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Sustainable Evolution of the Geographic System in the Regional Park "Carrascoy y El Valle" in the Region of Murcia (Southeast Spain)

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Abstract: The region of Murcia, located in the southeast of Spain, has historically been affected by deforestation and desertification processes that favour natural risks, sometimes ending in tragic personal consequences. To address this, at the end of the 19th century an ambitious plan was launched to reforest the mountains in the most problematic river basins. This article aims to study the changes experienced in the geographic mountain system "Carrascoy y El Valle" after reforestation, and their effects on different environmental processes. Two areas were selected to compare the evolution of the tree cover, using photographs from 1928 and current satellite images, and small grids were designed to analyze the current herbaceous and shrub cover. The results show a significant increase in tree cover in parallel to the mulch cover, which was higher in the shady than in the sunny orientation. The distribution of the herbaceous and shrub cover was irregular and unexpectedly higher in the sunny than in the shady areas, probably due to intensive trampling in the shady areas. Overall, the evolution of the geographic system "Carrascoy y El Valle" has been sustainable, with favourable effects on the ecosystem, erosion, landscape, and climate conditions, thus slowing down desertification.

Keywords: geographic system; sustainable evolution; reforestation; desertification; climate change

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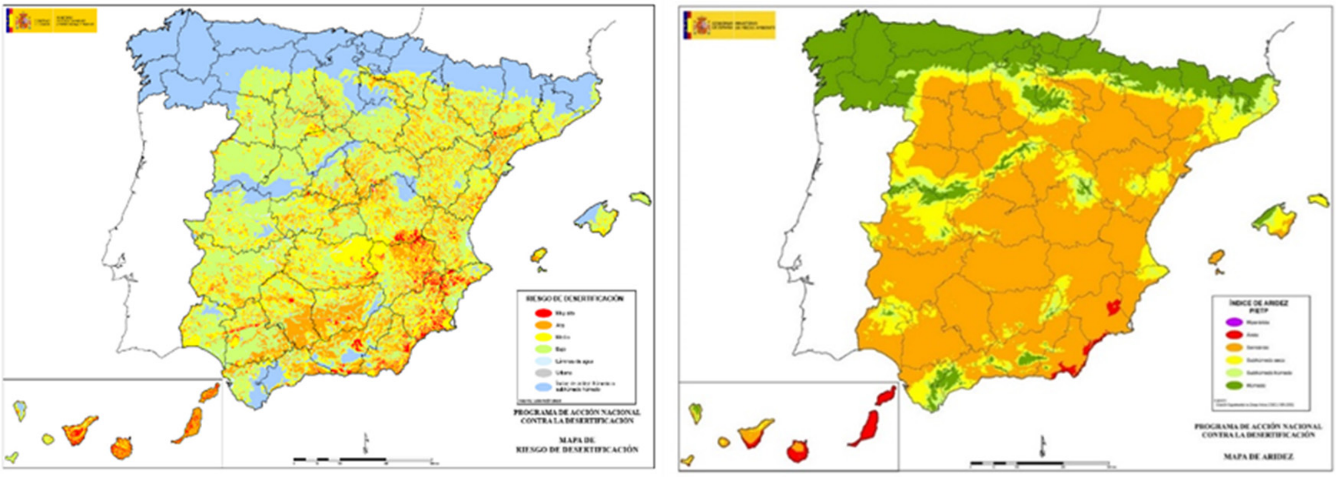
1. Introduction

More than 40% of the planet's land surface is at risk of desertification. In Spain, the Canary Islands and the Mediterranean region are the areas with the highest risk of desertification [1]. The region of Murcia, in the southeast of the Iberian Peninsula, is one of the most arid areas of peninsular Spain, and a large part of it is at medium to very high risk of desertification (Figure 1).

It is widely accepted that Earth's ecosystems provide a range of benefits to humankind, known as ecosystem goods and services [2]. Natural ecosystems, as part of the Earth's ecosystems, provide goods and services that are referred to as ecosystem services, and include the multitude of benefits that nature provides to society. It should be noted that forestry benefits from and in turn provides ecosystem services, by influencing the climate, facilitating the storage of carbon, moderating extreme events, and preventing erosion [3]. As part of the natural space in the region of Murcia, the Mediterranean forests fulfil ecosystemic functions, and some are protected by legal and administrative regulation such as Regional Park status. The forest systems of the region of Murcia can be seen as socio-ecological systems or socio-systems within the framework of what could be called eco-services [4].



(**a**) (**b**)

Figure 1. Map of (**a**) desertification and (**b**) aridity risk in Spain. Source: Spanish Ministry of Ecological Transition (MITECO) (2022) [5].

Furthermore, soil degradation, desertification, and deforestation are closely related to climate change [6]. When desertification, a natural process that brings us closer to desert conditions, is combined with human action, critical situations are reached that favour the establishment of deserts in certain territories, making it one of the main environmental challenges of the present time [7]. Deforestation or afforestation could favour or slow down the advance of the desert, while the acquisition of knowledge through scientific research provides effective solutions to situations of desertification [1].

The reforesting initiatives in the region of Murcia began 160 years ago. In 1862, the Murcia City Council asked the Spanish Central Government to reforest the mountains it owned, including "Sierra de Carrascoy" [8]. A tragic event with a thousand deaths, the floods of 1879 in the Segura river basin led to the establishment of the "Congress against the floods in the Levante region", which promoted reforestation in the Segura river basin [9].

In the associated regulations that were implemented in 1888, priority was given to the reforestation of several areas, including the "Guadalentín Basin" or "Rambla de Sangonera" [10], a basin into which a large part of the "Carrascoy and El Valle" Regional Park discharges water. Between the end of the 19th century and the beginning of the 20th century, important reforestation action was performed in the mountains of the region of Murcia, beginning in Sierra Espuña [11]. From the 1960s onwards, massive reforestation took place, radically changing the landscape in the Regional Park "Carrascoy y El Valle". Successive uses, such as agricultural, livestock, and forestry, have been transforming the previous systems in terms of structure and processes. In addition, the Regional Park "Carrascoy y El Valle" has increased over time the number of protected statuses granted. The reasons for this are its diverse environmental values, consequences of the changes in systems since it was included in the National Catalogue of Natural Spaces in 1917, specifically in the area of the "El Valle" mountain [12,13]. All these attempted reforestation actions met with adverse conditions that prevented their practical implementation at first, including the need for expropriation of privately owned land, since some public or collective lands were sold by the Ministry of Finance at auction in cases where technical forestry criteria were not met [11].

In Aristotle's Greece, in pursuit of objective knowledge of reality, reflections emerged on the interaction of real objects and how their behaviour manifests in a totality. This led Aristotle to affirm that the whole is more than the sum of its parts [14]. This would be a systemic view of things. However, in more recent times, in the framework of General Systems Theory, it is affirmed that there can be general laws of systems applicable to any system regardless of the particular properties of the system or of the participating elements [15]. In short, we are faced with a "whole" that expresses an aspect common to all systems.

A system is seen as a set of dynamically interacting elements hierarchically organised for a purpose [16]. Other authors state that it is something that bases its existence and functions as a whole on the interactions of its parts [17]. A system can also be defined as the combination of components acting together to achieve a specific goal [18], or as a complex object whose parts or components are related to at least some other component [19]. Nevertheless, systems are characterised by interaction, globality, organisation, and complexity [14]. The General Systems Theory defines systems as a complex of interacting components, including concepts characteristic of organised totalities, such as interaction, summation, mechanisation, centralisation, competition, and purpose, and applied to concrete phenomena [20].

Geography has not been traditionally alien to the systemic approach in its field of knowledge. However, from a modern perspective, geography can be included among the sciences that deal with the study of the earth's surface and the interrelationships present, sometimes even using the theoretical and methodological perspective of the General Systems Theory [21]. Espinosa [22] affirms that geographic and geomorphological studies are based on a systemic and holistic basis of reality. In the 1960s and 1970s, systemic analysis underwent rapid diffusion in the field of physical geography [23]. Bertrand [24] proposed a new purely systemic physical geography. From the mid-twentieth century to the present day, one of the fundamental characteristics of geography is the coexistence of a growing number of approaches, among them the systemic geographical approach, based on General Systems Theory [25].

On the other hand, the territory, a field of study of geography, contains, among other things, a geological substratum and biota in their natural forms and also in those that have been modified by human activity. Cerdán [26] calls this the territorial matrix or, as it is called by geographers and naturalists, the biophysical matrix. Furthermore, the territory is seen as a system formed by a set of subsystems placed on the territorial matrix, which represents a systemic view.

Approaching the knowledge of the earth's surface and its phenomena, we find a series of important elements. These territorial elements can be assimilated into the parts or components of a system. We also encounter physical, biotic, and human facts that occur on the earth's surface. These facts are studied by several sciences, among them geography, which adopts a holistic point of view. Territorial elements are perceived as integrated into sets or combinations, receiving the generic denomination of geographical facts. Geographical facts are combinations of biotic, abiotic, and human elements occurring on the earth's surface, which differ from each other in composition, nature, structure, appearance, and ways of acting. If the constituent elements of the geographical facts interact with each other to form a whole, we are dealing with a system [21], in which it is essential that all the elements are related to each other [27], and they must contribute to a specific aim [28]. It should be noted that where geographical facts exist, there are geographical systems [21].

In Rosnay's definition of a system [16], dynamism is explicated as one of its most important characteristics. Ogata (1988) [18] attributes dynamic connotations to the system, as consequences of its outputs and inputs. According to Flórez and Thomas [14], one of the fundamental aspects of systems is evolutionary, since the structure of a system is not static. Indeed, the complexity of a system is directly related to its evolutionary character. The dynamism of the elements of the system is considered by referring to the thresholds or limits of the system. Among the essential features of any system, its functioning has the character of a process, so that when it enters into contradiction with the structure it provokes changes and/or renovations in the structural elements, which translate into the qualities of a new order [29]. In short, due to their dynamism, systems show a changing and evolving character, especially those referred to as open systems..

The use of the systemic approach allows the description of open, dynamic, and evolving systems, where there are exchanges of energy and matter. Therefore, these open systems can be described as geographical, and the transfer of energy and matter makes them dynamic in their processes and thus in their structures. Such changes in systems can have an endogenous and/or exogenous origin. It should be emphasised that knowledge about these geographical changes has been increasing, leading to important progress and advances. Ultimately, geographical knowledge has been an inseparable part of the development of societies [25].

The area of study on which this work focuses involves natural and semi-natural media, and both can be described as open systems where the inputs and outputs of matter and energy contribute to a dynamic situation [30]. Dynamic relationships represent a series of inputs of energy and matter that are incorporated into the system where a number of actions are produced. These include the energy and matter being transformed and/or stored, while parts can leave the system (outputs) in the form of energy, matter, and even heat [31] (Figure 2).

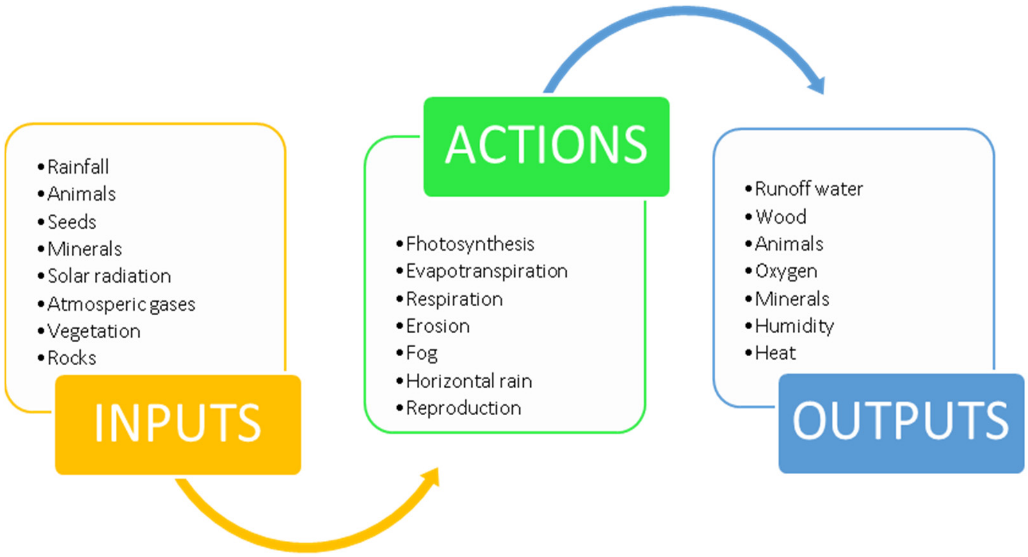


Figure 2. Diagram of the functioning of an open system. Source: Christopherson & Birkeland (2018) [31].

As for the term geosystem, it was first used in the framework of General Systems Theory by V.B. Sochova in 1960 [32]. The concept of geosystem can encompass the terms natural system and/or geographical system. The latter is defined as a natural system at a local or global level in which inert and living elements are interconnected by exchanges of matter and energy in a single whole [30]. Its link with geographical approaches is justified by considering the geosystem as a homogeneous natural geographical term linked to a territory, a spatial unit well delimited and analysed at a given scale [32], which represents the basic natural element of the system [33]. As the geosystem is considered a homogeneous natural geographical system linked to a territory [34], the geographer Bertrand proposes its use as a conceptual tool for the development of a new purely systemic physical geography [14].

According to De Bolos and Gómez [30], there is a relationship between landscape and geosystem. They state that the scientific definition of the landscape is that of a geosystem located in a specific space and time, considering that the only model of the landscape is the geosystem. Furthermore, it is very important to consider the landscape as a functional system in permanent movement, involving flows of matter, energy, and information. This systemic and functional character means that ecology plays an important role in the study of the landscape, especially in relation to its structure, configuration, variability, and the arrangement of its constituent units (tesserae). Ecology shares with other disciplines an interest in the morphological, structural, and chorological dimensions of the landscape. In fact, ecology's systemic view of the landscape is more concerned with the relationships between structures and processes than with classification [35].

The evolution of the geosystems in the Regional Park "Carrascoy y El Valle" can be assessed with the application of indicators, as suggested by Terrer et al. [36], for the natural areas of the region of Murcia. These indicators can be used to identify changes in the state of the geosystem over a given time, such as changes in its morphology and in its horizontal (geofacies) and vertical (geohorizon) spatial structures [34].

In order to understand the inputs, processes, structures, and outputs of a system, specific information is necessary according to the objectives set. To obtain this, it is interesting to resort to geographic information systems (GIS), which allow researchers to represent and manage data on certain aspects of the real world [37]. These are characterised by the capacity to integrate double aspects of geographic information, spatial and relating to attributes [38], facilitating the management and analysis of spatial information [39]. One of the main advantages of GIS is the access to remote sensing images [38], which do not require physical contact with objects and are acquired by different aerial navigation vehicles, some located in the upper or even outer atmosphere [38]. These so-called aerial images includeall types of images taken from the air, regardless of the procedure for capturing them [40].

The main objective of this work was to study the evolution of the geographical system of the Regional Park "Carrascoy y El Valle" between the beginning of the 20th century and the present day. Indeed, knowing the evolution of natural, forestry, or geographical systems is a matter of social, academic, and scientific interest, due to the effects that they may have on climate change and desertification. Likewise, information can be obtained to establish improvements in management, and therefore in decision making with respect to the sustainable geographical systems of the Regional Park "Carrascoy y El Valle".

2. Materials and Methods

2.1. Study Area

The area of this study corresponds to some of the existing systems in the territory of the Regional Park "Carrascoy y El Valle", which constitutes a geographical system made up of other smaller systems (Figure 3).

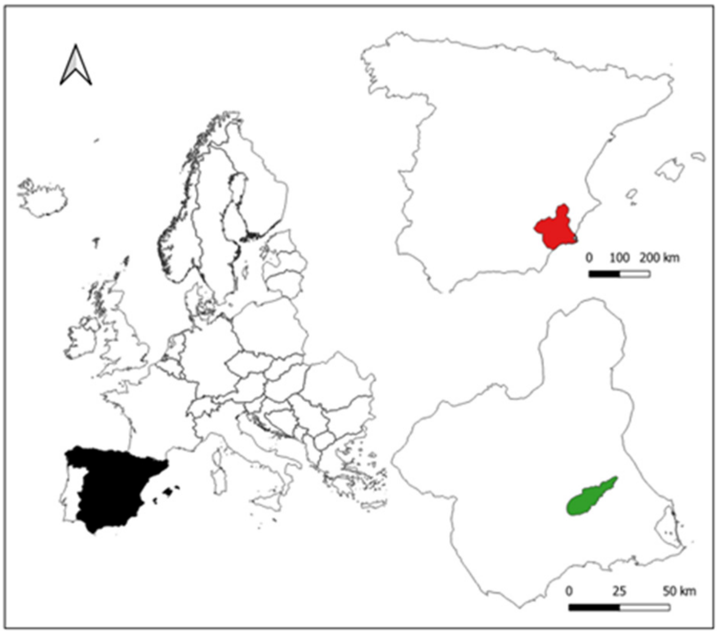


Figure 3. Location of the Regional Park "Carrascoy y El Valle", region of Murcia.

From among the set of systems with geographical interest present in the study area were chosen those that shape the land surface or geographical space in one way or another.

This study focuses on current forestry systems, intending to reveal the consequences of particular actions that are very important for the territory where they occur, such as reforestation [21]. Two analysis zones were selected, one in the "El Olivar" area of "El Valle" mountain and the other one in "Castillo del Puerto" and "Puerto de la Cadena" (Figure 4).

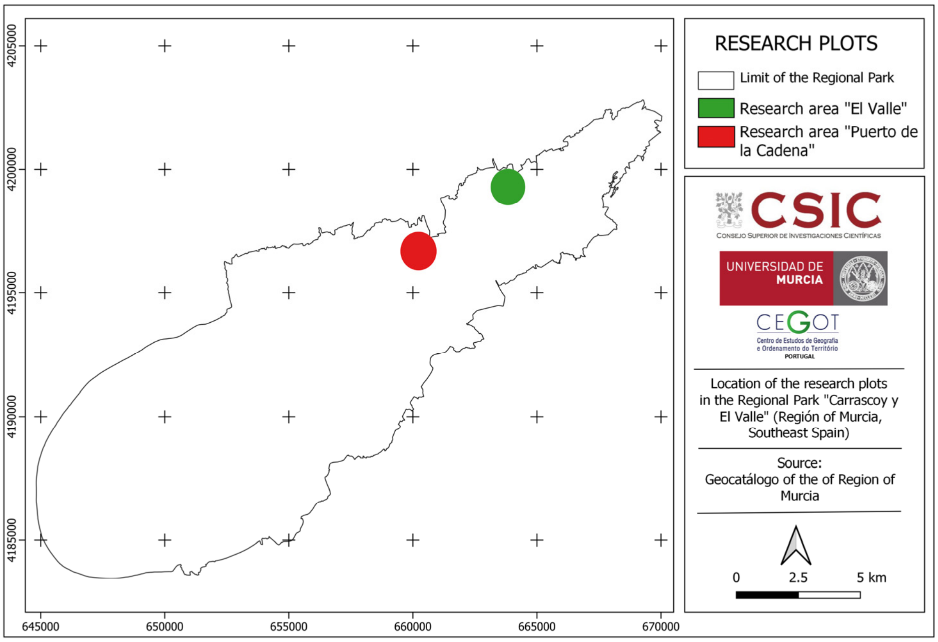


Figure 4. Location of the research plots.

Anthropic action in the study area led to the establishment of crops based on fruit trees, introduced by the owner to exploit the existing resources (soil, topography, etc.), and disappearing with changes of ownership, from private to public, and function, from exploitation for economic purposes to wild crops with social interest above their economic value.

The altitude of the study area ranges from 77 m in La Alberca to 515 m in El Puerto de la Cadena. The slopes vary from 31.5% in the area of the Castle and the Puerto de la Cadena watercourse, contrasting with percentages of 2.23% in the Olivar del Conde, although some slopes in the vicinity reach 25%. There are predominantly slopes with high-percentage gradients, leading to a rugged relief. This conditions the hydrographic network, along with a rocky terrain based on sedimentary materials (soft rocks), a rainfall regime characterised by torrential rain, and the presence of scarce vegetation in past times, giving rise to a dense hydrographic network based on a multitude of ephemeral watercourses (gullies, ravines, and some streams). The hydrological regime is defined by the absence of water in the riverbed, with moments of a massive presence of water reaching a height of up to one meter in the lower course.

Average annual rainfall is around 300 mm/m^2, reaching 320 mm/m^2 in the highest altitude areas. Average annual temperatures range from 17 °C in the lower areas to 16 °C in the higher areas. Frosts are practically non-existent, sometimes occurring in the depressions formed by the lower courses of the riverbeds.

The potential vegetation of the study area consists of rosemary (*Rosmarinus afficinalis*), mastic (*Pistacia lentiscus*), prickly gorse (*Calicotome spinosa*), and carob (*Ceratonia siliqua*), among others. To these species, we can add the Aleppo pine (*Pinus halepensis*) as some specimens had been found prior to reforestation.

The study area is located in the generally arid climatic framework to which the region of Murcia is subject, characterized by its presence in one of the driest areas of the Mediterranean climate. The southeast of the Iberian Peninsula is subject to a general regime of westward winds, which in their course through the peninsular continental mass arrive with little humidity in the region of Murcia. Once the westward winds overcome the southeast, upon contact with the Mediterranean in the Gulf of Valencia, they become charged with humidity again, which rarely precipitates in the region of Murcia due to the presence of neighbouring mountain reliefs located to the east.

Despite the significant aridity and low rainfall, it is surprising to see the vegetative development that forested areas in the region of Murcia have experienced over time, especially in the study area, given the higher water requirements of forest trees compared with shrub forests. This potential capacity for forested vegetation growth makes the study area an interesting geosystem to be investigated.

Originally, the land was forest until it was depleted. Part of it was devoted to agricultural activity, which was mainly settled in the less sloped areas (olive groves, cereals, and almond trees), although certain crops were located on some slopes (almond trees), and subsequently the land has been used for forestry until the present day.

2.2. Methodology

The design of this research is framed within the so-called longitudinal trend design, defined as those studies that analyse changes over time within a general population [41]. In relation to the scale of the system, in the case of physical geography, several orders of magnitude can be observed, from the global to the molecular level. The choice of the level is arbitrary, i.e., it can be considered from the whole of the earth's surface down to the smallest scale. The elements, their relationships, the flows of energy and matter, and certain processes determine the system of study. According to some authors this corresponds to a single model of the landscape, the geosystem. This facilitates the delimitation of the system, and therefore favours its spatial and temporal study, so that the spatio-temporal scale chosen will mark the differences depending on the focus of the analysis in question [20,30].

Specific territorial information was used to reveal how the selected areas have evolved after reforestation, extrapolating this to the global geographical system. Aerial and non-aerial photographs and satellite images were used. In the case of "Olivar del Conde-El Valle Perdido", the aerial photographs used were those of Ruiz de Alda's flight from 1928 and images from the PNOA from 2019, while for "Puerto de la Cadena-Castillo del Puerto", non-aerial photographs were employed from the periods 1958–2010 and 1963–2010, respectively.

The evolution of the system was studied using indicators, understood as a tool that shows signs or signals of a situation, activity, or result [42]. For this purpose, several variables were used, such as percentage of the area occupied by tree mass between two separate time periods, percentage of shrub and herbaceous mass, and the area covered by mulch (needles/leaf litter) at present. All these variables can be catalogued as discrete quantitative variables. With the support of GIS and field measurements, the values obtained allowed us to define characteristics and parameters to indicate the evolutionary changes that occurred in the study territory [43].

Regarding the "Puerto de la Cadena-Castillo del Puerto" plot, the estimation of the percentages of cover was carried out by the naked eye, comparing the photographs from the years 1928 and 2019. For the "Olivar del Conde-El Valle Perdido" plot, several actions and observations were carried out. Based on Ruiz de Alda's 1928 aerial images, and by comparison with the PNOA satellite images of 2019 at a resolution of 0.33 m, a map was drawn up in which the two situations can be visualised in parallel. Two enlarged areas were added to the graphic document, where the changes that occurred after reforestation can be seen in great detail. A complimentary map also drawn up to show the differences between the orientation and slope effects.

On the aerial photograph and the satellite image of the "Olivar del Conde-El Valle Perdido" plot, a net consisting of 77 grids was superposed, labelled on the abscissa axis using letters from A to K and on the ordinate axis using Arabic numerals from 1 to 7. The percentage of coverage in 1928 and 2019 was determined for each grid. With the information obtained, two double-entry tables were drawn up where the data were collected, one table per year, with a third table showing the annual increase. Additionally, 6 sample plots divided into 1 × 1 m^2 grids each were designed and randomly distributed, 3 in shady areas and the other 3 on the sunny side, in order to show in detail the plant mass cover (Figure 5). The percentage of surface area occupied in each grid by shrub and/or herbaceous plants, as well as the surface area occupied by mulch (pine needles, leaf litter, etc.) was determined. It was calculated taking into account the percentage of the area in each grid occupied by the two types of masses, then dividing the grids into smaller ones, through the visual appreciation of the researcher and/or contrast with others that showed total coverage or almost no coverage.

Figure 5. Detailed picture of the research plot disposition in the field.

3. Results

The comparison of the photographs of "Puerto de la Cadena-Castillo del Puerto" from 1958 and 2010 shows that the tree cover has reached almost the total area, with the exception of areas of the hill on which the castle stands (Figure 6). In a comparison of other pictures of the same area from 1963 and 2010, in addition to the spectacular increase in tree cover, there has also been a major change in the landscape, so the pine forest has hidden the laceration produced on the mountainside (Figure 6). On the other hand, in the area known as "El Olivar del Conde" on "El Valle Perdido" mountain, there was an increase in tree cover between 1928 and 2010. In this area, the cover is not total, although in some areas the tree density is very high (Figure 7).

In order to pinpoint more precisely the degree of tree cover in the study areas, a net of grids was designed for the "Olivar del Conde-Valle Perdido" plot (Figure 8). Tables 1–3 show the percentage of vegetation cover in 1928 and 2019 and the changes produced in the period between these two years. Grids indicated by the cells in grey were discarded as they were outside the study area. The cells highlighted in green refer to grids that were already covered with trees in 1928, probably Aleppo pine (*Pinus halepensis*), as the field study indicates. In brown colour are highlighted those grids located in areas of dry farming, mainly dedicated to the cultivation of olive trees (*Olea europea*), as indicated by the place name "Olivar del Conde" (in English: "Olive Grove of the Count"), although some areas were also dedicated to the cultivation of almond trees (*Prunus dulcis*) (Table 1). Cells marked in blue and numbers in bold blue are the grids that in 2019 presented plant cover equal to or higher than 90%, based on wild plant species with a predominance of Aleppo pine (Table 2). Finally, cells highlighted in yellow show increases in coverage close to 100% between 1928 and 2019. Only three grids, marked in red, presented a decrease in cover over the study period (Table 3).

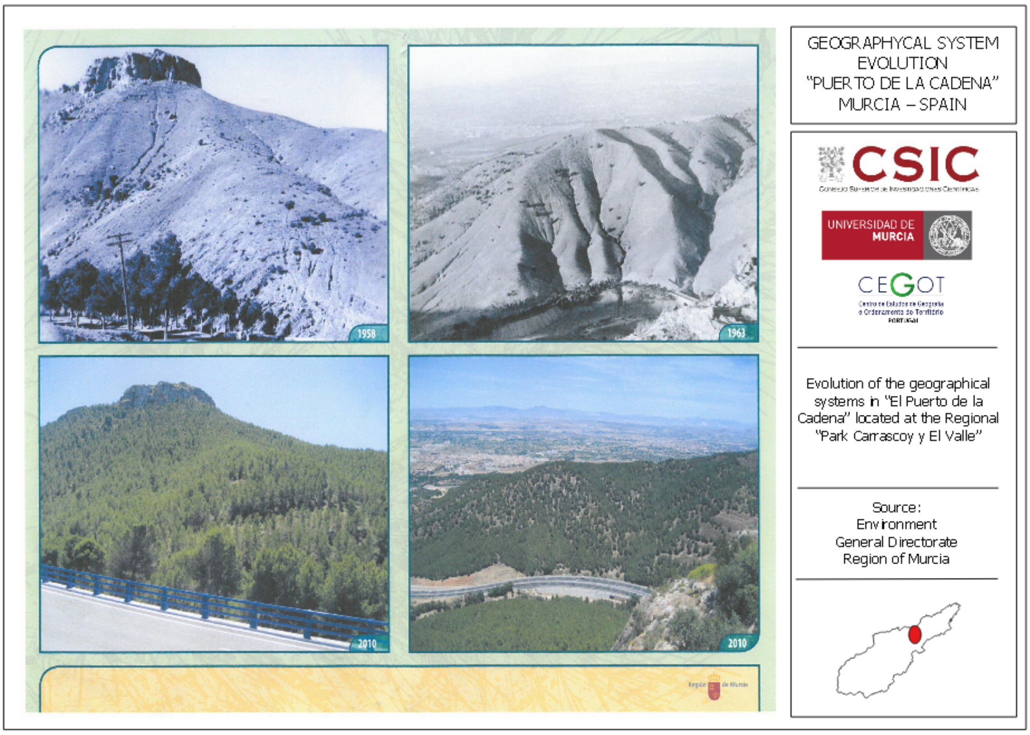


Figure 6. System evolution in the research plot "Puerto de la Cadena-Castillo del Puerto" (1958–2010 and 1963–2010).

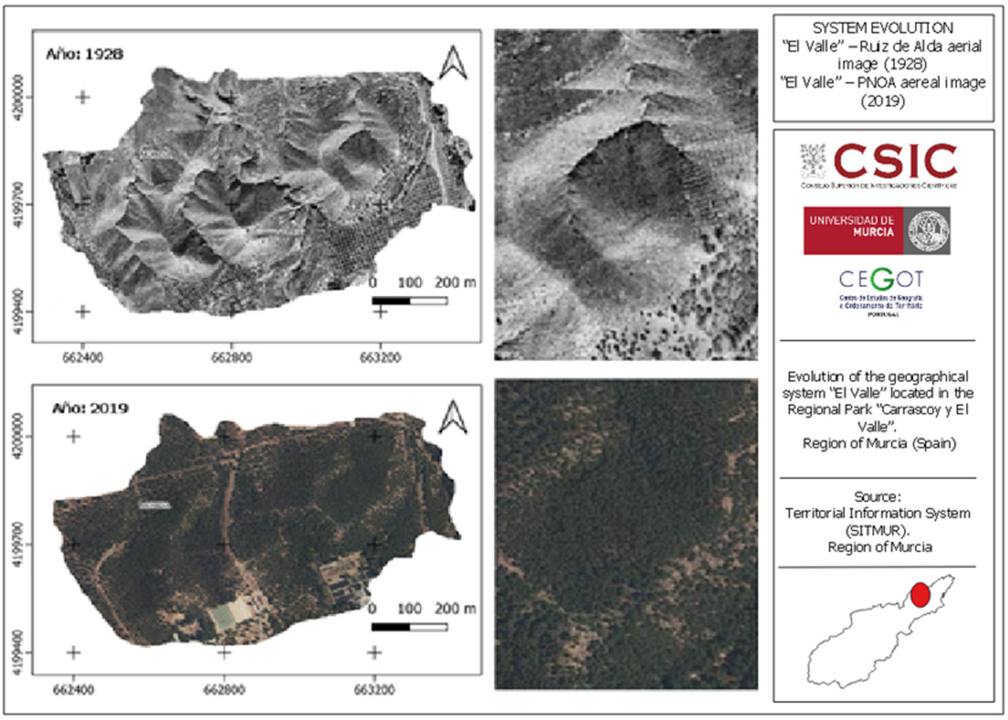


Figure 7. Evolution of the research plot "Olivar del Conde y El Valle Perdido" and detail of one of its parts (1928–2019).

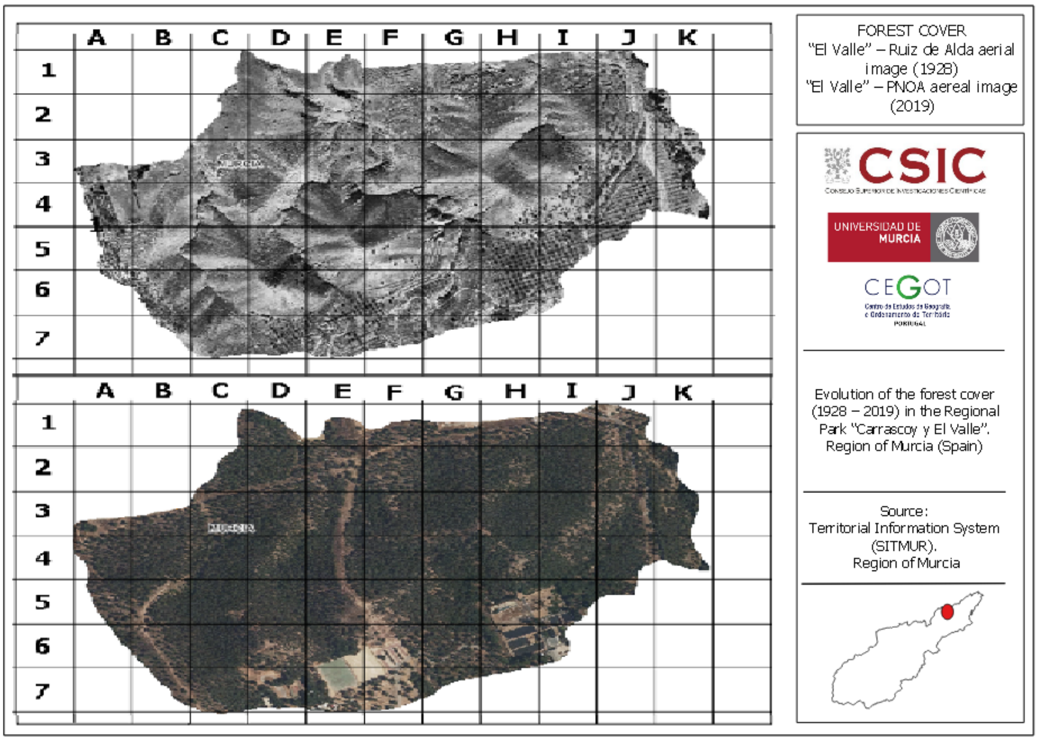


Figure 8. Evolution of the tree cover at the research plot "Olivar del Conde y El Valle Perdido" (1928–2019).

Table 1. Tree cover (percentage) in "Olivar del Conde-El Valle Perdido" (1928).

	A	B	C	D	E	F	G	H	I	J	K
1			0.5	0.5	0.3	0.4	0,5	0.5	0.5	0	
2			0.5	0.5	0.5	0.5	0.5	0.5	0.5	50	60
3	30	40	0.5	0.3	0.4	0.4	0.5	0.5	0.5	50	60
4	55	1	10	35	25	25	20	25	40	45	30
5	40	2	0.5	2	3	5	0	40	55	25	
6	50	25	15	1	10	5	2	25	20		
7		30	2	20	10	10	10	20			

Note: Forestry (green cells); agricultural (brown cells); out of the study area (grey cells). Source: own elaboration.

Table 2. Tree cover (in percentage) in "Olivar del Conde-El Valle Perdido" (2019).

	A	B	C	D	E	F	G	H	I	J	K
1			40	**90**	40	50	20	25	**90**	30	
2			**90**	**95**	60	80	**100**	**90**	**100**	60	70
3	40	85	85	**90**	75	**90**	**100**	**99**	**90**	85	**95**
4	80	**95**	**90**	**90**	85	**100**	**95**	**95**	**90**	**95**	**95**
5	70	75	**99**	**100**	85	80	**99**	30	50	**90**	
6	**99**	55	**100**	65	70	25	85	30	5		
7		50	85	25	25	10	70	90			

Note: Tree cover $\geq$ 90% (blue cells); out of the study (grey cells). Source: own elaboration.

Table 3. Increase in the tree cover (percentage) of "Olivar del Conde-El Valle Perdido" between 1928 and 2019.

	A	B	C	D	E	F	G	H	I	J	K
1			39.5	89.5	39.7	49.6	19.5	24.5	89.5	29.7	
2			89.5	**94.5**	59.5	79.5	**99.5**	89.5	**99.5**	10	10
3	10	45	84.5	89.7	74.6	89.6	**99.5**	**98.5**	89.5	35	35
4	25	**94**	80	55	60	75	75	70	50	50	65
5	30	73	**98.5**	**98**	82	75	**99**	**−10**	**−5**	65	
6	49	30	85	64	60	20	83	5	**−15**		
7		20	83	5	15	0	60	70			

Note: Coverage increase ≥ 90% (yellow cells); coverage decrease (red cells); out of the study area (grey cells). Source: own elaboration.

All the plots marked in green, which in 1928 had some type of forest cover, have increased their percentage of cover, some plots especially so (≥90%). In contrast, there was a decrease in vegetation cover in some plots (5H, 5I, and 6I) or little or no increase in others (7D, 7F, and 6H) due to the occupation of the land by service facilities within the protected natural space (forest nursery and recreational areas).

The shady–sunny effect resulting from the orientation of the reliefs from southwest to northeast determines higher humidity and lower temperature in the shady areas compared with the sunny areas. These climatic conditions influence vegetation density and plant development. In the study plots, it can be observed that in the shady orientation the cover does not reach 100 % but shows a higher cover index than in the sunny orientation (Table 4 and Figure 9).

Table 4. Shrub and herbaceous cover (in percentage) in "Olivar del Conde-El Valle Perdido" (2022).

Sunny Side				Shady Side			
Grid	**S-H**	**S-H**	**S-H**	**Grid**	**S-H**	**S-H**	**S-H**
6D	0	15	5	1I	0	0	0
	0	15	30		0	0	0
	20	10	10		0	0	0
6F	70	70	50	1F	15	50	30
	30	30	40		30	50	25
	15	5	10		70	45	70
4K	40	10	80	4B	0	15	5
	30	40	80		0	15	30
	30	15	10		20	15	10

Note: S (shrub cover), H (herbaceous cover). Source: own elaboration.

To study the effect of orientation on the understorey situation, 6 sampling plots with 9 grids of 1 m^2 were designed and distributed in different places within the study area. The data collected were the percentages of soil occupied by shrubs and herbaceous plants, as well as the existence of mulch. The results obtained show that the percentage of shrub and herbaceous species coverage was significantly higher in the sampling plots located in the sunny ($\bar{x}$ = 28.15%) than in the shady ($\bar{x}$ = 18.33%) area (Table 5). Furthermore, mulch cover was 100% in all subplots located on the shady side, while in one subplot located on the sunny side the mulch cover was lower (5–25%) (Table 6).

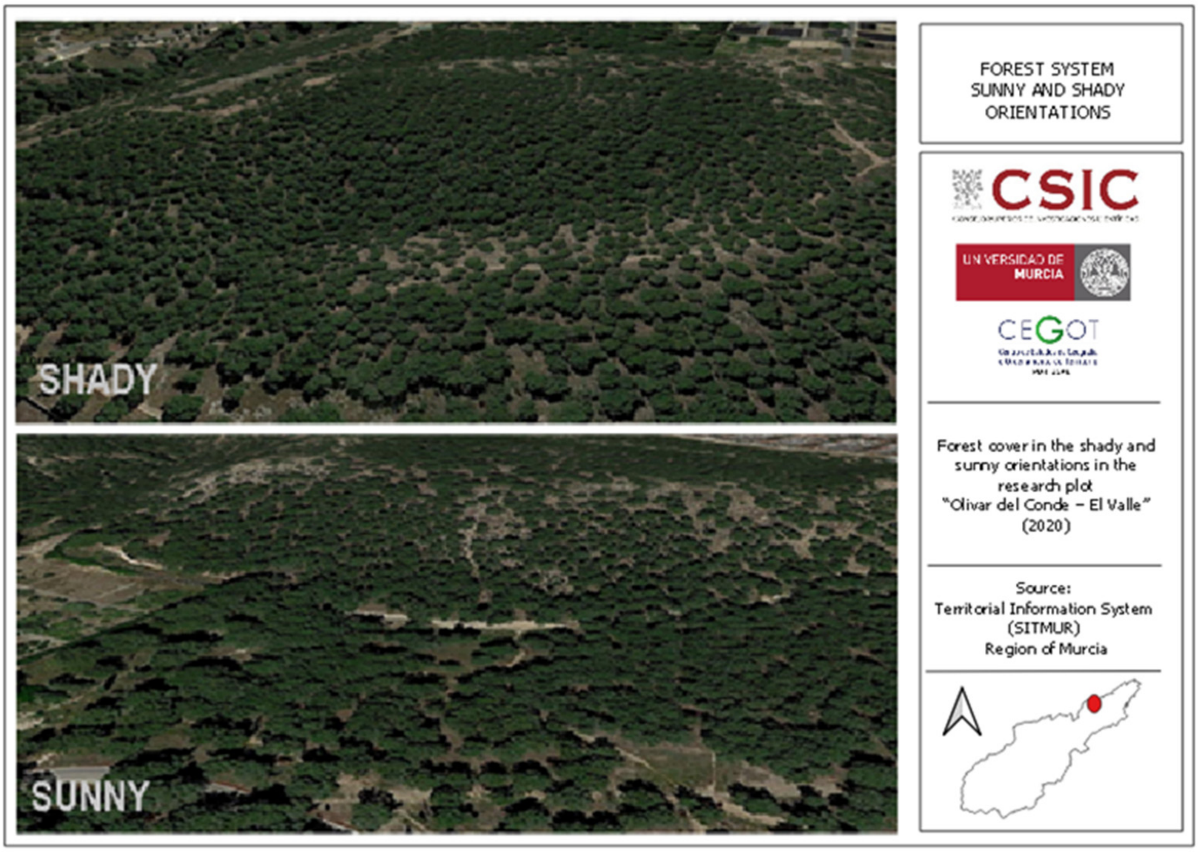


Figure 9. Partial aerial view of the research plot "Olivar del Conde-El Valle" from different orientations (2020).

As a consequence of the hydrological forestry corrections carried out in the study area, as well as the erosive effects of water, the hydrological regimes have been modified. The hydrographic distribution would have been very different without this type of correction, such as the transit of water through riverbeds in the "Rambla del Valle" (Figure 10). Indeed, a heavy rainfall episode occurred in 2019 in southeastern Spain, which registered 196.60 mm/m^2 between the 11 and 14 September at the La Alberca weather station in the lower reaches of the watercourses of the study area [44]. On 25 September 2022, a new episode of heavy rainfall resulted in 42 mm/m^2 in 15 min, of which 30 mm/m^2 precipitated in 10 min at the El Relojero thermo-pluviometric station at the head of the study area, representing rainfall intensities of 168 mm/m^2 and 180 mm/m^2, respectively [45]. This rainfall of 42 mm/m^2 caused an accumulation of 45,000 m^3 over the 1.5 km^2 (1,500,000 m^2) of the study area, exceeding the absorption capacity of the forest system, which was forced to expel the excess volume of water with consequent risk to the nearby population (Figure 10).

Table 5. Statistical values of the shrub and herbaceous cover in the sunny and shady areas of "Olivar del Conde-El Valle Perdido" (2022).

Statistic Value	Shadyside	Sunnyside
Mean	18.33	28.15
Standard deviation	6.05	4.07
Variance	17.99	11.67
Variation coefficient	0.98	0.41

Source: own elaboration.

Table 6. Mulching cover (in percentage) in "Olivar del Conde-El Valle Perdido" (2022).

Sunny Side				**Shady Side**			
Grid	**M**	**M**	**M**	**Grid**	**M**	**M**	**M**
6D	100	100	100	1I	100	100	100
	100	100	100		100	100	100
	100	100	100		100	100	100
6F	100	100	100	1F	100	100	100
	100	100	100		100	100	100
	100	100	100		100	100	100
4K	5	5	5	4B	100	100	100
	20	5	10		100	100	100
	20	5	5		100	100	100

Note: M: mulch.

Figure 10. Picture of the ravine watercourse "El Valle" in the research plot "Olivar del Conde-El Valle" (2022).

During the period from 1983 to 2006, 168 forest fires were recorded in the Regional Park with a burnt area of less than 0.5 ha. Figure 11 shows the exact locations of the start of the fires [46], which did not affect the study areas. In subsequent years, no forest fires have been registered in the study area.

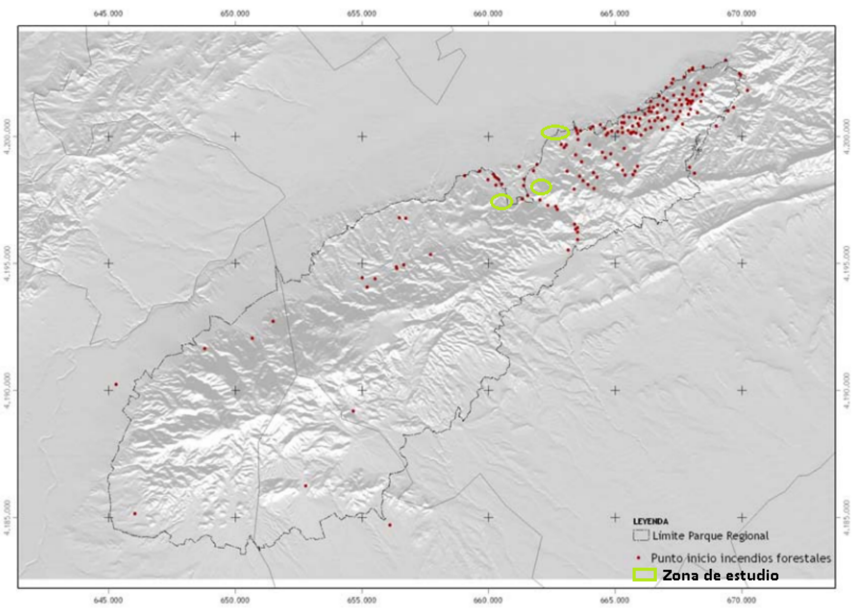


Figure 11. Position of the starting points of forest fires (red dots) in the Regional Park "Carrascoy y El Valle" in the period 1983–2006. Source: Regional Government Environment Unit [46].

4. Discussion

Based on the analysis of aerial and satellite images together with field observations in the Regional Park "Carrascoy y El Valle" between 1928 and 2022 (Figures 6–8), this article analyses the evolution of the geosystem with consideration given to forest cover. The territory of study has a complex topography, where climatic, hydrological, edaphological, and, especially, vegetation factors play important roles in desertification, as also described by Wei et al. [47] for northwest China (Figure 6). In contrast to the situation described by Martínez-Valderrama et al. [48] for areas affected by desertification in Spain, with the consequent loss of natural resources, the area of this study has evolved towards an improvement in wild flora, hydrological control of riverbeds, and soil erosion. It is important to note that the study area in 1928 was a geomorphological system with agrosystems inserted, composed of small individual farms, and a forest system with little shrub vegetation and scarce tree cover.

Studying the evolution of a system [14], specifically the forest system of the Regional Park "Carrascoy y El Valle", allows direct and indirect information to be obtained on the impacts in relation to desertification, as this is one of the areas of Spain at greatest risk [1] (Figure 1). Human beings have historically modified the system, taking advantage of ecosystem goods and services [2,4,12,13], extracting and introducing matter and energy, and thereby, establishing a dynamic relationship [14,16,18,30,31].

The high levels of deforestation between the late 19th and early 20th centuries in the mountains of the study area led to significant levels of desertification [5] (Figure 6) which, together with the steep mountainsides, lithology, and human actions, caused very severe erosion episodes, with the formation of gullies and small and medium-sized ravines that are hydrogeomorphologically active and visible today. The factors acting on the geosystem and leading to different erosion rates are multiple, as Bollati et al. [49] showed for the slopes of the Italian Alps. The factors described, together with the climatic conditions of southeast Spain where stormy phenomena cause torrential and high-intensity rainfall [44,45,50], have given rise to tragic events such as the deaths of a thousand people resulting from the floods of 1789 in the Segura river basin. This led to the promotion of reforestation in the basin as one of the measures to tackle such situations [8], thus radically changing the system and the landscape (Figure 6). It is worth highlighting the current presence of dry Mediterranean Aleppo pine (*Pinus halepensis*) that favours various ecosystem services and, in turn, influences the local climate, moderating the effects of extreme phenomena and preventing erosion [3,6]. An example is the significant reduction in erosion in the Sierra de Los Filabres (Almería, Spain) as a result of reforestation [51]. Furthermore, as the land surface of the study area has been occupied by forest, the landscape has also been modified [52]. These effects have been also observed in the nearby mountains, Sierra Espuña [11] and Sierra de Ricote, in the region of Murcia.

In relation to floods, those of 1931 directly affected the town of La Alberca due to the influence of adjacent wadis. The watercourses of the study area are not mentioned as determining factors in the floods that occurred in 1942. In 2019, another high-magnitude rainfall event occurred that affected the regions somewhat, with drags and small floods in the towns near the study area, but in which the mountain watercourses were less important than in previous events [53].

When comparing images of the area of study from 1928 with the current images, the most drastic change can be seen in the landscape, such that where there was no woodland or shrubbery before, today there exists a lush semi-natural forest [54] (Figures 7 and 8). These changes in the original geosystem brought about by modifying its initial state have led to a rearrangement of the system in terms of inputs, processes, and outputs, and this has contributed to a great deal of vegetation development [55]. The evolution of the geosystem, with vegetation as the most active and basic factor together with soil, climate, topography, and hydrology, plays an important role against desertification, as Wei et al. [48] found after studying the effects of spatio-temporal changes on desertification in northwest China. In our study, this is evidenced by comparing the images of "Puerto de La Cadena-Castillo del Puerto" (Figure 6).

The current development of the forest stand influences the geomorphology, affecting hydrological dynamics and erosion, as observed in the Pyrenees (Spain) by García et al. [56], where the action of rainfall has been modified by the trees. Nowadays, the presence of more vegetation, mulch, and plant debris in various stages of decomposition has changed soil conditions, thus improving the functions derived from reforestation [57]. It has also influenced the hydrogeological regime and, indirectly, desertification, as stated by Zhu [58] in his work on changes in dune shapes in the Hexi Corridor (China), where the main factor affecting such changes is climate.

According to a simulation by Haghtalab et al. of Amazon reforestation [59], the changes in the Amazon system, with lower temperature and higher rainfall, and their impact on climate change on a global scale can be compared to a much lesser extent to the changes caused by reforestation in the study area, where humidity has increased and the temperature has decreased. However, we cannot affirm that there has been a significant influence on climate change. Forest stands influence climate through atmospheric exchanges of energy, water, carbon dioxide, and other chemical species [60]. This influence can be modified by the transformation of the forest system by forest fires, which are frequent and important in medium terrestrial forest geosystems [61]. The study area has a comprehensive forest fire prevention and defence plan, which influences forest management [46].

The increase in the mass of vegetation, shrubs, and trees intercepts the arrival of rainfall on the ground and its subsequent surface displacement. By means of the radicular system, the presence of the plants modifies the mobility of water particles in the subsurface layers, which effects the hydrological regime, significantly reducing runoff and flooding. At the same time, the incidence of solar radiation on the ground is decreased, modifying the temperatures of specific places depending on the density of the vegetation cover. In the study area, there have been changes that have not been quantified due to the lack of measuring stations.

Importantly, we observed an influence of the shady–sunny orientation on the density of tree cover, being higher in the shady area than in the sunny area with regard to Aleppo pines (Figure 9). In Olivar del Conde, it has been possible to detect a greater development of forest trees, perhaps due to the fact that the soil type was previously agricultural and the slope was very low. In contrast, other authors have not detected significant differences in terms of forest cover between shady and sunny areas [62]. However, those authors discovered that rosemary (*Rosmarinus officinalis*) and *Brachypodium retusum* presented differences of 6.18% and 5.77%, respectively, due to the orientation. In our study area the differences were higher, reaching 9.82% for shrubs and herbaceous species. Surprisingly, the shady areas had much less underwood cover than the sunny ones, probably due to intensive trampling by humans and their pets in the shady area, which has been used intensively as a recreational zone (Table 4).

Some authors, as a result of their work in arid or semi-arid mountains in southeastern Spain, consider soil moisture as the variable that best explains the growth in semi-arid climate sites [63], so that greater humidity on the shady side and in the agricultural soils of the study area may have influenced tree development and therefore led to increased tree cover. These new systems bring social benefits, and it is desirable to quantify them in future work as a way of enhancing their value [64].

Reforestation has been a success in the study area, following the criteria established in 1884 in the Preliminary Project for Reforestation of the Murcia Forest District, where it is recommended to use the Aleppo pine (*Pinus halepensis*) in the study area, being the species best adapted to the climatic conditions due to the existence of previous stands. In nearby reforestation projects (Sierra Espuña), the ecological conditions for the use of certain species were considered [10], and were a complete success. This same approach was recommended by some authors for successful reforestation with Pinaceae (*Pinus*) in Mexico, where ecological conditions and microclimates are taken into account [65].

In other areas within the Mediterranean Basin, natural reforestation has generated changes in river channels [66]. In the work of Zouidi et al. [67] referring to forest soils with the presence of conifers (*Pinus halepensis*) in arid areas of Algeria, it was found that the lack of forest cover generates degradation of the physicochemical conditions of the soil. Another study on the biophysical effects of reforestation on the climate in the arid northwest of China showed how reforestation can produce changes in climatic conditions [68]. Research in Tanzania showed a decrease of 1.23 °C in the environment after reforestation [69].

Considering the existence of other regions with similar aridity conditions and significant rates of erosion, the knowledge of the potential for and development of wild vegetation in the study area can be extrapolated to other territories on Earth in order to carry out reforestation actions. Therefore, this study is of great global interest. Additionally, its novelty lies in providing information on the situation of tree-based reforestation in areas of high aridity and in relation to historical erosion rates.

5. Conclusions

The geographic system of the Regional Park "Carrascoy y El Valle" is a forest system whose changes of state show a dynamic character, with inputs and outputs of matter and energy that, together with the processes that occur within the system, modify its structure. The success of the reforestation, with the resulting improvement in vegetation cover reaching 100% in some cases, has led to changes in the state of the geosystem, such as reduction in erosion rates due to the soil's higher capacity to retain and intercept rainfall. The development of trees and shrubs has contributed to the modification of the hydrogeomorphological dynamics and structure, reducing the disastrous impact of torrential rainfall. Flood risks have been attenuated by the influence of reforestation on the hydrological network, with increased fluid retention and interception of solids. Climatic conditions have also been modified within the forest stand, with a reduction in temperatures and an increase in relative humidity, especially in relation to the surrounding areas.

Among the social benefits and ecosystem services provided by these forest stands, the attenuation of desertification at the local level should be highlighted, especially as the study area is located in one of the most arid areas of Spain with significant desertification problems. The analysis of the evolutionary sustainability of the geosystem shows a future trend towards an increasingly mature Mediterranean forest, contributing to minimizing the effects of erosion and desertification in the study area.

This is a novel study dealing with a forested area under adverse conditions for vegetative development. The area has a historical character that allows appreciation of vegetative adaptation to extreme environmental conditions. Importantly, the existence of other places on the planet with similar environmental characteristics gives this study a global interest.

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