footprints and shape the territorial identity. The tangible and intangible values of the landforms are viewed as indivisible and interconnected in the formation of the sense of a place, and knowing them is essential for planning a sustainable development (Werlen et al., 2016).

According to the theoretical background, the identification and definition of the geomorphological sites, as well as the valuation of their interests, were based on assessment criteria related to the meanings that granitic landforms could present. The sites assessment was addressed to promote the sustainability of a mountainous and rural territory, located in an internal border region of the EU. The qualitative and quantitative assessment was devised as a tool in order to establish the use and management priorities.

3. Study area

The Larouco Mountain is located in the NW of the Iberian Peninsula (IP), elongated in the NE-SW direction (Fig. 1). It belongs to the inland border between southern Galicia (Spain) and the North of Portugal, named as *raia seca* (dry border) in contrast with the borderline set by the fluvial watercourse of the lower Mińo River. The highest geodiversity values in this IP sector are closely related to their interests for understanding the origin and evolution of the oldest Iberian Massif terrains (Benito-Calvo et al., 2009). The granite intruded the engaging material in the intermediate stage of the Variscan cycle (between 328 and 339 Myr BP). The relief organisation is due mainly to Cenozoic tectonics since the morpho-structures of Galicia and the North of Portugal represent the most western extension of the Southern Pyrenean area in the Alpine Mountain Range (De Vicente and Vegas, 2009). Schmidt-

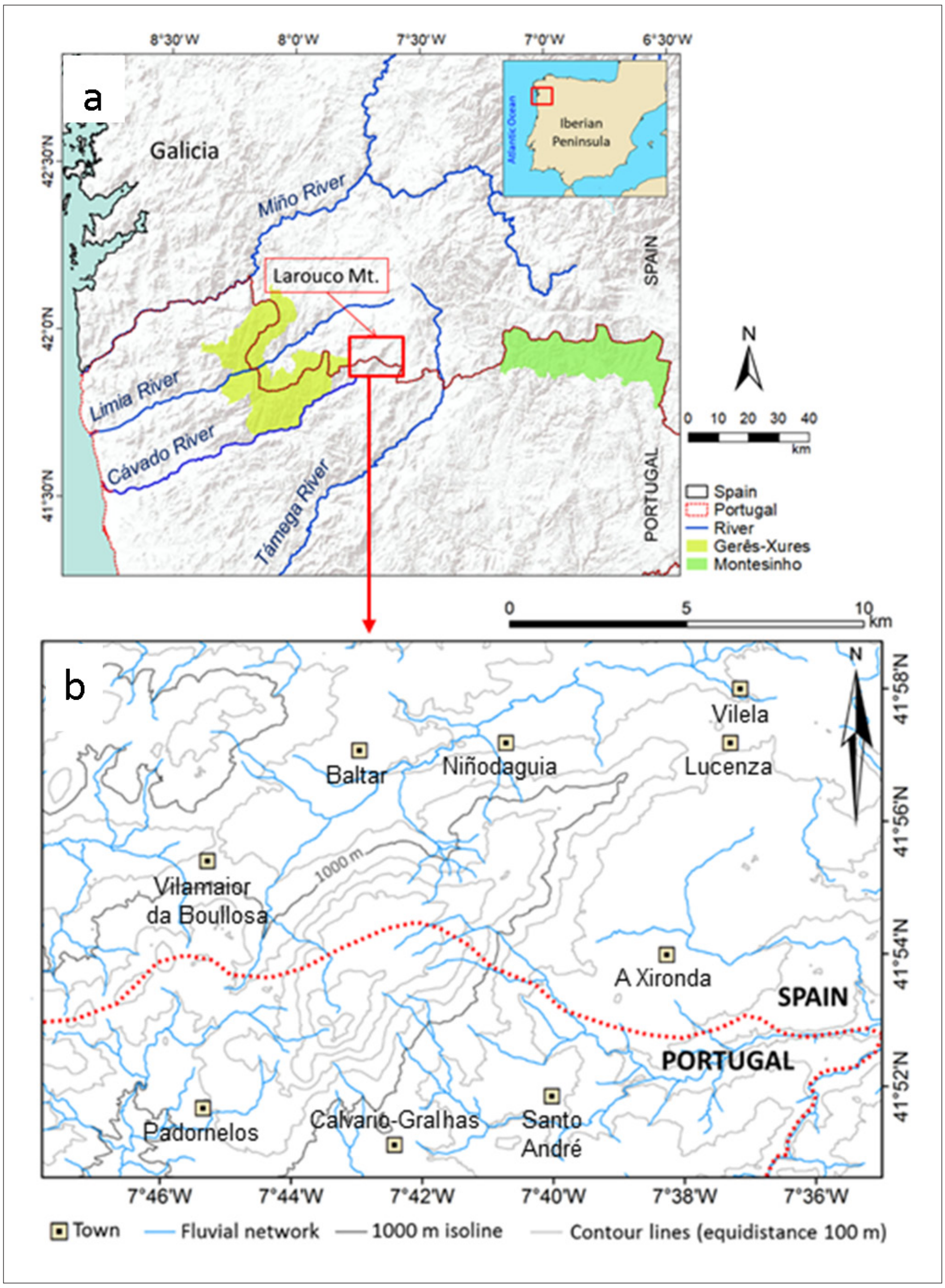

Fig. 1: Location and main features of the study area: a) location in the Iberian Peninsula and b) topographic features with location of towns. Source: authors' elaboration (Base Map ESRI for location and Base Map BTN25 Instituto Geográfico Nacional de España for area configuration)

Thomé (1978) pointed out that the Larouco summits would be affected by glacial processes during the Pleistocene, with two (independent) layers of permanent ice above 1,250 m. In the Portuguese area, Coudé-Gaussen et al. (1983) stated the importance of the snow, without ice formation, and Vieira et al. (2015) mentioned that the main processes would have been periglacial. The absolute dating attests to the presence of small glaciers in the nearby Gerês-Xurés Mountains (Vidal-Romaní et al., 2015), with an age of 300 kyr BP for the stage of maximum glacial advance during the Pleistocene.

The topography of the summit area is flat, slightly tilted from the SW to the NE (Fig. 2). The Larouco Mountain is the watershed between Limia, Támega and Cávado fluvial basins and their maximum altitudes are Pico Larouco (1,538 m) in Portugal and Coto Farelo (1,398 m) in Galicia (Spain). Maximum unevenness between the Mountain summit area and the bottom of the surrounding valleys is 100 m (NE), 500 m (SW), 400 m (E) and 558 m (W). The thermal variation in altitude (Rodríguez Guitián and Ramil-Rego, 2008) determines the bioclimatic zoning between the hill level (average minimum temperature of the coldest month > 0 °C) and the mountain level (average minimum temperature of the coldest month between > 4 °C and 0 °C). The total annual precipitation ranges from 800 mm in the surrounding valleys to 1,500 mm in the summit area (AEMET, 2016). Most of the mountain is covered by bushes, meadows and pastures, with crop fields limited to flat lands near population centres. Native forests (*Quercus robur* and *Quercus pyrenaica*) are found in the NW sector (1,000–1,200 m). Pine trees (*Pinus pinaster*, *Pinus sylvestris* and *Pinus radiata*), introduced by reforestation programs since the end of 1950s, define the forest on the Northern sector (1,150–1,390 m).

Since 2002, a private wind farm has operated in the municipalities of the Spanish territory. The demographic situation is affected by continuous population decline. Between 1980 and 2016 the mountainous area and its surroundings (municipalities of Baltar and Cualedro in Galicia, and part of Montalegre municipality in Northern Portugal) suffered a loss of more than 50% of its human resources (IGE, 2016; INE.pt, 2016). The population density is very low (12 per km^2) and the active population is employed mostly in the services sector (60%), and secondarily in farming (20%). Most of the mountainous territory is under common lands property. The present land uses of the mountain are devoted to cattle pasture; also important on the Portuguese side, there are activities for outdoor recreation.

4. Methodology

Definition of the criteria and indicators to select and assess the geomorphological sites was accomplished after review of the different methods applied. The Italian method (Panizza, 2001) proposed the use of intrinsic values (scientific, educational and paleo-geographical) and added values (scenic, socio-economic and cultural). The indicators of these central (intrinsic) and added values were diversified by the Swiss method (Reynard et al., 2007). Other methods applied to assess Spanish sites (Bruschi and Cendrero, 2009; Serrano-Cañadas and González-Trueba, 2005) pointed up the importance of use and management values (related to the accessibility, observation conditions, potential risks and threats). In Portugal (Pereira, 2006; Vieira, 2008), the sites assessment focused on the geomorphological values (including scientific and additional indicators) and the use/management values defined by the Spanish studies.

These proposals were tested by Erhartič (2010) in an assessment of the Slovene waterfalls, concluding that better selection depends on the research objectives and scale. The method applied by Višnić et al. (2016) looked at the existing ones with slight modifications, attempting to formulate the specific potential of the sites for geotourism. Moreover, the method to select and assess the geomorphological sites in the

Fig. 2: The Larouco Mountain: (a) the mountain seen from SW (Montalegre, Portugal); (b) panoramic view from the summit area towards NW
Photos: E. De Uña-Álvarez

granitic mountains of the Czech Republic (Kubalíková and Kirchner, 2016; Rypl et al., 2014) emphasised the creation of a geomorphological inventory; the assessment is addressed to preserve landforms and to promote sustainable uses in less-known and unprotected areas, considering scientific, educational, economic, conservation and added values. Due to the thematic and spatial overlap of the study area, the methodology used here follows the latest proposals applied in the North of Portugal (Pereira and Pereira, 2010; Vieira et al., 2014), taking into account the necessary approach to the regional scale (Reynard et al., 2016). The methodology has included a qualitative and quantitative assessment; the value scales and maximum scores for the different criteria were adjusted from the Portuguese method. Thus, the criteria chosen and applied were consistent with the approach of research in the Spanish-Portuguese border.

The research was developed in three stages. First, the characterisation of the study area (from bibliographic, cartographic, statistical, spatial data infrastructures and web resources) entailed the identification and recognition of geomorphological sites. The selection, description and mapping of the twenty-eight sites included in the initial list, were carried out by the authors through the development of detailed field work. According to the theoretical and methodological framework, the primary criteria for selecting any landform or landform assemblage as a geomorphological site were as follows: representativeness as a landscape component at the local or regional scale; scientific and scenic interests; relationships with other natural and cultural assets; symbolic significance; and possibilities of observation. An index card was created, including the location data (name, reference code, country, municipality, position, altitude and

Criteria	Indicators	Maximum
Scientific value (Sv)	Local rarity	
	More than five, three-five, two and none similar sites	1.0
	Regional rarity	
	More than five, three-five, two and none similar sites	1.0
	Geomorphological diversity	
	One, two, three and more than three interesting landforms	1.0
	Number of mentions in scientific publications	
	One, two, three-five and more than five	1.0
	Educational exemplarity for curricular contents	
	Primary, secondary, baccalaureate and university levels	1.0
Added value (Av)	Ecological: vegetation and singular ecosystems	
	None, introduced, mixed, natives	1.5
	Cultural: material and immaterial assets diversity	
	One, two, three and more than three cultural assets included	2.0
	Aesthetical: colour, shape, viewpoints and appearance	
	Slightly, medium and high contrast, with panoramic views	1.5
Use value (Uv)	Visibility: observation conditions	
	Only in situ, partially, full from <1 km, full from ≥1 km	1.5
	Accessibility: individual or public transport	
	Walking, cycling, by jeep, car and bus	1.5
	Accommodation and services proximity (spatial radii)	
	More than 30 km, 30 km, 20 km, 10 km	1.5
	Use potential: scientific, educational and socioeconomic uses	
	None, low, medium, high	1.0
	Use limitations in spatial and time scales	
	None, low, medium, high	1.5
Protection value (Pv)	Conservation of the essential features and the surrounding	
	Strong, moderately and little damaged or non-damaged	1.0
	Vulnerability: current exposure and threats	
	Extremely, high, moderate, low	2.0

Tab. 1: Criteria and indicators for the site assessments
Notes: The indicators for the scientific (Sv) and added (Av) values define the geomorphological value (Gv = Sv + Av). The indicators for the use (Uv) and protection (Pv) values define the use/management value (Mv = Uv + Pv). Max is maximum score. The scale to quantify indicators is specified as follows: for Max = 1.0 and four categories is 0.25, 0.50, 0.75 and 1.00; for Max = 1.5 and four categories is 0.25, 0.50, 1.00 and 1.50 (except none = 0); for Max = 2.0 and four categories is 0.50, 1.00, 1.50 and 2.00
Source: Modified by the authors from Pereira and Pereira (2010) and Vieira et al. (2014)

geographic coordinates), the indicators of interest (scientific, educational, ecological, cultural and aesthetic), and the use/management conditions (taking into account potential uses, conservation degree, current exposure and threats), for the sites' field records. At the end section of the index card, a summary description, cartography and images were attached. The criteria and indicators to assess the sites were adapted to the research objectives (Tab. 1).

The second stage of the research was focused on the database creation and qualitative assessment of the sites. In this way, the database was set up by assigning a nominal code to each site from their location in the relief units of valley (v), slope (s) or summit (t). This nominal code and its number provided the preliminary information on the spatial distribution of the selected sites. Then, the spatial distribution and geomorphologic categories (landform types) of the inventoried sites were analysed. The characterisation of the inventory also dealt with their local or regional rarity and interest for science, education, protection or different uses (looking at the current degree of conservation and vulnerability of the sites). The indicators for the scientific (Sv) and added (Av) interests of the sites define their geomorphological value (Gv), while the indicators for the use (Uv) and protection (Pv) interests define their use/management value (Mv). The qualitative labels assigned to the sites, from low to high, were determined by the records obtained during the field work.

In the third stage, the quantitative assessment of the geomorphological sites took place. It began by exploring the distribution of the geomorphological and use/management values. The highest possible score both for Gv (Sv + Av) and Mv (Uv + Pv) is 10 points. Due to its visual impact, proximity to the wind farm resulted in a decrement of 0.25 points in the quantitative assessment of the aesthetic indicator. The frequency analysis comprised five class intervals, established as follows: very low (≤ 2.0 points), low (2.1–4.0 points), medium (4.1–6.0 points), high (6.1–8.0 points) and very high (8.1–10.0 points). Then, statistical analysis was applied to explore the centrality, dispersion and variability of the results, checking for median significance by the application of the non-parametric Mann-Whitney test. This test compares the results of the ordered values and compares their medians: the null hypothesis is that both Gv and Mv medians are equal; the alternative hypothesis that there is a significant difference between the medians.

The total value (V) for the sites was obtained by adding the Gv and Mv results (V = Gv + Mv), so its maximum score is 20 points. The sites classification was determined by clustering with regard to the median of the V data (median method, Euclidean distance). The differentiation inside these groups provided the best available sites to create successful strategies for rural sustainability. In the data processing, robust statistical measures of the assessment criteria (lower quartile, median and upper quartile) were used for the final valuation of the sites. The sites selected as nodes to promote rural sustainability were defined after the interpretation of the qualitative and quantitative assessment, once applied to the preliminary sites list. The database construction, statistical procedures and graphical representations of the data were carried on Stat Graphics Plus software.

5. Results and discussion

5.1 Qualitative assessment: inventory characterisation

The preliminary inventory contained 28 sites, mainly located in the summit and slope units (Fig. 3, Tab. 2). The most representative landforms assemblages with scientific relevance were recognised at the Mountain top (t01, t04, t05, t06, t09, t12, t13, t14) and fluvial headwaters (s03, s08). The Larouco Mountain is mentioned in some studies on periglacial and glacial events in the NW of the Iberian Peninsula. The degree of geomorphological diversity is very high, since more than three interesting landforms were identified in the configuration of 17 sites. They

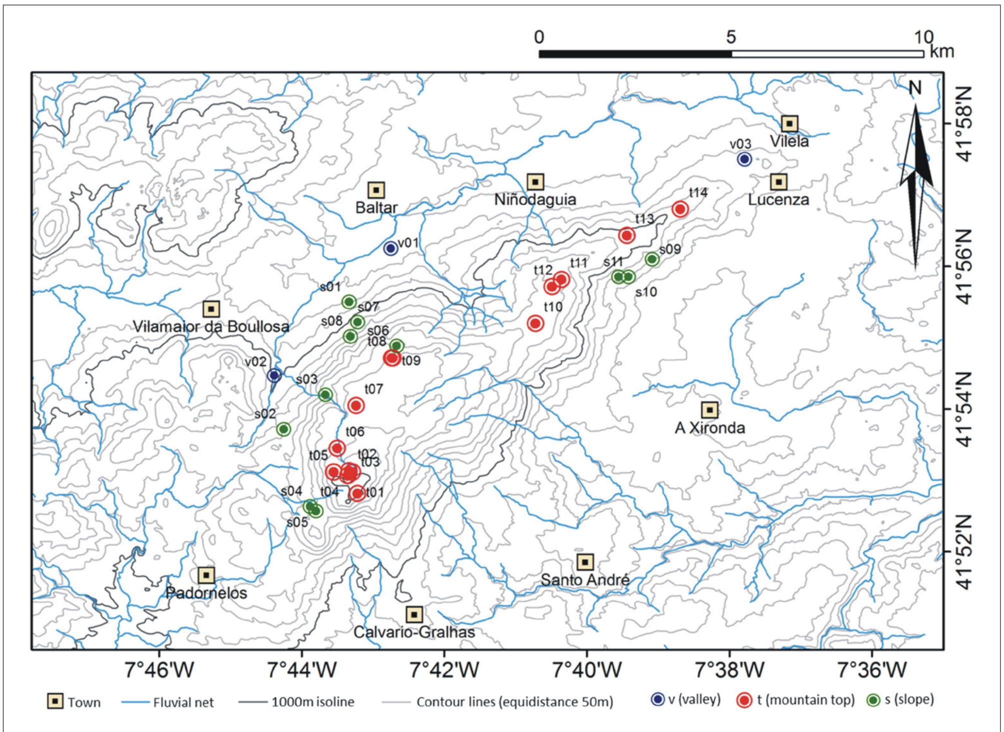

Fig. 3: Location of the inventoried sites
Source: authors' elaboration (Base Map from BTN25 Instituto Geográfico Nacional de España)

Code	Country	Alt	Landforms
v01	Spain	833	tor, boulder
v02	Spain	1001	small bedrock river, spring
v03	Spain	913	tor, boulder
s01	Spain	974	boulder, gnamma
s02	Spain	1133	tor, boulder
s03	Spain	1200	small bedrock river, block field
s04	Portugal	1270	logging stone, gnamma, tafone
s05	Portugal	1312	block, pseudo-bedding
s06	Spain	1321	tor, gnamma
s07	Spain	1114	tor, gnamma, tafone
s08	Spain	1139	torrent, block field
s09	Spain	890	block, logging stone
s10	Spain	906	sheet, boulder, gnamma, tafone
s11	Spain	915	tor, gnamma, tafone
t01	Portugal	1527	tor, pseudo-bedding, gnamma
t02	Portugal	1499	pseudo-bedding, cracking, gnamma
t03	Portugal	1493	plain, peat bog
t04	Portugal	1538	peak, block
t05	Portugal	1477	pseudo-bedding, weathering profile
t06	Portugal	1493	plain, boulder
t07	Border	1491	plain, boulder
t08	Spain	1345	tor, pseudo-bedding, gnamma
t09	Spain	1340	small bedrock channel, cracking
t10	Spain	1118	pseudo-bedding, logging, gnamma
t11	Spain	1160	tor, pseudo-bedding, gnamma
t12	Spain	1180	peak, tor
t13	Spain	1074	pseudo-bedding, block
t14	Spain	991	tor, logging stone, gnamma

Tab. 2: Main references of the inventoried sites (Alt = altitude in m a.s.l. Nominal codes from location: v = valley, s = slope, t = mountain top). Source: authors' elaboration

also have high educational interest, so they can be used at several education levels. Other interests rely on the scenic and aesthetic character (22 sites with panoramic views), although this quality may be affected by proximity to the wind farm (for instance: t10, t11, t12 and t13). The presence of native vegetation (s01, s02, s03 and s08) or singular ecosystems (Peat bog in t03), characterises the principal ecological interests. The Mountain holds a sacred connotation (Olivares Pedreńo, 2002) because it could be the domain of a pre-Roman god: this divinity, linked to storms and rivers, endows the name Larouco with a mythical meaning (Lourenço Fontes, 1980). Within the cultural assets linked to landforms, other symbolic meanings related to legends on treasures or wizards (s01, s02, s03 and v01), or archaeological and historical assets (for instance: rock art in s01, snow well in t04, and old shepherd refuges in t07) also stand out.

The observation conditions, accessibility and services proximity are very good for v01, s04, s05, t02 and t03. The potential for recreation and wildlife sports is very high in 18 sites. The degree of deterioration is related to refurbishment works to receive visitors (t01, t04, t05, t12 and t13), and the extraction of granitic blocks for the local building (v01 or v03). The main problems regarding the sites' engagement (as scientific, educational, recreational or cultural resources) derived from the need of preservation measures due to their vulnerability (e.g. Peat bog in t03, block fields in s03 and s08), the presence of remarkable cultural assets (e.g. petroglyphs in s01), and general exposure to deliberate fires.

5.2 Quantitative assessment: geomorphological and use/management values

Most of the inventoried sites present significant use and management values. This statement is supported by the results of the quantitative assessment. The results of the frequency analysis show the prevalence of high geomorphological values and high or very high use/management values within the inventoried sites (Fig. 4). Most of the sites obtained a geomorphological value (Gv) between 5.5–8.0 points and a management value (Mv) between 6.0–9.0 points. The exploratory analysis revealed low standard deviation (0.9) and standard error (0.2), regarding the averages for the Gv data (6.47 points) and Mv data (7.43 points). These statistical measures for data centrality were closer to the results delivered by their position measures: the Gv median (6.75 points) and the Mv median (7.50 points). This condition determined the use of the position statistical measures as the best comprehensive tools for the quantitative assessment. The difference between the medians of the geomorphological and management values is statistically significant, since the computed p-value (0.00053) from the application of the Mann-Whitney test was < 0.05 (95% confidence level).

In spite of the moderate values obtained from their rareness and scientific knowledge ratings, the sites have wider interests. The highest geomorphological values were obtained by eleven sites, with panoramic views, that present several values: assemblies of boulders on plains (t06); pseudo-bedding, polygonal cracking, pitting and weathering profile (t05); pseudo-bedding, tors and gnammas (t01, t04, t08, s01 and s02); block fields in torrent headwaters (s03, s08 and t09); and sheet structures diversified by tafone and gnamma cavities (s11). The highest use/management values were associated with five sites with high geomorphological values (t01, t04, t05, t06 and s02) and other sites that displayed assemblies of boulders, tafoni, gnammas and logging stones. All the inventoried sites obtained a total value ≥ 10 points (the median for $V = 14$ points). These values vary by mountain sector (Fig. 5). The highest total values characterise the sites of the SW mountain top, surrounded by slope sites with high total values. The sites of the NE sector show high total values, but mostly the results are below the V median. In the NW valleys, a high value for V is attained by only one site.

The dendrogram for V (Fig. 6) reveals three groups of sites with regard to the global quantitative assessment. The Va group ($V > 15$ points) links the sites that obtained the highest geomorphological or use/management values in the case study. The Vb group (V between 14 and 15 points) joins sites in which results were above the median both for the geomorphological values (except one site) and the use/management values (except two sites). The Vc group ($V < 14$ points) includes sites that attained assessment

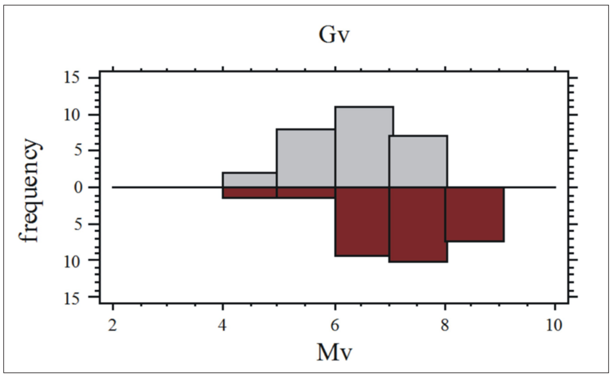

Fig. 4: Frequency distributions for the geomorphological (Gv) and management (Mv) values (The length of the bars represents the number of sites with value within each interval). Source: authors' elaboration

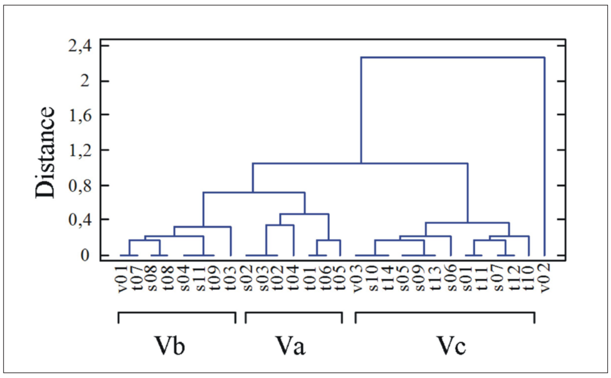

Fig. 6: Clustering by the total value (V) of the sites (Median method, Euclidean distance). Three groups are differentiated: Va (V > 15 points), Vb (V = 14–15 points), and Vc (V < 14 points). Source: authors' elaboration

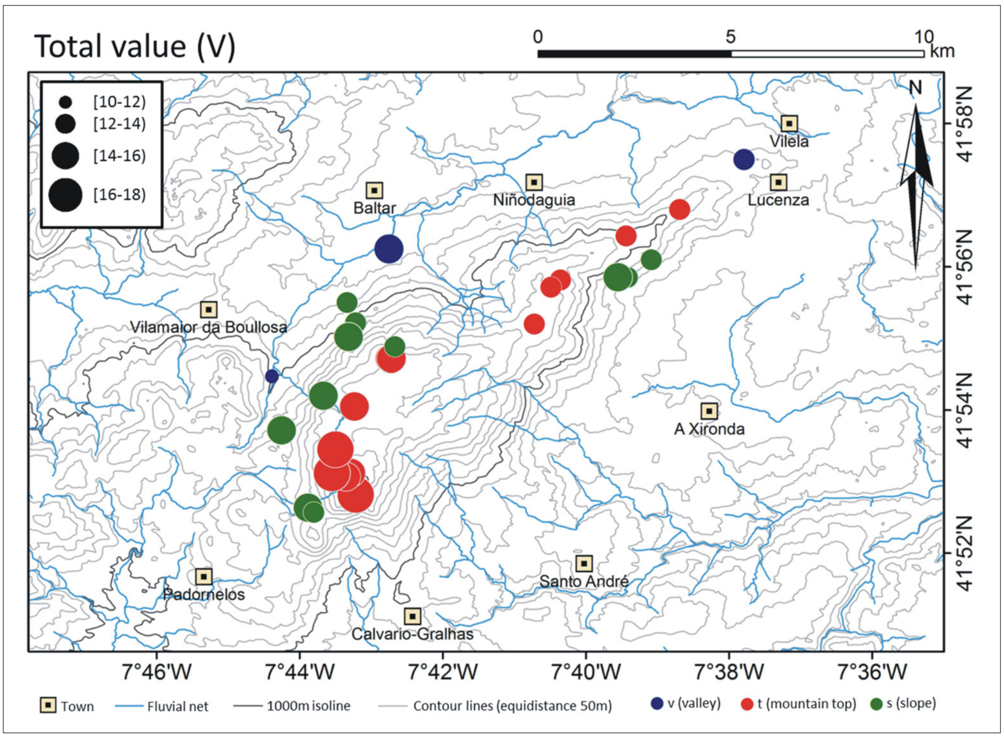

Fig. 5: Spatial distribution of the sites regarding their total value
Source: authors' elaboration (Base Map from BTN25 Instituto Geográfico Nacional de España)

results below the median for the geomorphological values (except one site) and the use/management values (except two sites). One site (v02 with V = 10 points) appears as an outlier to the aforementioned groups, getting the lower geomorphological value and the minimum management value in the study area.

Due to the disparities detected in the internal composition of the V groups, a detailed examination of the scientific, added, use and protection values was accomplished. In this way, the robust statistics of the values from each assessment criteria (Tab. 3) determine the site's ranking. The lower quartile, median, and upper quartile are thresholds demonstrating the relevance of the sites; these thresholds define the rank position with regard to the aforementioned criteria. The first position identifies the sites with results equal to or above the upper quartile of the data (highest values); the second position distinguishes the sites with results between the median and the upper quartile of the data (high values); the third position presents the sites with results equal to or above the lower quartile and below the median of the data (medium values); and the fourth position comprises the sites with results below the lower quartile (low values).

The sites that appear in the first and the second position were selected for the final list, since they hold a strong significance related to their high representativeness, geomorphological diversity and exemplarity for educational activities. Consequently, one site of the Va group (s02) and two sites of the Vb group (s04 and t08), which are in the fourth position for this criterion did not have sufficiently high values to be selected; otherwise, one site of the Vc group (t14) attained a result above the scientific value median, so it was selected. The sites in the fourth position by the results of the added and use criteria were not considered for the final list (for instance t09). The results of the protection criteria specified low, moderate or strong limits for the potential uses. After this analysis, nine sites (Table 4) were chosen as key resources for rural sustainability.

Statistics	Sv	Av	Uv	Pv
Lower quartile	2.75	2.63	4.50	2.00
Median	3.00	3.75	5.00	2.50
Upper quartile	3.50	4.00	5.87	2.50

Tab. 3: Statistical position measures of the data. These robust measures are selected as thresholds for the final valuation of the sites regarding scientific (Sv), added (Av), use (Uv) and protection (Pv) values
Source: authors' elaboration

5.3 Interpretation and significance for rural sustainability

Assuming that "rural development and environmental sustainability go hand in hand" (OECD, 2016, p. 30), the geomorphological sites may support initiatives which attract population and talent for a smart, sustainable and inclusive growth. But the definition of these territorial assets as key resources for sustainability and development requires knowing their use and management options under particular conditions. The potential to generate territorial advantages comes from a suitable preservation, use and management of these territorial assets. Likewise, the capacity to embrace different activities directly engaged in the environment or in its management – denoted by Courtney et al. (2006), the core activities and dependent activities – must be highlighted. Nine geomorphological sites comprise the focal settings for planning development strategies in the Larouco Mountain and the surrounding rural lands. They integrate the key geomorphological resources in order to propose tourism, leisure and educational priorities for territorial planning, encompassed in the local and regional scales.

The characteristic landforms assemblages of the selected sites are tied to granite deformation, alteration, weathering and erosion processes, together with the presence of water (Fig. 7). The local names express their dimensional and dynamic features: *pedra* or *pena* (castle rocks); *pico* (peak); *alto* (plain); *regata* (small stream); *corgo* (torrent); *turfeira* (peat bog); and *fonte* (spring). Other attached terms from the Galician language such as *dos cabalos* (of the horses), *da mina* (of the mine), and *muller* (woman), are indicative of the uses, legends or appearance of the sites. The SE slope of the Mountain appears as an empty sector of inventoried sites. This fact can be explained by the difficult accessibility and very low possibilities of observation. These conditions also determine the lack of mentions in books, papers and other scientific publications and the low use/management potential.

In the SW summit area (Montalegre municipality in Portugal), the selected sites show significant examples of the granitic landforms. The main values are related to their geomorphological and cultural diversity, their exemplarity for all educational levels and aesthetical interests (with panoramic views on the surrounding valleys of the Cávado, Limia and Támega Rivers). They have very good

Setting	Code	Local denomination	Sv	Av	Uv	Pv
SW summit	t01	Larouquinho	3.50	4.25	6.50	2.00
	t02	Larouco Cumbre	3.00	3.25	6.50	2.50
	t04	Pico Larouco	3.75	3.25	6.50	2.25
	t05	Fonte Pipa	3.75	4.25	6.50	2.00
	t06	Alto da Veiga	3.75	4.25	5.75	2.50
W slope	s03	Regata dos Cabalos	3.50	4.00	5.75	2.00
	s08	Corgo da Mina	3.50	4.00	5.00	2.00
NE summit/slope	t14	Pena Muller	3.25	3.00	5.00	2.50
	s11	Pedra Redonda	3.00	4.00	5.75	2.50

Tab. 4: Final selected sites with components of geomorphological (Gv) and use/management (Mv) values. The scientific (Sv), added (Av), use (Uv) and protection (Pv) values are detailed
Source: authors' elaboration

conditions for observation, visibility and accessibility, with possibilities for bus parking at the Larouquinho site (t01). Accommodation and services are available less than 10 km away, but these sites present moderate to high deterioration. The present uses focus on outdoor recreation and sports (paragliding and hang gliding), for which the Larouco Portuguese summit represents a national and worldwide reference (Taça Luso-Galaica, World Championship). The whole area may be suitable for scientific, educational and socio-economic uses (recreation and nature-based tourism), considering the necessary safeguarding of the landforms.

Both Regata dos Cabalos (s03) and Corgo da Mina (s08) are located on the Western slope of the Larouco Mountain, belonging to the municipality of Baltar in Spain. Their block fields obtain high rareness rankings, since they are singular landforms not only in the study area but also in the regional context. These sites are mentioned in scientific publications which deliberate the magnitude of the glacial events in the north west of the Iberian Peninsula (e.g. Vidal-Romaní et al., 2015). The assessment of these sites denotes medium geomorphological diversity; nonetheless, their ecological (presence of native forest), aesthetic (appearance and panoramic views), and cultural values (legends of treasures and the maintenance of traditional uses) are prominent. The two sites have good observation conditions and present a good conservation degree. The difficulties of access and vulnerability caution their scientific and educational uses, the latter restricted to baccalaureate and university levels. These proposed uses must look at geo-conservation strategies to manage them.

Other two selected sites are located in the municipality of Cualedro (Spain), in the NE mountain sector. Pena Muller (t14) and Pedra Redonda (s11) rely on very high geomorphological diversity. The contrast in shape and appearance and the panoramic views on the Limia and Tamega valleys offer aesthetic interest. The first site shows singular forms related to strong erosion processes which receive particular names (by their resemblance with animals or people), and also preserve the stone altar to celebrate the Larouco god pilgrimage. The latter, strongly rich in added interests, represents a sheet structure diversified by micro forms (tafoni and gnammas). Both sites have good observation conditions and easy accessibility by jeep or car, though the approach to them must be by walking; the

Fig. 7: Examples of landforms from the selected geomorphological sites: a) Pico Larouco; b) boulders and c) tor in Larouco cumbre; d) weathering profile in Fonte Pipa; e) view of the SW summit landscape; f) pseudobedding and g) gnammas in Larouquinho; h) block field in Corgo da Mina; i) singular landforms in Pena Muller; j) Pedra Redonda site with k) tafone and l) very developed gnammas
Source: Photos by M.C. Cuquejo-Bello

accommodation and services proximity is less than 20 km away. They are suitable for scientific, educational (secondary, baccalaureate and university levels) and leisure uses.

So, the Larouco Mountain retains the legacy of the landforms evolution and landscape dynamics. The selected sites include information on endogenous processes, exposed across the discontinuities of the rock (pseudobedding, polygonal cracking and sheet); furthermore, they provide remarkable examples to understand the granite weathering processes (corestones and grus in a weathering profile), and the landform features through broader dimensional scales (gnammas, tafoni, boulders, tors, block fields, castle rocks, plains and bedrock channels). In the neighbouring protected Mountains of Portugal, similar landforms have been assessed as significant components of the landscape (e.g. Pereira et al., 2015). In the Mountains of the Czech Republic, the aforementioned study cases (Section 4: Methodology), as well as recent contributions (Rypl et al., 2016) state the significance of these landforms as singular features which need to be protected. An important value of the Larouco Mountain is related to its significance for Quaternary research. The sites portrayed by Schmidt-Thomé (1978) as cirque-like niches are located in Fonte Pipa, Alto da Veiga, Regata dos Cabalos and Corgo da Mina, but the abundance of the minor rock basin cavities indicate the absence of glaciation. In the last two places one can find block fields that represent periglacial inheritances. The identification of these landforms brings new evidence for knowledge of the Quaternary processes in the Galicia region – North of Portugal Mountains.

The preservation of these characteristic landscape features has an important public interest since they express the diversity of our common heritage (Council of Europe, 2006). The case study is situated between two protected areas (Fig. 1a): the transboundary Biosphere Reserve of Gerês-Xures (to West) and the Montesinho National Park (to East), where the granitic landforms are promoted as landmarks. The results of this study show that the Serra do Larouco has geomorphological values which justify its protection, as a part of the territorial identity of the Galicia – North of Portugal border. Furthermore, given the results from the use and management indicators, the selected sites may be defined as a set of potential geomorphosites, bridging the gap in environmental protection and the territorial development of this Spanish-Portuguese border. Currently, there is a clear imbalance between Galicia and the North of Portugal, both sharing the study area. In Portugal, territorial management has a strong interpretative imprint led by the activity of the Ecomuseo do Barroso (Montalegre), promoting cultural and rural tourism; in comparison, in Galicia, there is little knowledge of this mountainous space and only isolated initiatives of outdoor recreation and rural tourism are promoted. The recognition of the integrated values from nature and culture at the local scale could diversify and sustain initiatives for balanced rural development in this cross-border mountain.

Geomorphosites might become drivers of sustainable growth involving the relationships between people and place (McGranahan et al, 2011). The main challenge to connect global and local strategies, across well-managed geomorphological sites, is to make "geodiversity relevant to people, where they live and how they live" (Prosser et al, 2011, p. 341). In the European cross-border Mountains, relations based on cooperation are the main scenarios to reinforce links between nature conservation, socio-economic development and people well-being. This framework encourages institutional collaboration, always including education and public awareness, a territorial process fostered above all in the sites that remain 'hidden' for managers (Matthews, 2014). The Galicia-North of Portugal European Grouping of Territorial Cooperation (GNP-EGTC) was established in 2010 as an institutional framework in light of the global and European situation. The objectives of their joint investment programme 2014–2020, based on the territorial sustainability principle, are addressed to improve the shared management of the human environment and to consolidate the common identity. A strategic line, defined as "protection and effective use of the territorial resources", is focused on the increase of cross-border attractiveness and the planning of nature-based tourism. But specific guidelines for inland mountainous areas, related to their environmental values, are unclear. The foremost difficulties for the management of this shared territory concerns the different government systems in Portugal and Spain (Oliveira, 2015). In the North of Portugal, the policy decisions depend on the national government, while Galicia is an autonomous community where determinations hinge on the regional government.

In the context of regional development, the case study and its surrounding area embody the situation of mountainous and rural inland territories in the North of the Spanish-Portuguese border. Local population density is far below the population density of Galicia (93 inhab./km^2) and the North of Portugal (112 inhab./km^2). At present, the main threats at the Larouco Mountain are depopulation, land abandonment and deliberate fires. On the other hand, the main strength is represented by the landforms and landscape significance that evince diverse potentials for sustainable development. Besides this, the existence of an old cross-border identity can be the support for inclusive and smart relationships. The remoteness from the urban coastal settlements, the scarcity of innovation and the poor knowledge of this mountain are undoubted weaknesses for rural development, but sustainable management of their shared geo-resources, which keep the outstanding values, can enable the prompt opportunities by the regional, European and global institutions. Such a change, however, entails a more meaningful involvement of the institutional and social actors in the territory.

6. Conclusions and future research agenda

The inventory of geomorphological sites reveals the diversity of granitic landforms in the Serra do Larouco, which remains little known outside the area. Their assessment reflects several types and degrees of significance in other granitic terrains. The granitic landscape of the study area holds interesting landforms assemblages, although it lacks legal protection. The study area keeps a record of the origin and evolution of the relief in the Galician-Portuguese border. The association of the minor landforms with endogenous structures and the spatial distribution of the macro landforms reflect the control of the rock discontinuities patterns in the genesis and evolution of granitic relief. Landforms are polygenetic, developed by differential processes of weathering and erosion: the last stage in the landforms development relied on the action of periglacial processes during the Quaternary.

The categorisation and characterisation of landforms through the sites assessment provides specific information about landscape features. The method applied in this research allowed us to know the main interests and values of the inventoried assets, helping the comparison not only with other areas located in the South of Galicia (NW Spain) and the North of Portugal, but also with other works in the European territory. Both the characterisation and the qualitative and quantitative analysis of the data establish a set of values which are connected with the identity and function of the territory. As the research achieved in the Portuguese territory indicates, however, it is important to take into account that the variability of the rareness scores is always related to the selected spatial scale. The application of statistical exploratory techniques provides significant results on the data centrality, dispersion and variability, which give support to analyse and explain the assessment results. The summary statistics and position measures limit subjectivity in the interpretation, and make both the understanding and selection of the outstanding sites easier.

In view of the geomorphological and management values of the sites, their preservation is encouraged. It should be addressed to bridge gaps in geo-conservation and other environmental or socio-economic policies that affect rural sustainability of the border area. Proposals for sustainable use and management of such potential geomorphosites endorse several options with respect to planning development strategies. The selected sites symbolise the landscape key resources to sustain local populations, attract new residents or visitors, and improve current territorial conditions. These sites hold important assets which must be recognised and be valued by different stakeholders of the territory.

Consequently, further advances of the present research need to study more deeply the perception and prospects of the main territorial actors in a local and regional context. Moreover, the suitable outreach of the meaningful results from this study is crucial. Due to the symbolic identity of the Serra do Larouco, both in the context of the European border regions and the Spanish-Portuguese border, the forthcoming research will also be focused on the shared environmental policies by the institutional agencies.

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