Ecological Restoration of a site in semi-arid southeast Spain

Bachelor's Thesis Project by Thor Kuchler

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Preface

This report is the result of the thesis project done at AlVelAl, an association that aims at implementing regenerative agriculture and ecological restoration and revitalizing the local economy in the Altiplano region in Southeast Spain. The thesis project was to design a plan for the ecological restoration of a degraded site on an isolated farm called La Junquera, on the border of Almeria and Murcia. La Junquera was where I lived and worked most of the time during my thesis project.

Acknowledgements

Thanks to all the people on La Junquera. Thanks to all the local experts which were willing to share their knowledge; Pedro Sánchez Gómez, Juan Francisco Jímenez, Jordi Cortina, Miguel Angel Esteve Selma. Thanks to supervisor Yanniek Schoonhoven and farmer Alfonso Chico de Guzman for all the help. Thanks to Anko Stilma for the supervision.

Abstract

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1. Introduction

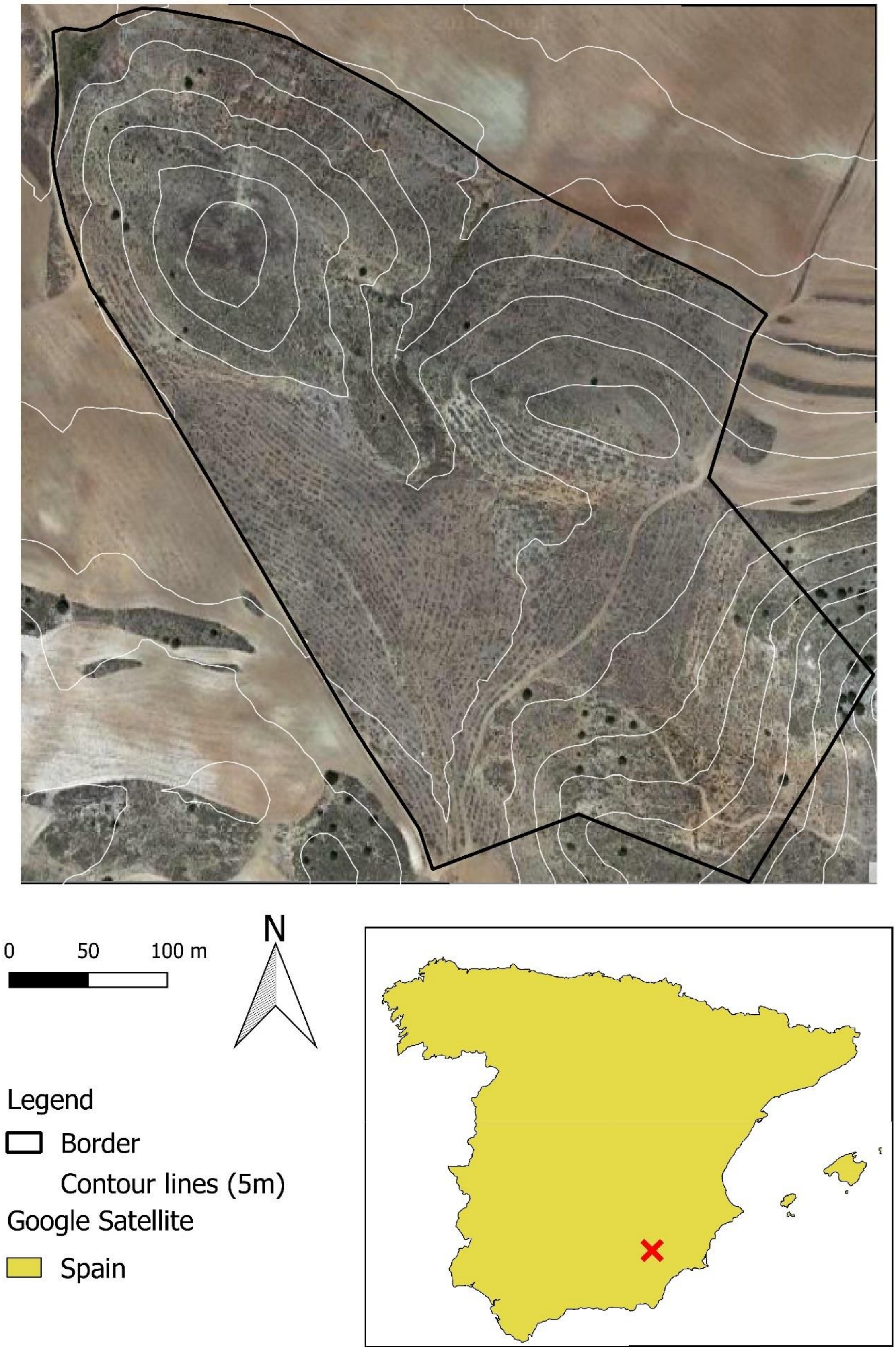
Land degradation is a widespread, global problem and has a very complex nature. It typically is caused by mismanagement or overexploitation of natural resources. It is characterized by a loss in productivity, soil, vegetation cover, biomass, biodiversity, ecosystem services, and environmental resilience (UNCCD, 2017). Effects of land degradation vary per land use type. Natural areas and forests, for example, often suffer a loss of biodiversity and ecosystem structure, which in turn can cause soil erosion and losses in ecosystem services.

Novel organizations such as Commonland and Alvelal adopt a holistic approach in addressing land degradation, which consists of implementing regenerative agriculture and ecological restoration, with a particular focus on creating new business cases around restoration, economic self-sustainability and value creation (Ferwerda, 2015). They collaborate with a diverse network of different partners to achieve their restoration goals.

Alvelal, for example, collaborates with a group of local farmers to advance the use and knowledge of regenerative agricultural practices such as swales, cover crops and compost. They collaborate with local universities and scientific institutes to aid the development of sustainable agricultural systems. They try to facilitate the implementation of sustainable practices by local farmers through setting up a farmer cooperation, creating shared infrastructure, providing access to funding and aiding in commercialization of organic products. Moreover, they set up ecological restoration projects in degraded natural areas (Alvelal, n.d.).

La Junquera, is one of the organic farms that work together with Alvelal. The 1100 ha farm is run by Alfonso Chico de Guzman, who has taken up farm management since in 2012. The thesis project was carried out for and on La Junquera and Alfonso is hereafter named the client. On La Junquera, like most other farms in the region, main crops are almonds and cereals. The farm is developing into a more regenerative farm, currently there are experiments with crop diversification and with swales and ponds. The farm lies in the region of Murcia on the approximate latitude of 38° and has an average elevation of 1150 meters above sea level. The prevailing climate is a semi-arid Mediterranean climate with hot dry summers, cold winters and most rainfall in the spring and autumn, with most rain in autumn (Conesa García, 2006). The landscape consists of a high plateau with various mountain ranges, undulating hills and in the valleys dry riverbeds called ramblas.

The farm has about 800 ha of arable land and 300 ha of natural areas. Some of the natural areas are densely forested whereas others are bare and seemingly degraded. The study site which is to be restored covers 16 hectares and lies adjacent to young almond plantations and other natural zones. Very few trees remain on the site and a large surface of it consists of abandoned agricultural fields. It has a vegetation of low shrubland with many woody perennial evergreen plant species. Terrain characteristics are diverse, ranging from hill tops to sloped hills, and from flat plains to dry valleys (ramblas).



Map 1 Restoration site and location in Spain

1.1 Problem analysis

This problem analysis focuses on the 16-hectare restoration zone. Naturally, the problems that are described are valid for much of the degraded land in the region.

In essence, the problem at hand is the degradation of the natural zone of interest. At the basis of this degradation lies the partial removal of the original vegetation. This causes a variety of subsequent problems which in turn degenerate the ecological functioning of the area.

Originally, without any disturbance of the restoration site, the natural vegetation would probably be an oak forest consisting mainly of Quercus ilex subsp. rotundifolia (Rivas-martinez, 1987). Human disturbance has caused most of the dominant tree layer to be removed. Due to the long history of land use it is difficult to exactly know what has happened when in terms of disturbance. Obviously, most trees were removed at a certain point in time. The grazing of sheep also was part of the disturbance on the area of interest, as has been confirmed by the client (A. Chico de Guzman, personal communication).

The initial disturbance, the removal of the dominant tree and shrub layer, have the following (interlinked) consequences:

- **Simplification of vegetation structure:** The tree layer is a key facilitator of biodiversity through its structure: it provides shade which has a cooling effect and causes more moisture to be retained, it reduces wind velocity and thereby its adverse effects, it provides shelter for all kinds of organisms and it creates microclimates which in turn facilitate biodiversity. Having the tree layer removed limits all these facilitative effects.
- **Change in species composition:** The removal of trees and large shrubs directly influence the species composition, there are significantly less holm oaks (*Quercus ilex subsp rotundifolia*). Indirectly, because the system changes through the simplification of vegetation structure and change of soil properties, a different set of species will be favoured whereas others will disappear. In other words, the ecosystem is set back in its succession process.
- **Loss of ecological functioning:** Beforementioned simplification of vegetation structure and change of species composition restrict the ecosystem functioning, albeit on a local scale. The ecosystem is limited in the provision of services that it would normally provide, such as: erosion mitigation, temperature control, moisture retention and soil development. Also, the loss of certain species reduces food availability for animals, as is the case with the holm oak.
- One important aspect of restricted ecological functioning, and a whole problem on its own, is **disturbed soil and a subsequent vulnerability to erosion**: The absence of a dominant tree layer exposes the soil to more extreme conditions, thereby affecting the soil's structure and its capacity to counter erosion. Because less organic matter is accumulated in the soil than normally, the soil can retain less moisture. When the soil has less organic matter, and is generally more exposed to sunlight, it is also likely that soil biodiversity is affected as a result. Moreover, without a protective tree layer, the soil is more exposed to the erosive force of rain. Soil erosion is clearly visible in the form of erosion channels and sedimentation areas.
- **Loss of biodiversity:** Through beforementioned problems the system is impoverished and this, most probably, although not actually tested in the area of interest, causes a loss of biodiversity.

As a comparison, in another part of the farm, a dense forest cover still remains and contrastingly, you can find dark brown deep soils there with a lot of organic matter.

Secondly, the natural area is important out of a regenerative agriculture perspective. In regenerative agriculture or agro-ecology they aim to approach the farm as an integrated whole. The presence of a healthy ecosystem on and around the farm is valued because it contributes to its overall health. Ecosystem services such as pollination and biological pest control are those which are important to agriculture. But also, in a more indirect way, a healthy ecosystem provides protection from erosion, wind and excessive heat. The problem out of the (regenerative) farming perspective could be defined as: degradation causing a limited availability of ecosystem services.

1.2 Problem statement

Former land use has left the ecosystem on the restoration site in a degraded state. The dominant tree layer is removed, and the ecosystem's structure and species composition has changed. The changes in vegetation structure, vegetation cover and species composition cause a degeneration in ecosystem functioning, thereby causing soil erosion, limited ecosystem services and probably a reduction in biodiversity.

1.3 Vision of the client

The client wants to restore degraded natural areas on his farm because he wants to create a place with more biodiversity, more habitat and simply more beauty. The client also expressed interest in the integration of the natural areas into the farming system and create an added value.

1.4 Objectives

Overall Goal: The goal of this project is to plan the ecological restoration of a pilot site of 16 ha on the farm la Junquera. The plan aims to initiate the re-establishment of the compositional, structural and functional attributes of the reference ecosystem by reintroducing key native woody species that will promote and accelerate succession. Also, the plan aims to augment functioning of the site in relation to the farm.

1. **Conserve existing in-situ ecological values***
   1.1. *Conserve occurring vegetation, rare species and their habitat*

2. **Restore compositional attributes****
   2.1. *Re-establish a cover of plant species that belong to the reference ecosystem or an intermediate succession phase*

3. **Restore structural attributes*****
   3.1. *Create more microclimates and habitat diversity through the increase of the physical structure of trees and larger shrubs*
   3.2. *Increase the vegetation cover*

4. **Restore functional attributes*****
   4.1. *More water is retained on site*
   4.2. *Soil protection and soil formation processes are restored*
   4.3. *More carbon is sequestered*
   4.4. *Biodiversity and habitat diversity is increased*

5. **Stop soil erosion**

2. Research

2.1 Research questions

Following research questions were designed based on the objectives:

Research question 1: What is the current status of the site in terms of local climate, soil, terrain, vegetation and degradation?

Research question 2: What is the reference ecosystem?

Research question 3: What are constraints for ecological restoration in this region and what are approved restoration techniques?

2.2 Research methodology

The research questions are answered with one or a combination of the following methods:

1. Literature review
2. Expert interviews
3. GIS analysis
4. Field research

2.2.1 Site diagnosis

Even on a site of 16 hectares, soil, terrain, vegetation and degradation can vary a considerable amount so it is important to collect accurate field data to base the design of the plan on.

	METHODS	DESCRIPTION
Climate	**1**	Climatic conditions such as patterns and dynamics of seasons, precipitation, temperatures, wind, etc. will be described.
Terrain	**3**	The topography of an area determines many things such as hydrology, soil, slope and aspect. Slope analysis allows to assess accessibility, soil depth and susceptibility to erosion. Aspect analysis is important because aspect determines the amount of insolation and in turn the amount of evaporation. Therefore, slope's aspect can affect growing conditions and can influence species composition.
Soil	**1,2,3,4**	Soil analysis is important because soil affects a multitude of factors, particularly in seedling establishment. Soil characteristics will be not inventoried in-depth because I assume that, because I will plant only native species that are adapted to the local soils and do well in the variety of soils, it is not necessary to be aware of minor spatial variations in soil types. The soil variable of soil depth will be taken into account because it is an important factor that can influence plant establishment success and species choice (J. Cortina et al., 2011). Also, the apparent distinction between wetland and dryland soils is included in the analysis, as it affects species choice as well. The different steps of this method are explained below.
Vegetation	**1,2,3,4**	Vegetation on the restoration site is quite diverse. A vegetation inventory is done to determine current species richness, vegetation cover, vegetation structure and check whether species of special interest occur. Also, inventorying vegetation is important for demonstrating change after restoration interventions have been done. These inventories are essentially a monitoring baseline. The different steps of this method are explained below.
Degradation	**3,4**	Degradation and soil erosion is clearly visible in some parts of the restoration zone. To assess the severity of erosion and localize measures against it, it is necessary to map where the erosion takes place. Erosion is on the restoration site mostly visible in the form of erosion channels. The different steps of this method are explained below.

Table 1 Methodology site diagnosis

SOIL

	METHODS	DESCRIPTION
Soil types	**1**	A literature study on local soil types that are likely to occur on the restoration site
Soil depth	**3,4**	Assessment of soil depth is done by hammering an iron rod into the soil, until at max. 50 cm deep (which is deemed deep enough for any arborescent vegetation type (J. Cortina, personal communication). Sample locations are based on a subdivision of ridges, hilltops, slopes, valleys and plains in GIS made with a slope map. The underlying assumption that will be tested is that ridges and hilltops will have more shallow soils. Sampling points are randomly assigned in the different subdivisions by GIS. Soil depth was sampled on 26 points.

Table 2 Methodology soil diagnosis

DEGRADATION

Methods	Description
3	Remote sensing the area with satellite imagery. Checking for rills, bare areas or disturbed landforms.
4	Ground truthing, checking indicated degradation from the previous step and inventory in detail where a rill begins, what its trajectory is and where the run-off material is deposited.

Table 3 Methodology Degradation diagnosis

VEGETATION

First of all, I identified different patches of vegetation that were easily discerned visually by 1) remote sensing with satellite imagery, and 2) by ground-truthing this in the field.

Secondly, vegetation composition and vegetation covered was measured in 17 quadrats. Vegetation composition is basically the combination of the species richness -the number of different species present - and the relative abundance of these species. Species diversity for each vegetation stand will be represented by using the Shannon-Index. This index will allow to compare between areas or between points in time (Colwell, 1988).

Vegetation cover will be estimated during the transects. The vegetation cover is the proportion of the ground surface covered by the vertical projection of the plant. Estimating vegetation cover gives an indication of the amount of bare soil.

Plant identification has been done by making use of the flora guide of Murcia (Sánchez-Gómez & Guerra-Montes, 2011). However, the authors of the flora guide have personally helped in identifying most plants on the restoration site already. This data was compiled in a plant list.

It is very possible that rare species or species that have a short lifetime are not inventoried during monitoring. A compiled list of all plant species identified on the restoration site will be added to compensate this loss.

Quadrat method

Vegetation quadrats measuring vegetation cover and species diversity. A 20-meter measure tape will be laid out, pointing northwards, departing from points that were randomly generated with QGIS within the different vegetation patches. Different quadrats will be laid out next to this line for measuring different vegetation layers;

1. A 20 x 10 quadrat for counting and determining for trees and shrubs having a circumference or cover of equal or larger than 100 cm and a height over 60 cm.

2. A 5 x 5 quadrat for counting and determining trees, shrubs and herbaceous species having a circumference or cover between 40 and 100 cm. Also, vegetation cover is estimated in this plot and represented as percentages.

3. Two 1 x 1 quadrats for counting and determining herbaceous species smaller in circumference than 40 cm.

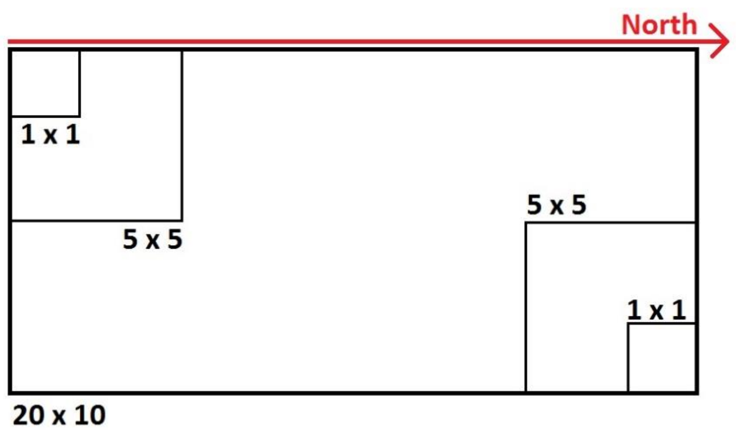


Figure 1 Quadrat

2.2.2 Reference ecosystem

An important aspect of ecological restoration is identifying a reference ecosystem (or ecological reference) that informs the restoration planning (Society of Ecological Restoration, 2016). The reference system usually is the type of ecosystem that would be present if there was no human disturbance. Basically, a restoration project aims to go from a degraded ecosystem to a system which is as close as possible to the reference ecosystem. To create a detailed ecological reference, it is, where possible, necessary to study reference sites with none or very little human disturbance.

The identification of the reference ecosystem was done through literature research (1), expert advice (2) and field visits (4). The reference ecosystem was studied and described by looking at its compositional, structural and functional attributes.

COMPOSITIONAL ATTRIBUTES

Compositional attributes include the floral and faunal species composition. Determination of the compositional attributes is done by compiling a list of reference plant species by consulting literature about the potential vegetation and the local reference ecosystems. Eventually, this list was compared with the species list of the restoration site to see which species are missing or are underrepresented. I focussed primarily on the floral composition of the reference system.

STRUCTURAL ATTRIBUTES

Structural attributes represent the physical configuration of vegetation, for example different layers of vegetation or different habitat structures. Ecosystem structure is described by looking at: layers and vertical stratification, patches of different vegetation or mosaics, diversity of habitats, average tree density, average tree size and average tree diameter.

FUNCTIONAL ATTRIBUTES

Functional attributes are the result of structural and compositional attributes and the ecological processes they take part in such as predation, facilitation, symbiosis, soil building, moisture retention or nutrient cycling (Vold & Buffett, 2008). These are the processes that make an ecosystem function, and they provide all the ecosystem services that are beneficial for humans.

Functional attributes are more difficult to study or to describe quantitively. Therefore, in this case, the subject is approached by assuming that the functionality of the ecosystem follows the reinstatement of the compositional and structural attributes. However, functional attributes are described generally to gain a better understanding of the local ecosystem.

HUMAN INFLUENCES ON THE ECOSYSTEM

Humans have traditionally had a large impact on the landscape in the region. I will describe what have been the major anthropogenic disturbances for the reference ecosystem and how it has created the landscape we see nowadays in this region.

2.2.3 Restoration practices

There is a variety of local conditions that can impede restoration attempts, such as droughts, erosion or herbivory for example. In order to improve seedling survival and deal with erosion during and after restoration interventions it is necessary to have a clear overview of the different environmental constraints as well as potential restoration techniques for dealing with these. Fortunately, a considerable amount of experience has been gained already in ecological restoration in South-east Spain as well as in similar semi-arid areas. During this research phase I will focus on learning from the lessons that have been learned already. I will describe the local (environmental) constraints for restoration and summarize potential methods for dealing with those, with special attention to erosion and seedling survival. This will be done mainly through literature research (1) and expert advice (2).

2.3 Research results

2.3.1 Site diagnosis

CLIMATE

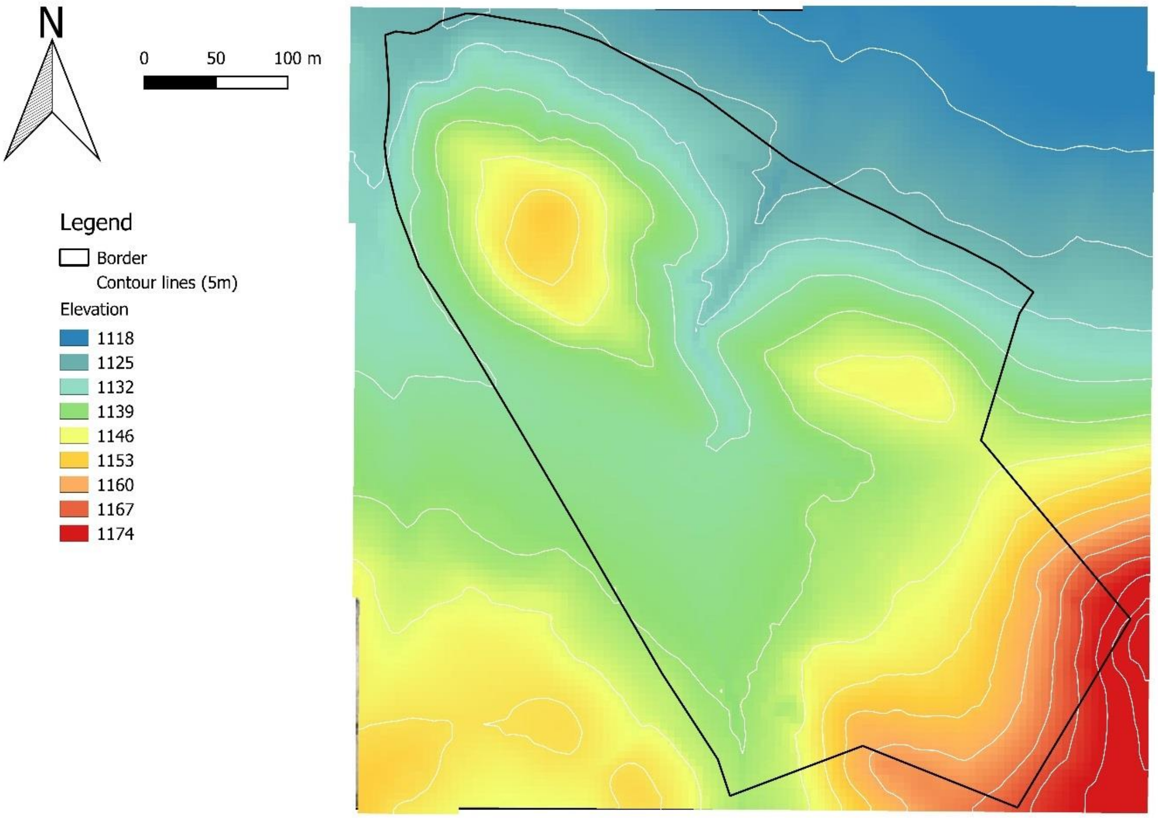
The study area lies on the approximate latitude of 38° on an average elevation of 1150 meters above sea level. The exact coordinates of the restoration site are 37°56'44.4"N 2°10'28.4"W. The prevailing climate can be described as a semi-arid Mediterranean climate with hot dry summers, cold winters and most rainfall in the spring and autumn, with most rain often in the autumn (Conesa García, 2006). Geographically seen, the climate of the region of Murcia is mainly governed by its latitude, the south-eastern orientation and its sheltered position from Atlantic influences due to the Baetic mountain system on the south. The north-eastern province (Comarca del Noroeste) has, due to its higher elevation, a cooler and wetter climate than the coastal regions. Mean annual temperatures lie around 12-16 °C (Conesa García, 2006; de la Cruz, Yanes, Sánchez, & Simón, 2010) The north-eastern province has, of all Murcia, year-round the lowest temperatures. Typically, winters are cold, and summers are dry and hot. Frost is common in winter (on average 50 frost days per year) and mean minimum temperatures can reach down to -15°C (Conesa García, 2006). Mean maximum temperatures can reach up to 36°C.

Most precipitation occurs during winter, spring and autumn with most rain falling in spring and autumn (Sánchez-Gómez & Guerra-Montes, 2011). The amount of precipitation for La Junquera lies between 350-400 ml (Conesa García, 2006). Precipitation can vary greatly in between years, with variations greater than 100 ml having been measured in the weather station of Topares (a village near la Junquera) (A. Chico de Guzman, personal communication). Low intensity rainfalls are most common throughout the region (an average 8 mm per rainfall day), however, intense rainfall events occur every once in a while (de la Cruz et al., 2010), where 100 ml can precipitate in a few hours. Torrential rainfall can cause a lot of soil erosion in a short amount of time.

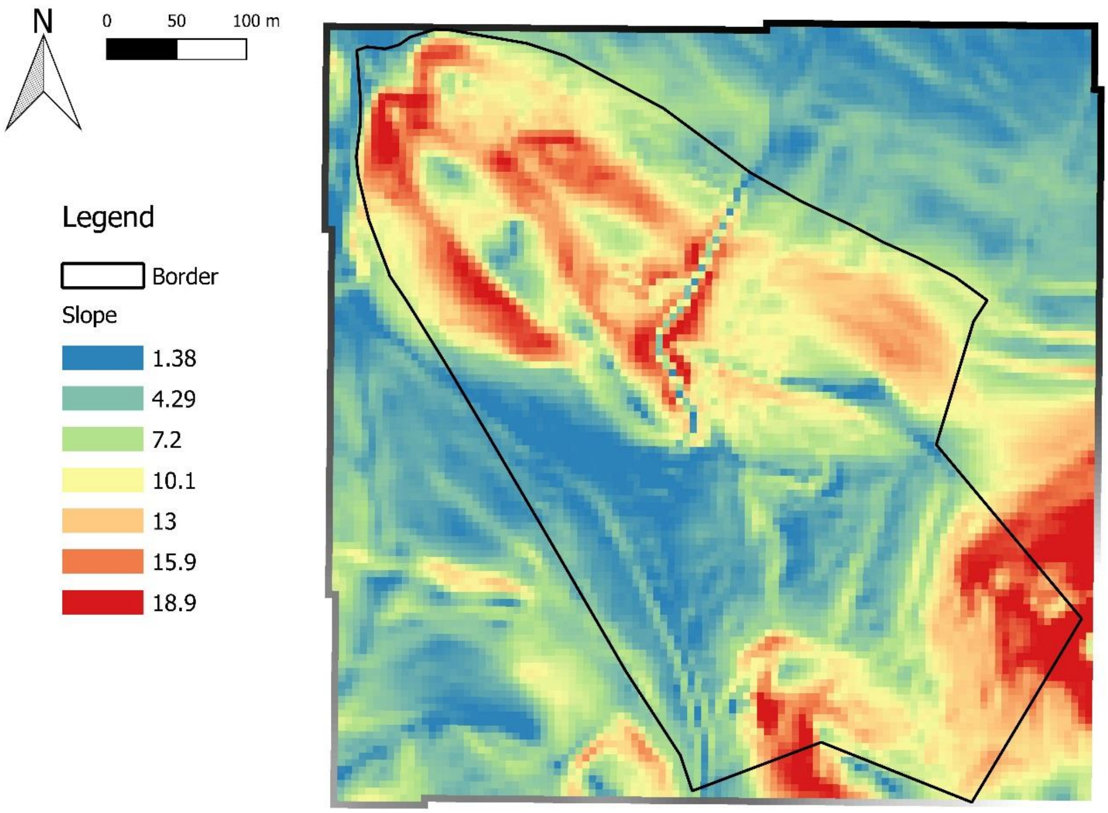
The dominant wind direction is from the west. Winds can be very strong and can contribute to soil erosion by taking up soil, especially in summer.

TERRAIN

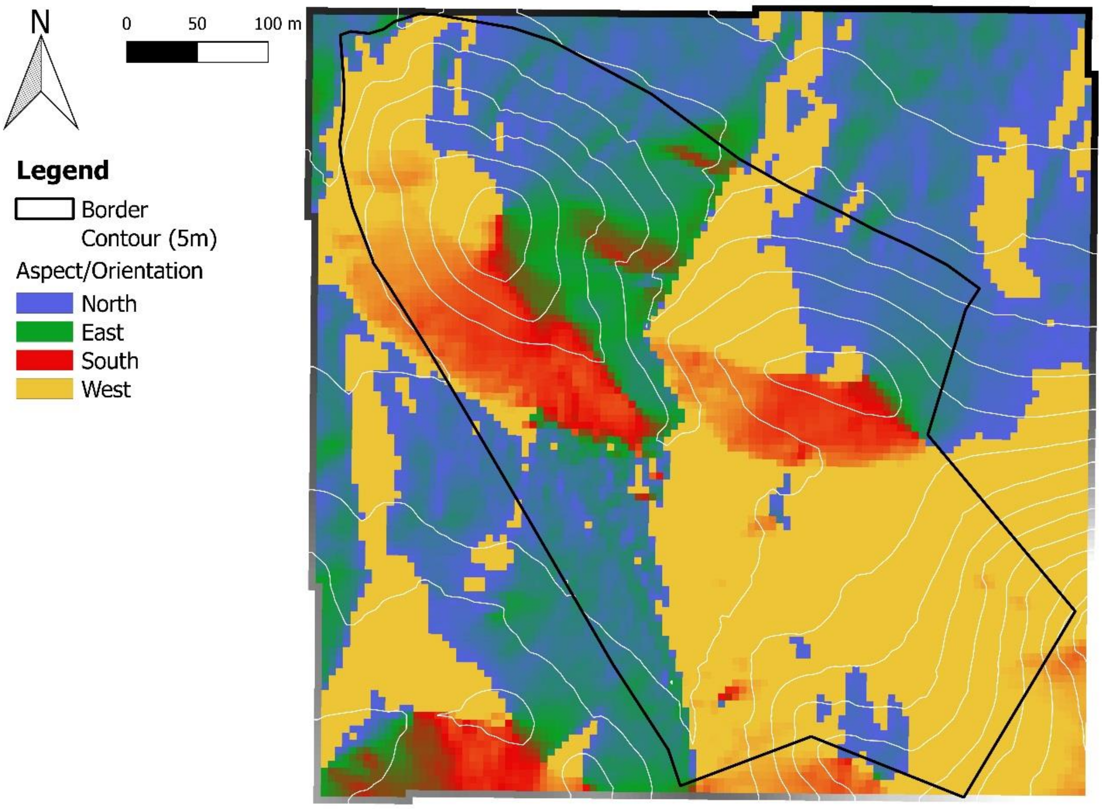
The elevation of the site ranges between 1116 and 1182 meters above sea level. The terrain on site has two solitary hills with in between a valley, better described as a rambla. A rambla is a dry stream bed that only fills and flows temporarily when it has rained enough. Bordering the two hills on the south lies a relatively flat plain and in the southeast corner of the plot lies a slope which leads up to another rocky hill.



Map 2 Elevation in metres above sea level



Map 3 Slope in degrees



Map 4 Aspect

<u>SOIL</u>

The most common soils in the region are described below (Servicio Geográfico del Ejército, 2018). Geological origins of the area begin with the mountain formation which formed the Baetic system (esp: Cordillera Betica) about 16 million years ago. The mother materials result out of the sediments that this elevated land deposited. Much of these sediments have marine origins because the region used to be an inland sea. Due to this process, soils are generally alkaline because they contain minerals rich in calcium. Also, most soils are rich in clay. About 75% of the area's sedimentary rock types originated from materials such as sand, clay and different conglomerates (Cruz Pardo, 2010).

- **Calcic cambisols**
  Soils that are little developed, with little horizon differentiation and relatively little organic matter. (Driessen, Deckers, & Nachtergaele, 2001). In the region of Murcia, these soils develop in areas that receive somewhat more precipitation and/or are exposed less to evaporation as related to the Murcian average (Conesa García, 2006). Most cambisols in Murcia contain plenty of calcium carbonate for which they are classified as being calcic. According the soil map of the region of Murcia, most soils on La Junquera are of this type, however, the map is not very detailed. (Servicio Geográfico del Ejército, 2018)
- **Calcaric regosols**
  Soils that are weakly developed with little to no horizon differentiation (Driessen et al., 2001). Other properties are difficult to describe because regosols form a taxonomic rest group. These regosols on the farm are classified as being calcaric which means they contain plenty of calcium carbonate and are relatively alkaline as a consequence.
- **Litosols**

Shallow soils, found in mountainous regions, generally with steep slopes. Often these soils are eroded. The shallowness of litosols do not allow trees to grow on them so the natural vegetation on them consists out of shrubs, herbs and grasses.

- **Gypsisols**
  Soils with a sizable accumulation of gypsum (calcium sulphate). Presence of gypsisols (or at least soils that contain a certain amount of gypsum) on the restoration site is clear due to indicator plants such *Ononis fruticosa* and *Matthiola fruticulosa* (P. Sánchez Gómez, personal communication). Gypsisols do not occur much in the region.
- **Fluvisols**
  Fluvisols develop in the depressions and valleys where groundwater is close near the surface, on La Junquera, being high up the watershed, fluvisols are confined to small, narrow valleys. The plant *Scirpus holoschoenus* often indicates the presence of groundwater. Typical properties of fluvisols are that they (can) receive fresh sediments during floods and that they show an irregular organic matter profile (Driessen et al., 2001).

Effects of soil properties

Some soil properties have a strong effect on the growth and establishment of seedlings. Logically, it is important to be aware of these aspects in relation to reforestation.

The texture of the soil, the size of the soil particles, stoniness, soil depth, the degree of compaction and organic matter content all affect the soil's capacity to retain and transport water and make it available for plants. Moreover, these characteristics also affect rootability.

Generally, local soils have a clayey texture and thus a small soil particle size. A very clayey soil can retain water so well in micropores in such that it is limitedly available for plants. Furthermore, clayey soils in dry climates can exhibit crusting, the forming of a thin layer that reduces porosity and makes it more difficult for seedlings to establish and for water to infiltrate (Lal, Blum, Valentin, & Stewart, 1997).

Furthermore, most local soils generally contain a lot of stones. This reduces rootability for plants and also affects soil preparation.

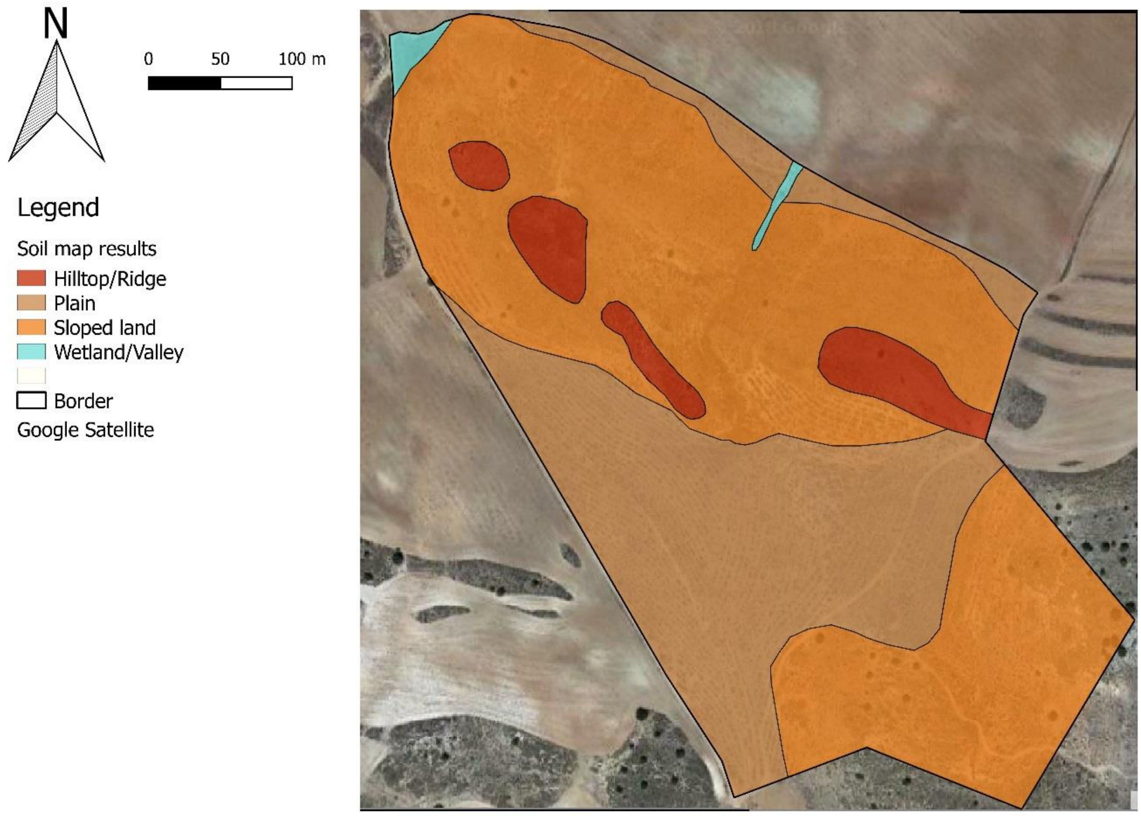
Also, the amount of nutrients also is of importance for plant growth and water retention. Of course, sufficient nutrients are needed for plants to grow and soil organic matter also increases the soil's capacity to retain water and deliver it to plants. In general, most soils have low organic matter contents. On the contrary, fluvisols generally have a higher organic matter content.

Salting: Due to low precipitation and high evaporation, salts do not get washed away easily in these soils but can instead accumulate closer to the surface. Increased salinity can impede plant growth

Soil depth

Shallow soil depth is typical for the locally abundant litosols. It greatly affects the establishment of species. Trees cannot grow in too shallow soil and the vegetation will consists of shrubs, herbs and grasses. Thus, from the point of view of ecological restoration it is important to know which soils are too shallow for planting trees. A soil depth of 30 cm is regarded a minimum for planting trees (J. Cortina, personal communication).

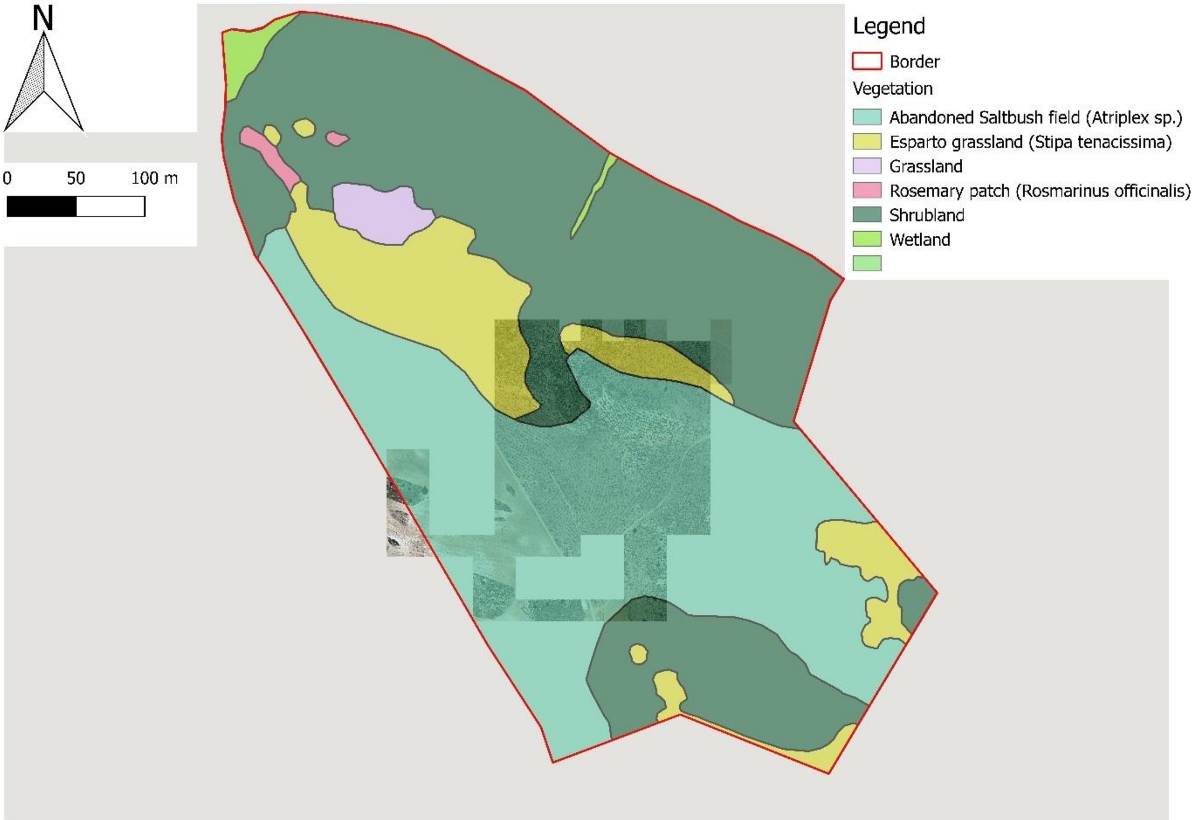
Results of the soil depth inventory show that ridges and hilltops generally have confirmed the assumption that ridges have shallow soils. An average soil depth of 31,8 cm was measured on the ridges. Soil depth on sloped land and on flat plains was all close to 50 cm depth, being adequate for planting. The location of the hilltops, plains and sloped land is represented in the map below.



Map 5 Different soil depths based on topography.

VEGETATION

At first sight it is evident that there are very few trees present on site and it shows that the land has had a history of degradation. Hence, also as indicated by the currently present species, the actual vegetation is best described as degraded shrubland (Región de Murcia, 2018). Nonetheless the restoration site still has a diverse vegetation with a few species of special interest. On 21 May a field visit with local botanist Pedro Sánchez Gómez and Juan Francisco Jiménez from the university of Murcia was arranged to quickly identify as many plant species as possible. 160 species were identified. The different vegetation types are explained hereafter.



Map 6 Vegetation patches

Atriplex – Artemisia – Santolina

The dominant species within the tree/large shrub layer is *Atriplex sp*. (87,5%). Within the small shrub layer the main species are *Artemisia campestris* (39,9%) and *Santolina chamaecyparissus* (34,2%) and to a lesser extent also *Medicago sativa* (6%) and *Dactylis glomerata* (6.8%). In the herb and grass layer the dominant species are *Plantago albicans* (55,9%) and *Papaver rhoeas* (17,2%).

The average estimated vegetation cover is 54%.

This vegetation is found on the flat patch of land and on the hill bordering to its eastern side. This land has been used for agriculture most recently. About 30 years ago, this area was planted with an *Atriplex* species which I have not been able to identify. At that time the planting of a variety of endemic and exotic *Atriplex* species was part of the agricultural trend to find new profitable types of land use. Its purpose was to create nutritive animal fodder on marginal lands. At this site the experiment was eventually abandoned. The presence of *Artemisia campestris* and *Santolina chamaecyparissus* indicate that the vegetation is in an early stage of succession (P. Sanchez Gómez, personal communication).

Photo 1 Atriplex – Artemisia – Santolina vegetation

Stipa tenacissima grassland

The dominant species within the tree/large shrub layer is *Stipa tenacissima* (84,2%). Even though it is grass it is a quite large perennial plant and meets the size requirements which were set for this vegetation layer. Within the small shrub layer, the main species are *Stipa tenacissima* (58,6%), *Genista* scorpius (10,35), *Bupleurum fruticescens* (9,3%) and *Thymus vulgaris* (8,4%). In the herb and grass layer the dominant species are *Brachypodium retusum* (33,3%), *Dactylis glomerata* (15,1%), *Thymus vulgaris* (7,6%), *Teucrium pseudochamaephytis* (4,3%), *Plantago albicans* (4,1%).

The average estimated vegetation cover is 59%.

Esparto, the Spanish common word for Stipa tenacissima, is a grass that traditionally has been used for its fibres. A wide variety of such as mats and baskets were made of this sturdy material. It used to be a product which was worth a good amount of money and so, much natural areas were planted with the large grass species. Hence, Esparto is still abundantly present in the cultural landscape even though it has no financial value anymore. In addition, it is difficult to say what its natural distribution is because of the former human involvement.

Due to the broad base of the Esparto it helps catching soil run-off. Moreover, the plant grows outwards vertically through root nodules. Eventually, the ‘centre’ of the plant dies and the outer plant parts survive. In the middle remains a microsite, with a soil enriched with a lot of organic matter and a spot which gets shade from the surrounding esparto plant (P. Sanchez Gomez, personal communication).

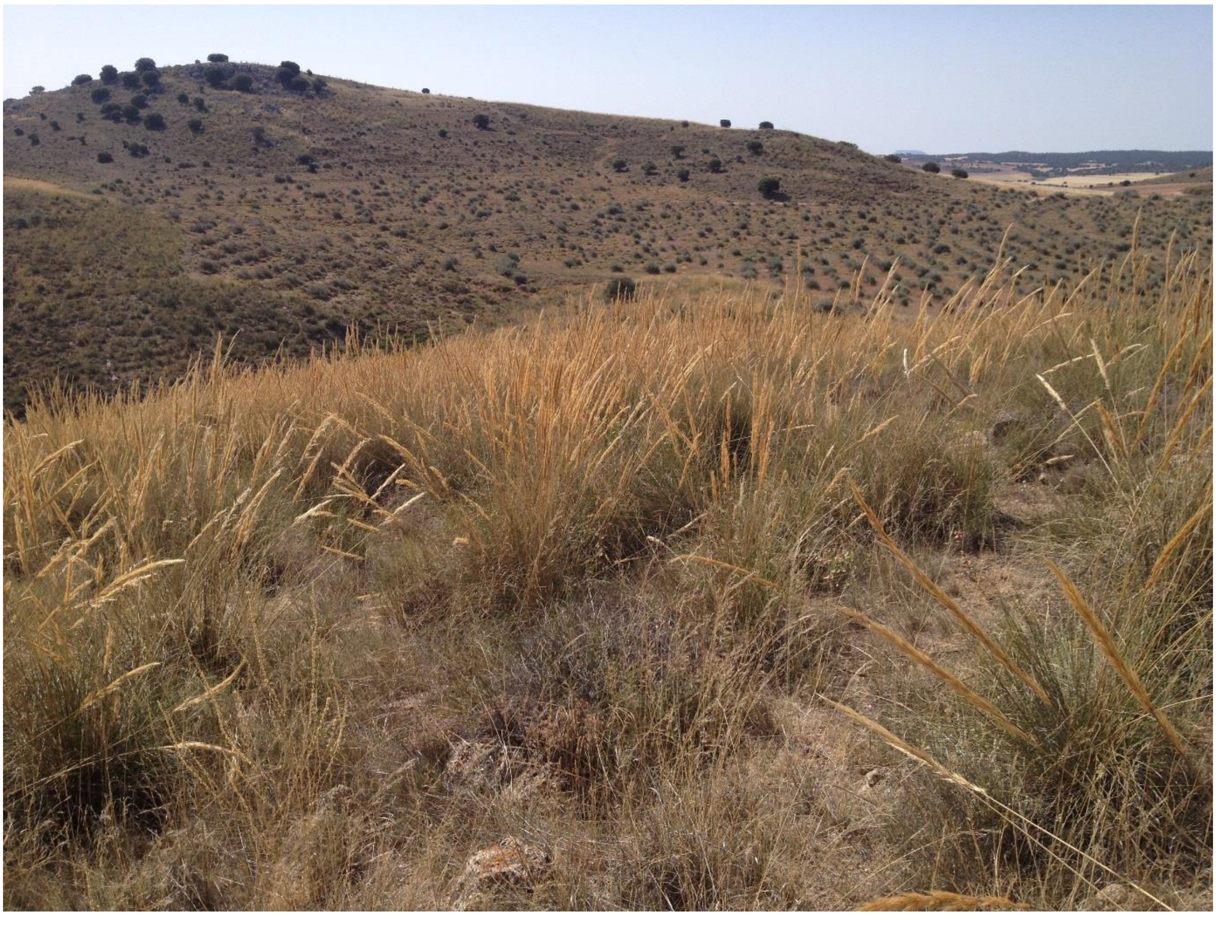


Photo 2 Stipa tenacissima grassland

Genista shrubland

The dominant species within the tree/large shrub layer is *Genista scorpius* (74%) and in the small shrub layer, the main species are *Genista scorpius* (31,4%), *Santolina chamaecyparissus* (30,3%), *Thymus vulgaris* (15,1%), *Bupleurum frutescens* (13,3%).

The herb and grass layer is very diverse with a total of 42 species encountered in the 1x1 quadrats. The *Cistaceae* is well represented by the *Helianthemum* and *Fumana* genera (15,6%). Two dominant grasses are *Dactylis glomerata* (17,4%) and *Brachypodium retusum* (11,5%). Also, quite some members of the *Lamiaceae* family are present, of which: *Teucrium similatum* (6,1%), *Thymus vulgaris* (4,4%) and *Phlomis lychnitis* (4,2%). Also *Plantago albicans* is relatively abundant (7,7%). Both the *Cistaceae* and *Lamiaceae* family are very typical for the Mediterranean flora.

The average estimated vegetation cover is 57%.

This type of vegetation indicates some degree of disturbance. Genista scorpius is a plant that occurs often in degraded vegetation (P. Sánchez Gómez, personal communication). This vegetation is further in the succession than the atriplex vegetation which was mainly dominated by Artemisia campestris and Santolina chamaecyparissus.

Photo 3 Genista shrubland

Grassland of unidentified grass

The top of the most western located hill is covered by another unidentified species of grass. In the large shrub layer only a few Stipa tenacissima were encountered. The small shrub layer mainly consisted of Artemisia campestris (89,2%) and in the herb and grass layer is found mainly: the very small Androsace maxima (38,9%), the unidentified grass (29,2%), Teucrium pseudochamaephytis (11,8%) and Plantago albicans (9,7%).

The average estimated vegetation cover is 49%.

Rosmarinus shrubland

Some small areas are dominated by Rosmarinus officinalis. This vegetation type was not taken up in the vegetation monitoring as it covers only a small area. Moreover, it only differs from the Genista shrubland in that the main large shrubs are Rosmarinus, the rest of the undergrowth is very similar to that of the Genista shrubland vegetation type. Rosmarinus officinalis is an important plant for bees, it starts flowering very early in the year (from January onwards).

Photo 4 Rosmarinus shrubland

Wetland vegetation

Two small areas have a typical wetland vegetation; 1) in the rambla/valley in between the two hills is a wetland vegetation consisting mainly of *Scirpus holoschoenus, Juncus maritimus, Scirpus holoschoenus* and *Elymus sp*., 2) in the northwest corner of the site lies a small wetland which is fully covered by *Scirpus holoschoenus.* For the wetland vegetation I adapted my method because the size of the wetlands was smaller than the size of the quadrat I used for surveying vegetation in my method. Instead of measuring different sizes of plants within quadrats I now noted all species that I encountered following one transect line so to still get an overview of which species occur in the wetlands. In the rambla, there is also a *Tamarix sp.*, a typical plant of wet areas in this region.

Vegetation cover was close to 100%.

Photo 5 Wetland vegetation

Biodiversity indices

The transect data was used to calculate the Shannon diversity index and so to assess the diversity of the studied vegetation. The Genista shrubland is most diverse.

VEGETATION TYPE	SHANNON INDEX
Atriplex - Artemisia - Santolina	2,135
Stipa tenacissima grassland	2,46
Genista shrubland	3,02
Grassland of unidentified grass	1,867
Rosmarinus shrubland	n.a.
Wetland vegetation	n.a.

Species of special interest

During the field visit with the Murcian botanists a few rare species were found.

- *Onosma tricerosperma* occurs mainly on the eastern hillslope. The surroundings of La Junquera is the only place in Murcia where this plant is found.
- *Ephedra nebrodensis*. A rare gymnosperm.

These following plants were taken up in the EU Habitats directive 92/43/CEE – Annex II (P. Sánchez Gómez, personal communication).

- *Thymus vulgaris*
- *Tamarix sp.*
- *Satureja obovata subsp. obovate*
- *Salvia lavandulifolia subsp. oxyodon*
- *Pinus halepensis*
- *Ophrys scolopax*
- *Ophrys lutea*

A few plants indicate that the soil contains gypsum: These plants are *Matthiola fruticulosa* and *Ononis fruticosa*. Moreover, gypsum soils are generally rich in species of the genera of *Thymus, Teucrium, Helianthemum* and composites such as *Centaurea, Jurinea, Santolina and Frankenia* (European commision, 2013) and, so far, 10 species of these genera have been encountered on the site.

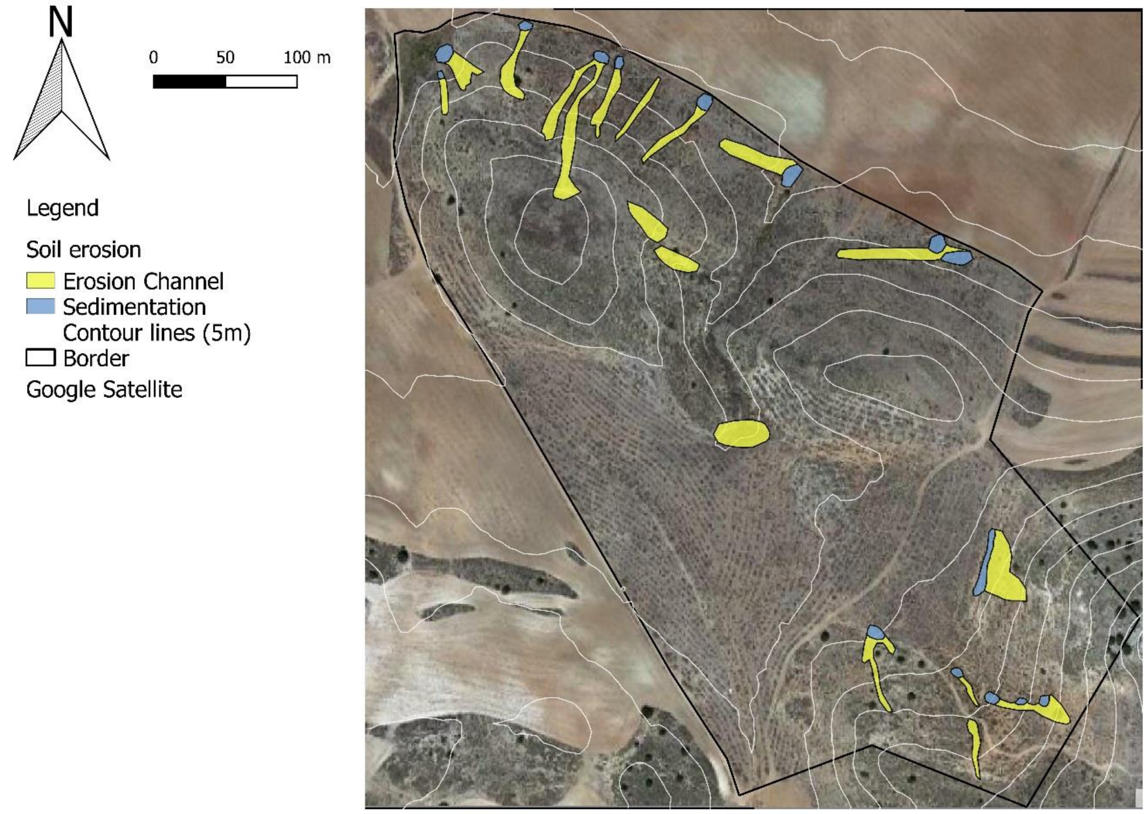
Photo 7 Ephedra nebrodensis

Photo 6 Onosma tricerosperma

DEGRADATION

The current state of degradation has been described already in the problem analysis. It consists mainly of the clearance of the native vegetation and soil erosion.

The goal of this plan is to restore the vegetation to resemble more closely a native type of vegetation, in that sense, the degradation of the vegetation will be restored. But, as is clearly seen in the field, also soil erosion forms part of the degradation. The location of erosion activity, mainly in the form of rills, has been mapped by a combination of remote sensing and ground truthing. I have shown the trajectory over which soil runoff travels, unto where it is deposited.



Map 7 Location of erosion channels

2.3.2 Reference ecosystem

The identification of the reference ecosystem is based upon different works of literature, conversations with local experts and observations in the field. The choice of explaining the ecosystem in terms of its functional, compositional and structural attributes is based upon the International Standards of ecological restoration (Society of Ecological Restoration, 2016)

Naturally, there is not only one type of reference system. The reference system in large consists of a variety of different ecosystems which vary on the basis of soil type, water availability and altitude. Moreover, no hard boundaries exist between these systems so there is overlap as well. The reference systems are characterized based on the dominating species because these play the largest role in the system's function and structure. Also important to mention, is, that the soil on which all these ecosystems are based is generally quite basic. The following potential reference systems were discerned (Atlas de la Region de Murcia, 2018; Región de Murcia, 2018):

- Evergreen forest/woodland of Quercus rotundifolia. This is the main reference ecosystem for the project's locality (Chaparro, 1996; Conesa García, 2006; Rivas-martinez, 1987)

The area also holds potential for housing, and/or the current vegetation already shows certain aspects of, other reference systems, being:

- Ramblas with riparian vegetation
- Low open forest with Juniperus spp.
- Gypsophilous shrubland
- Pinus halepensis forest

FUNCTIONAL ATTRIBUTES

Ecosystem function is defined as the whole of ecological processes that follow from organisms interacting with each other and with their abiotic environment (Clewell & Aronson, 2013). Mediterranean ecosystems (MEs) are found in a few places around the world and their functionality is similar and can be explained in a general way.

Key characteristics

Typical of MEs is that they occur in climates with a cool wet winter and a warm dry summer (Esler, Jacobsen, & Pratt, 2018). Also, seasonal winds are common and play an important role in most MEs. In Spain it is called the 'Poniente'. It is a dry warm wind occurring in summer, it heats the land even more in the already dry and hot summer and consequently increases the risk of forest fires.

The precipitation in different MEs varies but is generally low and most MEs are classified as being arid to semi-arid climates. In the region of Murcia, precipitation ranges between 200 to 650 mm per year (Conesa García, 2006). Annual summer droughts form a barrier for most life forms and all are in some ways adapted to deal with the harsh circumstances. Furthermore, precipitation and droughts can be very irregular as well, showing much interannual variation. These irregularities, or in other words, the variation of annual droughts or wet years, greatly affect ecological processes such as seedling recruitment of trees and shrubs, primary productivity, reproduction of plants and animals but also affect the composition of ecosystems (Ferrán, Vayreda, & Ninyerola, 2009).

The general low water availability limits the primary productivity of MEs.

MEs are considered as biodiversity hotspots and they have a lot of endemic species (Esler et al., 2018)

Fire is also common in most MEs as a result of climatic circumstances. Fires occur as part of a fire regime with a certain frequency and intensity. In Spain, fires occur with an average interval of 50 to 100 years (Esler et al., 2018). Many plants have adaptations to cope with fire, they can either resprout from the stem or the root or they have seeds that can withstand fires (R. Vallejo, Baeza, & Chirino, 2009). The *Quercus rotundifolia* can, for example, resprout from its stem.

Humans have a large effect on MEs all over the world in the form of agriculture, logging, mining and urbanization. Especially in the Old world Mediterranean basin humans have shaped the landscape over the course of several ages and in most cases the landscape has many cultural components.

Vegetation

Plants have to adapt to the Mediterranean climate to: cold temperatures and in some cases frost, warm temperatures and associated heat and drought stress, disturbances of regular fires and of predation. Similar plant adaptations in similar climates have caused MEs over the world to look alike (Miller, 1983). As a result, evergreen vegetation with sclerophyllous (thick and leathery) leaves is common to most MEs.

MEs have a variety of vegetation types, such as forest, open woodland, low shrubland and grassland. More specifically, these vegetation types lie on a gradient relative to the amount of available water. In the region of Murcia, under the limit of 280 mm of precipitation solely shrubland occurs, in between 280 and 400 mm there is a transition zone where forest or shrubland can occur, depending on factors such as the slope's orientation, soil and small scale climatic effects, and above 400 mm it is more likely to have only forest. In addition, river valleys and areas with little soil such as rock outcrops are an exception to this basic rule. Note also, that the effect of the slope's orientation on vegetation type decreases as the precipitation goes up. This gradient of vegetation types related to precipitation in combination with the variety of soil substrates cause Mediterranean landscapes to be very patchy, different vegetation types form a mosaic. These mosaic-like characteristics affect much of the ecosystem's functioning and give a partial explanation for the high biodiversity. Different vegetation types provide different habitat for different type of organisms and generally provide different ecosystem services.

COMPOSITIONAL ATTRIBUTES

An ecosystem's composition basically consists of the species that inhabit the ecosystem and their relative proportions. Again, most emphasis is on the most dominant plant species because they form the fundament of the ecosystem. Faunal species composition has been described but was added to the annex. Moreover, plant communities can be characterized in many different ways. I have tried to look at different sources and combine these into one fitting picture.

The locality of La Junquera forms an interesting area in terms of species composition because it borders different biogeographical regions, meaning that you can find species that are associated with each of these different regions. These are:

On the continental or western side, the 'Betic' Province and the Province of 'Castellano – Maestrazgo – Manchega'. These two biogeographic 'provinces', generally harbour more species of mountainous and colder environments. On the other side, the eastern side and the side of the Mediterranean sea, is the 'Murciano – Almeriense' Province, floristically having more species of dry and warm environments (Instituto Geográfico Nacional, 2018; Rivas-martinez, 1987; Sánchez-Gómez & Guerra-Montes, 2011). Moreover, La Junquera lies next to the Andalusian Altiplano region, also a region with a unique flora (de la Cruz, Yanes, Sánchez, & Simón, 2010).

Moreover, La Junquera lies on the border of two bioclimatic zones, the supramediterraneo = >1100 m, those climates associated with mountainous areas, and the mesomediterraneo = >1100 – 400, those climates associated with plateaus.

Holm oak forest

The main reference system for the site is the **evergreen *Quercus rotundifolia* forest or woodland**. Forest has a closed canopy and woodland has a more open structure. Its distribution and species composition is described by different sources.

Following the main Spanish phytosociological work of Rivas-martinez (1987), the potential natural vegetation is most similar to the following plant community, or serie as it is called in phytosociology:

Serie 22B: Castellano-Aragonesa de la encina. Belonging to the holm oak forests (Q. rotundifolia) of Eastern Spain in meso(termo)-mediterranean regions. With the phytosociological name of *Bupleuro rigidi-Querceto rotundifoliae sigmetum = Asparago acutifolii-Quercetum rotundifoliae*.

The dominant tree species in this plant community is *Quercus rotundifolia*. Other species that are associated with different developmental stage of this vegetation type, are *Quercus rotundifolia, Rhamnus lycioides, Retama sphaerocarpa, Genista scorpius, Ephedra nebrodensis, Stipa tenacissima* and small shrubs or grasses of *Teucrium, Bupleurum, Thalictrum, Jasminum, Lavandula, Helianthemum* and *Brachypodium*.

Interestingly, most of these species are found on the La Junquera as well, which affirms that the selected serie applies to the site. Specifically, *Genista* is said to be associated with degraded shrubland (Rivas-martinez, 1987). This corresponds nicely with the conclusion of the site diagnosis; the vegetation is in a degraded state and *Genista scorpius* is common.

The reference system is classified by the EU habitats directive as ***Quercus ilex* y *Quercus rotundifolia* forests (9340)** (European commision, 2013) and by the EUNIS classification system as **Meso-Mediterranean continental *Quercus rotundifolia* forests (G2.12411) and/or Supra-Mediterranean Iberian continental *Quercus rotundifolia* forests (G2.12412)** (MAPAMA, 2017)**.** Two EUNIS classifications are given because La Junquera is located on the border of the Meso-mediterranean and Supra-mediterranean climate zones.

Another source, specifically focuses on the *Quercus ilex* and *Quercus rotundifolia* forests (Ferrán et al., 2009). They mention the following genera that dominate the understory on alkaline soils: *Juniperus, Genista, Erinacea, Thymus, Lavandula, Satureja*, *Asparagus*. Most of these genera are also found on the restoration site. With special regard is mentioned the shrub species of *Berberis vulgaris subsp. australis* also known as *Berberis hispanica*, which presence is associated with floristic influences from the biogeographical region of the Betic province. This species was also found on La Junquera, although not on the restoration site.

The same publication explains that, naturally, the Q. rotundifolia is the dominant tree but that many other tree species coexist with it, depending mostly on climate. For the location of La Junquera the Q. rotundifolia forests are most likely to provide habitat for tree species such as Juniperus oxycedrus, Juniperus phoenicea, Pinus halepensis and Quercus coccifera. In slightly wetter parts also Quercus faginea (a deciduous oak species) might occur. And in wetter and colder parts the Juniperus thurifera might also occur. Moreover, J. oxycedrus, J. phoenicea and Q. rotundifolia are mostly small trees and could be better viewed as understory species.

The interpretation manual for the natural and semi-natural habitats of the region of Murcia (Ariza et al., 2010) mentions several species in the understory: *Daphne gnidium, Pistacia lentiscus, Rhamnus* *alaternus, Quercus coccifera, Juniperus oxycedrus* and *Rhamnus lycioides subsp. lycioides,* of which the last three occur amply on la Junquera.

It describes the main substitutionary vegetation type as consisting mainly of Rhamnus lycioides and Quercus coccifera, and also frequently Pinus halepensis.

Other reference ecosystems

A few other vegetation types, or at least some aspects of them, also occur, or, could potentially occur, on the restoration site. These are:

Ramblas with riparian vegetation: A different vegetation grows in the valleys were groundwater is year-round accessible. On la Junquera the ramblas are currently most often covered by the grass-like bulrush *Scirpus holoschoenus*. Originally, many of these areas were covered by forests of several species. Species that are associated with the riparian vegetation, and of which most are also present on La Junquera, are: *Populus alba, Salix sp., Tamarix sp. Crataegus sp., Rosa canina, Quercus faginea subsp. faginea* and *Berberis hispanica.*

Low open forest with Juniperus spp.: In litosols, shallow stony soils, a different plant community is more likely to constitute the oak forest (Región de Murcia, 2018). It has species of *Juniperus phoenicea, Juniperus oxycedrus* and *Quercus coccifera*. Also, plant communities with *Rosmarinus officinalis*, *Thymus vulgaris* and other *Labiatae* occur often on shallow stony soils (Alvelal, 2017)

Gypsophilous shrubland: Through the help of the Murcian botanists I found out that a few of the species that were found on the site are associated with gypsisols, soils that are rich in gypsum. This indicates that at least a part of the soils contain enough gypsum for these plants to flourish. They are often rich in thymes (*Thymus*), germanders (*Teucrium*), rockroses (*Helianthemum*) and composites (*Centaurea, Jurinea, Santolina, Frankenia*) (European commision, 2013). At least 10 species that belong to those genera are found on site. More specifically, important gypsum indicators that were found on site are *Matthiola fruticulosa, Helianthemum hirtum and Ononis fruticosa* (Universidad de Alicante, 2018; P. Sánchez Gómez, personal communication).

Pinus halepensis forest: These forests are widely distributed in Murcia and have been the preferred species in past reforestations, making it difficult to ascertain what its natural distribution is (Conesa García, 2006). It is considered native for at least two-thirds of its expanse (European commision, 2013). The understory species composition is very similar to those of the holm oak forest and is made up of: *Asparagus acutifolius, Pistacia lentiscus, Rhamnus lycioides, Daphne gnidium, Thvmus vulgaris, Rosmarinus officinalis, Cistus albidus, Genista scorpius, Helichrysum stoechas, Sideritis leucantha, Phlomis lychnitis, Satureja sp., Teucrium polium, Stipa tenacissima and Juniperus oxycedrus* (Región de Murcia, 2018). Though being a potential vegetation for the site, most sources indicate that the Q. rotundifolia forest is the actual reference system. Nonetheless, it is included here because it can potentially occur in some patches or coexist with predominant oak forest.

	Dryland species	Wetland species
Trees	Quercus rotundifolia	Tamarix sp
	Pinus halepensis	Salix sp
		Quercus faginea
		Populus alba
Treelets	Quercus coccifera*	Crataegus sp.
	Juniperus phoenicea*	
	Juniperus oxycedra*	
	Retama sphaerocarpa	
Shrubs	Rhamnus lycioides	Rosa sp.
	Genista scorpius	Berberis hispanica
	Asparagus acutifolius	Scirpus holoschoenus
	Rosmarinus officinalis*	
	Cistus albidus*	
	Ephedra nebrodensis	
	Ononis fruticosa	
	Santolina chamaecyparissus	
	Artemisia sp.	
	Bupleurum frutescens	
	Thymus vulgaris*	

*Table 4: Dominant woody species of the reference ecosystem. * = Species that do well on shallow soils.*

<u>*STRUCTURAL ATTRIBUTES*</u>

Structural characteristics of an ecosystem include the spatial configuration of the system's species, horizontally; -density, distribution of species, vegetation patterns- and vertically; -stratification-. Moreover, it also includes the sizes, shapes and organization of physical (living & non-living) structures that provide habitat for animals, plants and fungi (Society of Ecological Restoration, 2016).

As mentioned before, Mediterranean vegetation is typical in that it has much environmental/spatial heterogeneity, in other words, Mediterranean landscapes have a patchy or mosaic-like vegetation consisting of different vegetation types (Blondel & Aronson, 1999). I primarily refer to a landscape scale (>1 ha) but also on a smaller scale (10 m^2) the vegetation is typically patchy (Tongway, Cortina, & Maestre, 2004). At the basis of this small-scale patchiness lies the scarcity of resources, the main one being water. Plants grow best in those spots that due to microrelief receive most water and nutrients. These spots are also being described as 'resource islands' (V. R. Vallejo et al., 2012).

Vertical stratification is, just like the spatial organization, very varied, primarily because of abovementioned environmental heterogeneity, which is in turn caused by variations in soil substrata, water availability, orientation, climatic aspects and human influences. Stratification is probably most diverse in a mosaic-like vegetation with patches of different plant communities. In a closed canopy holm oak forest the understory is generally poorer because the oaks take much of the space and available light (Ariza et al., 2010).

The main structural component in the holm oak forest is of course the individual itself. On average, the tree has a limited size (Ferrán et al., 2009). In a large scale inventory of holm oak forests (Ferrán et al., 2009), the quadratic diameter of all measured trees was 14,8 cm. The average height was 5,1 meter, with outer values ranging from 2 to 12,9 meter. In contrast to these numbers, on La Junquera there are a few very large and very old Q. rotundifolia trees, with at least a diameter of a meter.

Tree density of the Q. rotundifolia forest as explained by Ferrán et al. (2009) has an average of 870 stems per hectare for the region of Murcia (all stems of the inventory were >7,5 cm in diameter).

Moreover, the main reference ecosystem of a holm oak forest has, certainly when being older, plenty of dead wood and tree cavities in old trees. Both provide important and unique habitat for species that are almost exclusive to these kinds of habitats. On the other hand, an old-growth forest will also limit habitat for other species, such as rabbits for example.

Also, other structural elements that create different habitats are:

- Rock outcrops: They provide habitat for an exclusive set of plant species.
- Deep soils: those with plenty of organic matter will provide habitat for many soil organisms.
- Ponds: Bodies of surface water will attract a lot of species that otherwise would not occur.

HUMAN INFLUENCE ON THE SYSTEM

When looking at the landscape on La Junquera it easily becomes clear that humans have changed it in all kinds of ways. Although being a matter of perspective, the landscape could be seen as severely degraded or as being a cultural landscape. The precise history of the local land use is difficult to trace back. However, with the help of local experts and some literature it is possible to create an image of what happened. Land use goes back a long time because Murcia has been inhabited for many centuries already (Sánchez-Gómez & Guerra-Montes, 2011). In comparison to the other MEs, the old world Mediterranean basin has had human influences for the longest time (Aronson, Clewell, Blignaut, & Milton, 2006).

The land use that has been historically part of this landscape consists mainly of:

- **Grazing** with the local 'Segureño' sheep breed on natural areas. The lands that were difficult to cultivate were used for grazing. Grazing can, depending on the grazing intensity, put pressure on the development and regeneration of young plants, thereby turning succession towards a more open woodland instead of a closed forest. Many authors see overgrazing as a major driver of degradation and soil erosion, whereas others (Perevolotsky & Selig, 1998) advocate that (intensive) grazing is an important part of the cultural Mediterranean landscape.
- **Grain cultivation** has historically been very common in these regions and still is. It involves regular ploughing and generally causes high amounts of soil erosion. Its degrading effects are even more increased with the modernization and intensification of agriculture. On the restoration site, the zone which is planted with *Atriplex sp.* is clearly most recently used for agriculture, but other areas might as well have been used for crop cultivation longer ago. Unfortunately, no records are available for finding out.
- **Logging** for household fuel use and for making charcoal was for a long time an important and common rural activity. The *Quercus rotundifolia* has the ability to resprout so it recovers quite well after being cut. But nonetheless, much land remains without its original tree cover. Even if coppiced trees regrow, the vegetation's structure is affected.
- **Cultivation of Esparto grass (Stipa tenacissima):** Esparto was a much-demanded fibre crop in the region. Even though the Esparto grass is a sort of semi-natural type of vegetation, it still necessitated the removal of the natural vegetation.

2.3.3 Restoration practices

Ecological restoration and reforestation follow different principles in Mediterranean climates than in temperate climates. In temperate climates there is, for example, more emphasis on natural regeneration, whereas in arid climates direct planting is more common. Naturally, it is the difference in climate and ecological dynamics that deliver other challenges and that determine a successful outcome. In this chapter are explained the most common practices and the current state of the art regarding ecological restoration in South-eastern Spain.

PLANTING RESTRAINTS

The first and foremost restraint for establishing seedlings in this climate is the water scarcity in summer (V. R. Vallejo et al., 2012). Plants must endure the combination of high temperatures, high evapotranspiration and scarce rainfall.

Moreover, when seedlings are planted out and change from their nursery environment to the harsher conditions outside they experience a lot of short-term stress, called transplantation shock.

Due to these factors, mortality rates are often highest in the first year (Alberto Vilagrosa, Valdecantos, Cortina, & Bellot, 1997; Villamar, Vallejo, & Villagrosa, 2016). Chirino et al., (2009) mention that the key obstacles to plantation success are: 1) the post-transplant shock that seedlings experience after planting, and 2) the intensity and length of summer drought.

Many soil characteristics also play a key role in the establishment of new plants, in large because the soil is the medium that stores and distributes water to plants. Soil texture and particle size influence the soil's capacity for holding and transporting water. Fine-textured soils (clay) generally can retain water quite well, but a downside can be that the water is not available for plants because it is held too strongly in the soil's micropores (Alberto Vilagrosa et al., 1997). Also, organic matter content influences water holding capacity positively, a richer organic soil contains more water.

Soil depth, stoniness and compaction also influence the soil's capacity for water retention. A shallow soil simply has low volume to store water in (V. R. Vallejo et al., 2012), stones do not take up water at all, and compaction makes that water cannot infiltrate. Moreover, these are also factors that make it difficult for plants to create healthy root systems and hence impede establishment. Seedlings planted in soils shallower than 40 cm are said to have very low survival rates (V. R. Vallejo et al., 2012).

Another important soil aspect is microbial life. Many species of bacteria and fungi live underground in symbiosis with plants and are crucial for helping them access nutrients and water which would otherwise be out of reach (e.g. mycorrhizae and rhizobium bacteria) (Bardgett, 2005). In eroded, exposed or compacted soils, soil life is often very limited and thus cannot play their supportive role in the ecosystem.

Herbivory is a well-known challenge for restoration practitioners. It is standard practice in reforestation projects and also in fruit & nut tree plantations to put a protector, also named tree shelter, around the seedling. Herbivory is said to be the second most important cause of seedling mortality (after summer drought) (Jordano & Zamora, 2002).

At last, the overarching restraint is degradation because it influences and often reinforces all the other restraints. It causes soils to become more inhospitable, even more so with the absence of any vegetation. Moreover, if active soil erosion is present on site it can severely impede seedling establishment and growth. Thus, stopping active soil erosion has a priority in restoration.

SEEDLING SURVIVAL

Seedling survival after the first summer is an important indicator for plantation success. V. R. Vallejo et al. (2012) mention that seedling survival was related to the number of successive days with none or very little rain (<5mm per rain event). During severe droughts, mortality rates doubled. Interestingly, with the implementation of many of the later described restoration practices, the same pattern; mortality being proportional to the length of the dry period, is present as well, but, the severity of the mortality is much lower.

Survival rates of reforestation projects in SE Spain show a wide variation, ranging from very low to very high (Jordi Cortina, Peñuelas, Puértolas, & Savé, 2006). Below are shown some examples of survival rates in reforestation projects.

In a reforestation project in Alicante, near the Mediterranean Sea, survival rates for two different plantations were 12,3% and 30,8%, after respectively 12 and 11 years of being established. Lowest survival rates were encountered during the first years, where in the first year survival rates averaged around 47% (Villamar et al., 2016).

Another article mentions survival rates of 68,2 and of 29,6 after two years, the first being on soils that consist of marlstone deposits and the latter on soils that consist of limestone deposits. So, soil properties can greatly affect the survival rate (Jordano & Zamora, 2002), varying, however, a lot per species.

Yet another article mentions a survival rate of 51% after 16 months specifically for *Quercus ilex*, one of the main species that will be planted.

At last, in another study they observed an average survival rate of 50% after 6 years for a variety of species (A. Vilagrosa et al., 2001)

RESTORATION PRACTICES

In determining the restoration outcome there is a whole set of variables that can be influenced. To respond adequately to the difficult conditions, a lot of techniques have been developed, some based on old traditions, others on scientific inquiry. Most reforestation projects in SE Spain perform seedling planting instead of letting natural regeneration do the work because most woody species recover very slow and most woody late-successional species do not form a seed-bank (Jordano & Zamora, 2002).

Erosion control

Stopping active erosion processes has priority above re-establishing native vegetation because continuous soil loss can severely disrupt ecosystem function (Tongway & Hindley, 2004). Erosion prevention or repair in an early stage is simply much cheaper and easier than repair (in a late stage) (Bainbridge, 2007).

Stopping erosive processes starts with slowing water run-off speeds and reduce run-off rates altogether. In erosion channels such as gullies and rills this is normally done by placing dam structures at regular intervals. Run-off in sheet erosion processes is reduced typically by mulching/brushpacking the soil with such materials as branches, straw or jute textile. The mulching improves germination and growth conditions for plants (Tongway & Ludwig, 1996).

Furthermore, it is essential to revegetate the treated slopes and the rills with woody species to, in time, provide soil protection during rain events, cover the soil with litter, and intercept soil and water runoff (Tongway & Ludwig, 2012)

Plant species selection

This is the most basic variable that can be influenced. First of all, the selected species must be well adapted to the local climate, soils and types of disturbance. To ensure successful establishment, species selection should be mainly based on the native flora and vegetation of the area, as they are naturally best adapted to the local conditions (V. R. Vallejo et al., 2012). Moreover, species selection depends largely on the specific restoration objectives. The main objective of this project is to establish a vegetation made up of native species that originally would occur on site. Many of these are so-called late-successional species such as *Quercus spp.* Many works comment that late-successional species are difficult to establish in degraded circumstances (R. Vallejo & Alloza, 1998), however, with thanks to recent research, better results are being obtained (Aronson et al., 2006; Baeza, Valdecantos, & Vallejo, 2005). With regard to the project site, the vegetation is degraded but still relatively lush, so to which degree this will impede the establishment of late-successional species is debatable.

Seeding

Seeding is an attractive option for restoration because it is cheap and has low impact during field operations (Andel & Aronson, 2012). However, processes of predation, germination and establishment all strongly limit plant establishment, thereby not making it a very favourable technique (J. Cortina et al., 2011). A planted seedling simply has much better defence against external influences than a seed. Nonetheless, seeding still might be attractive under some circumstances. In that case the process can be positively influenced by germinating the seeds before sowing and sow them in favourable microsites, where they have more shade and less predation risk (Chirino et al., 2009; A. Vilagrosa et al., 2001). Moreover, in a seeding experiment it turned out that using treeshelters, greatly increased the germination and survival, because predation by small rodents was high (Chirino et al., 2009)

Planting stock quality

Over the last decades, nurseries have done much effort to improve seedling quality. The goal of improving seedling quality is to improve establishment success by reducing drought stress and transplantation shock. Basically, the improvements in seedling quality mean that a higher survival rate can be obtained.

Most important seedling quality features are based on the work of Chirino et al. (2009), J. Cortina et al. (2011), Jordi Cortina et al., (2006) and Alberto Vilagrosa et al., (1997):

Containers:

- Container depth: Deep containers allow species with a long tap root (all *Quercus spp.*) to develop a better root system with a longer tap root that will reach deeper soil levels quicker, thereby improving the survival rate. Chirino et al. (2009) achieved positive results in experiments with containers of 30 cm long, with a volume of 589 cm^3.
- Container size: In general, larger containers improve the species establishment (Alberto Vilagrosa et al., 1997). Chirino et al. (2009) used in their experimental restoration project a container of 400 cm^3.
- Container type: Containers that have lateral ribs are beneficial because they impede root spiralling and stimulate the development of secondary roots.

Substrate: The type of substrate influences water holding capacity. The combination of coco fibre and peat (50:50) works well. In addition, the adding of hydrogel, a substance that can absorb a lot of water and make it available for plants, can greatly increase the water availability for the seedling.

Pre-conditioning: Certain nursery protocols can help to activate the plant's mechanisms of drought adaptation and prepare them better for the transplantation. Chirino et al. (2009) used the following procedure: 1) cultivation in direct sunlight for 9 months in the nursery, in a similar climate as the restoration site, 2) Watering was given when the seedlings needed it, so to avoid giving too much water, 3) Close to the end of the cultivation, several drought cycles were applied to activate the drought mechanisms of the plants.

Fertilization: There is a consensus that addition of fertilizers (mainly nitrogen, phosphorus and potassium) increase seedling establishment and survival rate in semi-arid climates. Moreover, nutritional hardening, applying less nutrients at the end to stimulate mechanisms of stress-resistance, is still in development, but already shows promise (Chirino et al., 2009).

Timing

The timing aspect is not very variable. The best time to plant seedlings or seeds is in autumn. Seedlings will then receive most water before the summer drought starts. In very dry areas, it is advisable to carefully plan the planting prior to a significant rain event (Jordi Cortina et al., 2006). Even on La Junquera, which is less dry than many coastal areas, it might still be wise to strategically plant out shortly before a rain event.

Planting densities

The density with which seedlings are planted is an important variable. In essence, planting density + survival rate + growth will eventually determine the development of the vegetation's composition, structure and functioning. The density of planting depends on many things; soil, relief, climate, species and of course on the objectives. If, in my case, the objective is to re-establish a native forest, then a planting density is based upon the average density of such a forest. Various sources indicate a varying planting density, ranging from 400 to 2500 plants per hectare (Chirino et al., 2009; J. Cortina et al., 2011; F Bautista Expósito, personal communication).

Microsite selection

A relatively new approach within ecological restoration in arid or semi-arid climates makes use of the concept of microsite selection. It consists of planting out seedlings in spots that have favourable conditions for seedlings, those spots that; receive more rain-water, have more nutrients, have a cooler, shaded microclimate, etc. If no proper microsites exist, then these can be made as well by creating micro-watercatchments for example. The development of this approach is based upon the ecological characteristic of vegetation in arid climates to exhibit small-scale patchiness (as described in the chapter on compositional attributes). Potential downsides of microsites are that more time is needed for selecting or making them. Moreover, mechanical digging of planting holes might become extra challenging because machinery can easily damage the favourable microsite conditions (J. Cortina et al., 2011)

Important 'microsite creators' are those plants that generate facilitative interactions for neighbouring seedlings, also known as 'nurse plants' (V. R. Vallejo et al., 2012). They provide lower temperatures, a soil rich in organic matter, higher water availability and a lower soil penetration resistance. Examples of nurse plants are *Stipa tenacissima* and spiny shrubs (which protect from grazers) such as *Genista scorpius* and *Rhamnus lycioides* (V. R. Vallejo et al., 2012). There are studies that found significant higher survival rates of seedlings under nurse plants than seedlings planted out in the open (Castro & Zamora, 2004). Even though there is proof that some plants have a facilitative effect, not all large woody species function as nurse plants, and so, much uncertainty remains about how to effectively use this restoration strategy.

Photo 8 A young oak has established itself in between a dead Atriplex bush, an example of a favourable microsite

Soil preparation

Various techniques relating to the soil have been developed, mainly aimed to help seedlings survive periods of drought. These include:

- Deeper planting holes: One study demonstrates that when planting hole depth is increased from 40 to 60 cm, seedling performance increases by 15% (Alloza, 2003). The rationale behind is that the seedling's root system will quicker reach the soil layers that retain more moist in summer droughts. In an ecological restoration project in Alicante, the used hole size is 60x60x60 cm (Chirino et al., 2009). Another source mentions a size of 40x40x40 cm (Jordi Cortina, 2015) Different sources recommend digging holes mechanically because it is faster, cheaper and holes are generally of better quality than if done by hand. Of course, machinery has the disadvantage of creating compaction, damaging vegetation and having limited access to difficult terrain.
- Digging holes in advance: A few local experts mentioned that it is of vital importance to dig holes 1 to 2 months in advance, for improving the soil structure and aerating the soil. However, there is a lack of scientific literature on the specific method (J. Cortina, personal communication).
- Water runoff harvesting: The aim of this method is to intercept water runoff in a rain event and divert it to the planted seedling. This is, for example, done by creating 'micro-dams' around a planted seedling in a V-shape. So, the water that comes from up-slope will get caught in the created small water catchment and will infiltrate to where the young plant can access it. In essence, this method creates a microsite which has on average more water. In one restoration project they found it increased survival rates (Chirino et al., 2009).

Soil amendments

- Mulching:
  Mulching is the covering of the ground with materials such as straw, wood chips, cardboard, stones, etc. it helps to reduce erosion because it softens the impact of falling raindrops, it helps water infiltration and avoids soil crusting. In addition, mulching reduces soil temperature and consequently also evaporation, also it helps to suppress weeds. Some studies have recorded positive effects of mulching on survival rates in SE Spain (Jiménez et al., 2016). Traditionally, stone mulches were used in drylands such as SE Spain.
  Mulches can also be combined, for example, cardboard and stones (Kilby, 2010).
- Compost:
  Mediterranean soils are typically low in organic matter and have low phosphorus availability. The addition of organic matter improves soil structure and soil fertility (V. R. Vallejo et al., 2012) Jordi Cortina said they used 1 kg. of compost per planting hole but commented that that is at the high end, so 0,75 kg. would also suffice (J. Cortina, personal communication).
- Hydrogels:
  A novel type of soil amendments are hydrogels. It is a type of hydro-absorbent polymer that is able to retain a lot of water and make it available for plant roots. Studies have shown that the use of hydrogels can significantly increase water retention in the soil, thereby promoting the performance of seedlings. However, in another study (Chirino et al., 2009), conducted in Valencia, the effects of hydrogel on seedling performance were measured to be low.
- Bio solids:
  Biosolids are a residue of (municipal) waste water treatment plants and they contain a lot of organic matter and nutrients. They are applied to promote seedling establishment. In theory it is a win-win situation because it is a rest-product which is turned into a useful resource. However, in practice there are quite some downsides and their use is debatable. Foremost,

they can contain heavy metals. Moreover, research showed that biosolids often have no or negative effect on seedling survival

- Mycorrhizae:
  Soil biology and specifically soil fungi such as mycorrhizae are essential partners of many plants because they help the plant to access water and minerals which would otherwise would be inaccessible. If a soil is very degraded, soil life often is also limited. So, in such a case it can be wise to inoculate plants with the native soil organisms when they are being planted out (Bainbridge, 2007). In this way populations of soil organisms can be restored. If restoration is done in an already vegetated area it is questionable whether most soil organisms would not already be present.

Tree protection

Grazing by wild ungulates is an important planting restraint. The most common solution is the use of treeshelters, tubes that protect the stem and leaves of the tree. It is mainly intended for protecting against herbivores but according Chirino et al. (2009) inside the tube is created a beneficial microclimate, and, the tube also protects seedlings from the drying effects of the wind. However, ventilated tree shelters should be used so that excessive is avoided. (V. R. Vallejo et al., 2012). Bellot, Urbina, Bonet, & Sánchez (2002) state that a tube of 30 cm in height improved growth.

Bird-mediated restoration

Birds distribute seeds of many different plants through their faeces. Most often, they poop out the seeds when they are sitting on a tree or bush. This is why natural succession on sites with trees or bushy vegetation is faster than on open sites without. This ecological process has been put to use in restoration, so far mostly in tropical forests, but it could be functional in drylands as well. Perches of woody structures could be set up to attract birds and to stimulate seed distribution. In addition, if the vegetation composition lacks certain species, these can be introduced by putting these seeds in feeding stations. Though, it is then required that these seeds are a food source for seed-eating birds.

Irrigation

Irrigation is seldom used in restoration projects in Mediterranean areas because the costs are simply too high. As a result, much emphasis is put on maximizing efficient water use by catching as much rainwater as possible and leading it to the seedling, and, reducing evaporation. Also seedlings can be manipulated to reduce their water usage (V. R. Vallejo et al., 2012)

3. Program of Requirements

I envision the site in 30 years as a young forest with a diverse structure. An increased habitat diversity makes that animal species occur that otherwise would not have occurred here. The site has more shaded places, and the (soil) temperature is generally lower than before. The young forest has initiated the creation of forest soil by litter accumulation. The vegetation cover increased and there is considerable less bare soil. The site has increased in biodiversity. The site has turned into a place where people like to come and one that serves to inspire people to implement more ecological restoration in the region.

The plan requirements that are specified here are based on the wishes of the client, the problem analysis, the site diagnosis, the determined reference system and the investigated research methods.

3.1 General requirements

1. Monitor the restoration development to inform further restoration on the farm.
2. Use simple and cheap solutions and preferably with local materials.
3. Apply proven restoration methods to increase survival rate: 1) Selection of best adapted species, 2) Digging deep holes of 60 cm, 3) Maximize water use efficiency with micro-catchments, 4) Use (potential) facilitative interactions of Atriplex shrubs, 5) Compost, 6) Mulch, 7) Tree shelter, 8) Use of high-quality seedling stock
4. Erosion control is prioritized to stop any further soil loss and stabilize the soil.
5. Create where possible an added value for the farm in terms of productivity, functional biodiversity (pollination and biological pest control) and aesthetics.
6. The species selection is based on the potential natural vegetation and the reference ecosystem of Holm oak forest as described in the chapter of the reference ecosystem.

3.2 Conservation requirements

7. Minimize disturbance during fieldwork:
   7.1. Minimal damage to vegetation, with extra regard for protected and rare species, these being *Ephedra nebrodensis* and *Onosma tricerosperma*
   7.2. Limit compaction by heavy machinery as much as possible.
   7.3. No intensive labour during bird breeding season.

3.3 Requirements for restoring compositional attributes

8. Use native key-stone woody species to restore the structure, composition and function associated with the reference ecosystem. The selected species are represented in the reference ecosystem chapter.
   8.1. Planting of the selected species is based predominantly on soil humidity (wetland soils vs drylands) and soil depth.

3.4 Requirements for restoring structural attributes

9. Increase vegetation cover through the planting of native key-stone woody species.
10. Create a more diverse vegetation structure through the planting of native key-stone woody species.
11. Target planting density is 600 trees per ha. This is informed by the average reference ecosystem's density of 870 per hectare but adjusted to be a bit lower so the forest will have a more open structure.

3.5 Requirements for restoring functional attributes

12. A pond is installed to retain more water on the site and increase habitat diversity.
13. Soil protection and formation processes are recovered with the planting of native key-stone woody species.

4. Plan development

4.1 Proposed restoration actions

Here an overview of the proposed restoration actions is given.

4.1.1 Erosion control

Erosion control has priority above other restoration practices to prevent further soil loss. The measures that are targeted were identified during the site diagnosis. The gullies marked with an X (see map) are largest and should be treated first. Not all erosion channels will need check dams. The work must be done manually because the channels are not well accessible, and the work is too precise for an excavator. The proposed method for checking erosion is comprised of the following steps:

	Steps
1	The largest erosion channels will be filled up with check dams of approximate 40 cm high at an interval of 10 meters . Check dams are made of stones gathered in the surroundings and of cut Atriplex branches. The stones are placed into a hole that is dug on the bottom and into the sides of the channel. This is done to prevent the water to erode the check dam at intense rain events. When the stone wall is build, Atriplex branches are put at the upslope side of the dam to help intercept water and soil runoff. A video of the Government of Malawi (2016) clearly instructs the proposed technique.
2	In case the erosion channel and the surrounding slope has much bare soil, this will need to be mulched with Atriplex branches which come from the site. Other materials such as straw will also suffice. In case of small erosion channels with little erosion, step 1 can be skipped and these can be just mulched, specifically applying mulch more thickly to spots that show more erosion (Tongway & Ludwig, 1996).
3	At last, on the long-term vegetation cover must be provided to restore ecosystem functioning, which will protect and build soil. Vegetation cover is made up of species that are mentioned in the next subchapter.

Table 5 Steps of erosion control

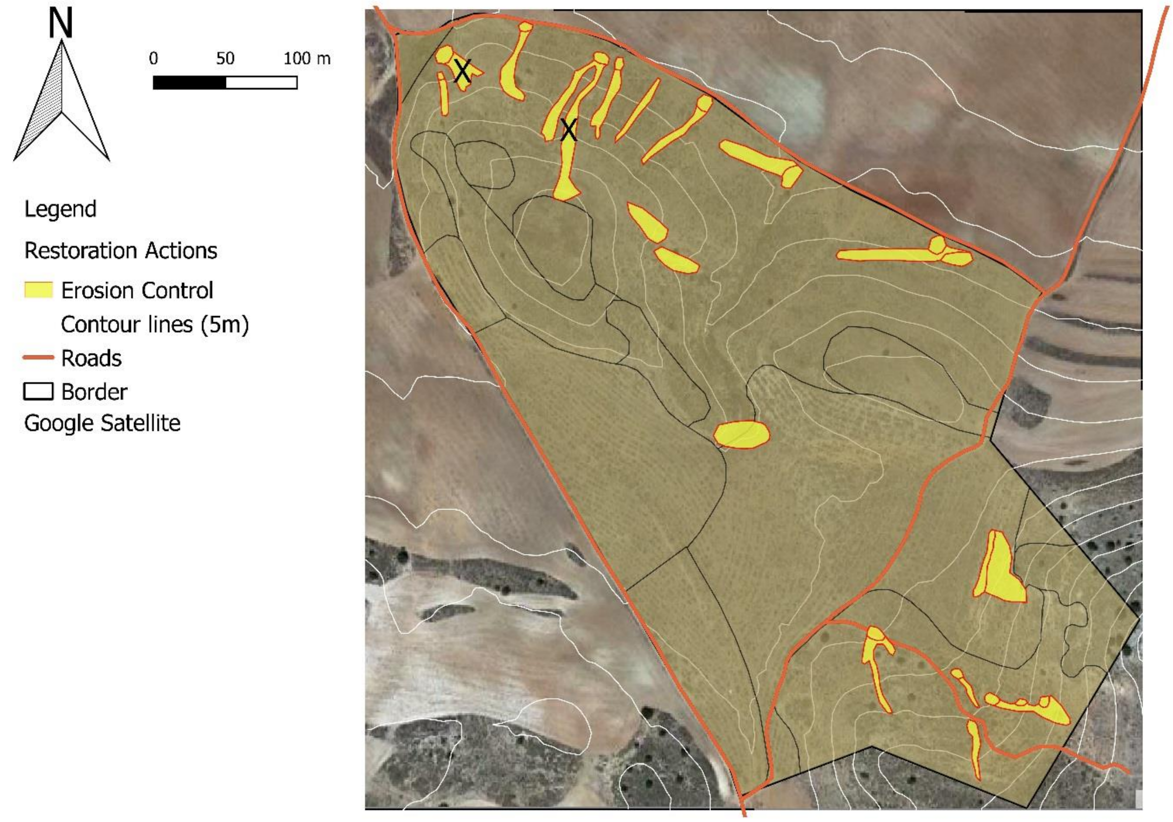


Table 6 Localization of erosion control measures

<u>*Cost estimation*</u>
The use of local materials, the stones and the Atriplex branches, will reduce costs. However, labour will have to be done manually as the terrain is not well accessible. It is estimated that manual labour will cost 640 € for making all dams and that 80 manhours are needed. For the complete calculation see annex.

4.1.2 Establishing native species

The establishment of native woody species is at the core of this project and it is the main way of restoring the reference system's composition, structure and functioning. Approximately 12 ha will be planted with native species to re-establish the composition, structure and function of the reference system. Different zones are defined which have a slight different approach based upon differences in soil, terrain or vegetation. Some considerations that influence the design process are treated below.

Seedling quality

I recommend to check and evaluate seedling quality before purchasing using the summary of quality features as described in the chapter on restoration practices. If a large stock of seedlings is ordered a long time upfront it might be possible to have the nursery follow a certain growing protocol. Moreover, I advise to buy from a nursery that has already experience in these kinds of techniques.

Planting & Survival rates

Based on literature research on survival rates of local reforestation projects, I assume that a survival rate in between 30 – 50 % is well attainable. Actual survival rates are difficult to predict because they depend largely on uncontrollable weather conditions. Planting can be phased over the first years to be able to better respond to varying survival rates. For example, when 800 trees are planted and after the first year 50% died, then the next autumn yet another 400 can be planted in the holes with the dead trees to increase the final density. Additionally, this is a way to spread out costs and labour over a longer period.

Planting density

As the goal is to initiate the re-establishment of the reference ecosystem I will look at the average density of a Murcian Holm Oak forest, which is 870 stems per ha (Ferrán et al., 2009). However, because the precipitation on the site averages around 300 – 350 mm per year, it is just on the border of an ecotone, there were open woodland is substituted by closed canopy forest (see reference ecosystem chapter). Taken that into regard, I propose to take a lower target density of 600 trees per ha. This will create a more open forest, thereby decreasing the risk of planting a higher density than that a natural system actually could support (J. Cortina et al., 2011). This density will, however, establish plenty of seed dispersers that accelerate the natural regeneration process of woody species, so that in ± 60 years a forest can grow denser if it has a natural tendency to it. Additionally, a lower planting density is economical because considerable less work and costs are involved.

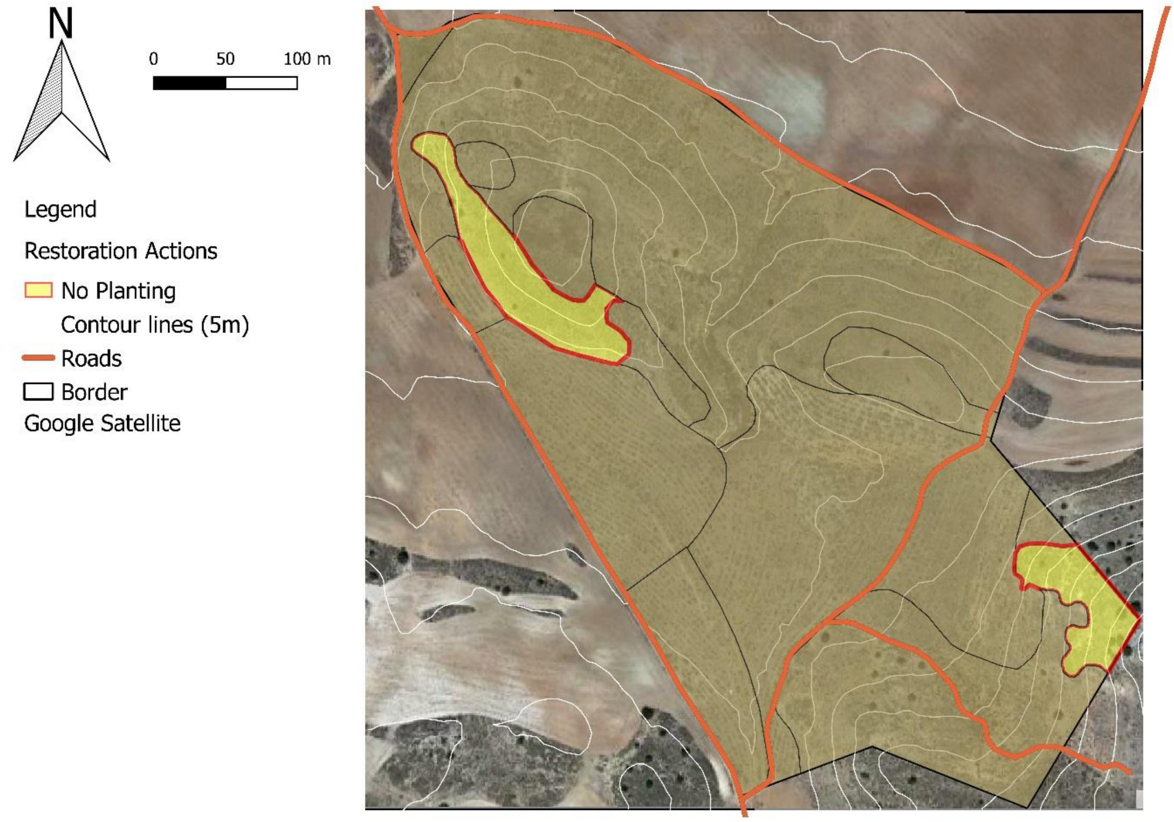
The intended density of 600 trees per ha is achieved by an initial higher density of 800 trees per ha. The second year, depending on the survival rate, a replanting can be done to achieve the intended density.

Digging & Disturbance

Ideally, as little compaction and damage to vegetation as possible is caused during digging. However, there must be a compromise between caution and workability. Mechanized labour is much quicker and consequently cheaper, and holes are generally better dug by a machine than by hand. The downside is that most heavy machinery damages vegetation and causes compaction, depending on weight and machine type. Digging mechanically is recommended if possible, regarding that disturbance is minimized. Use, if possible, a small low weight caterpillar excavator or spider excavator to minimize compaction. Moreover, field operations with heavy machinery should not be done during spring, when most plants flower.

No Planting

Some areas are not planted to conserve some of the current vegetation, e.g. the Esparto grassland (Stipa tenacissima) and maintain a structurally diverse landscape. Moreover, Esparto grass provides the soil with protection against erosion, therefore the large grass is left as it is on the steep slopes. The areas where no action is taken comprise 1,038 ha.



Map 8 Areas that are not planted

Zone A

This zone is considered the standard as no special considerations regarding restoration apply to it. With 8 ha it is also the largest zone. It covers land that is now mainly occupied by Genista – Santolina – Thymus vegetation. It consists primarily of sloped land and most erosion was observed in this zone. Species selection is based on the main ecological reference of Quercus rotundifolia forest/woodland. The proposed planting density is 800 trees per hectare. During planting activities extra care should be taken of the rare species Onosma tricerosperma and Ephedra nebrodensis which location is included in the map.

Proposed site preparation methods:

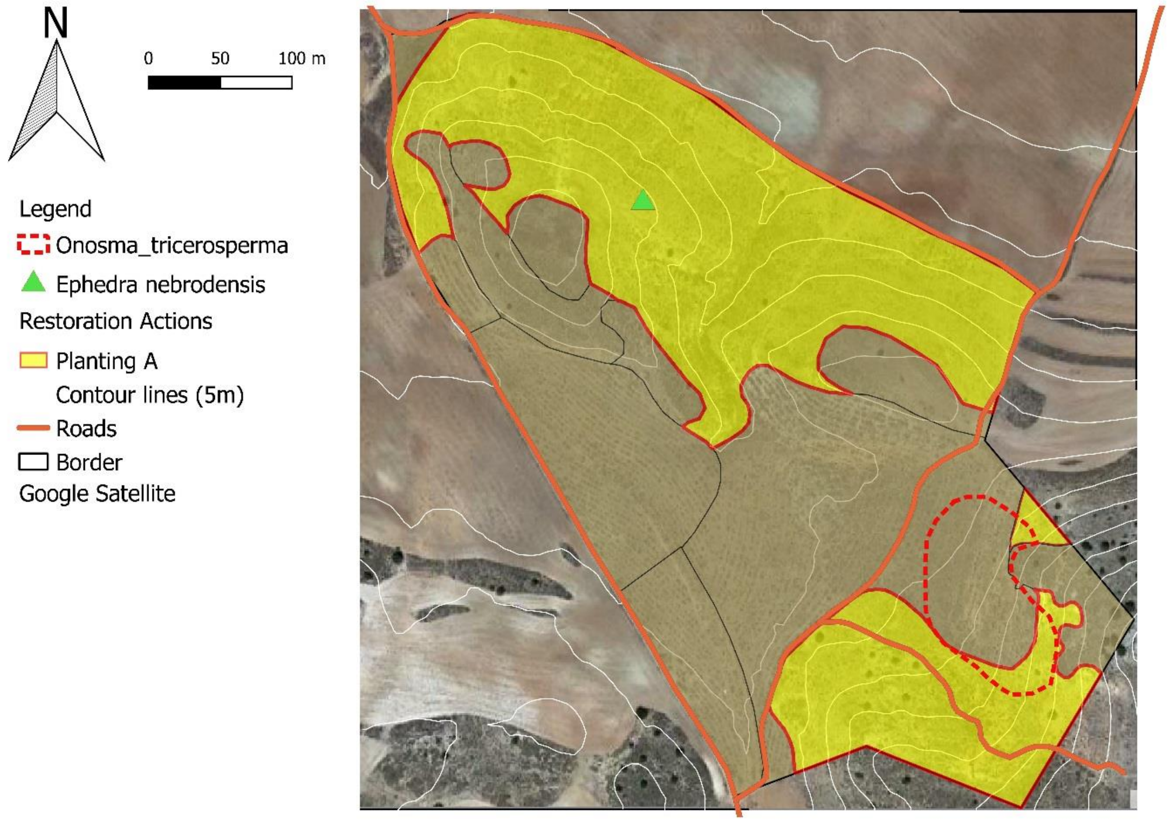
METHOD	DESCRIPTION
Digging	Mechanically if possible, regarding that disturbance is minimized
Deep holes	Holes with a depth of 60 cm. Dimensions of 40x40x60 or 60x60x60 are common
Compost	Add 0,75 kg of compost per hole. Mix it slightly with the earth in which the seedling is placed.
Cardboard Mulch	Place uncut cardboard around the seedling and cover it with rocks to keep it fixed. Approximately 0.75 m² per tree.
Microcatchments	On sloped land make small V-shaped diversion dams, each side of the V should be approximately 1 meter and the seedling should be at the bottom of the V.
Treeshelter	

Table 7 Site preparation methods Zone A

Species selection:

SPECIES	%	AMOUNT
Quercus ilex subsp. rotundifolia	65	4160
Pinus halepensis	5	320
Quercus coccifera	5	320
Juniperus phoenicea	5	320
Juniperus oxycedra	5	320
Retama sphaerocarpa	5	320
Rhamnus lycioides	5	320
Rosmarinus officinalis	5	320
SUM	**100**	**6400**

Table 8 Species selection Zone A


N
0
50
100 m
Legend
Onosma_tricerosperma
Ephedra nebrodensis
Restoration Actions
Planting A
Contour lines (5m)
Roads
Border
Google Satellite

Map 9 Zone A

Zone B - Atriplex

This zone is in terms of seedling species selection not any different than zone A but it is selected as a different zone because it is covered with a different vegetation of Atriplex – Artemisia – Santolina. The presence of the large Atriplex shrubs allow to test if they can function as nurse plants by planting seedlings on the shadier north side of the shrub. Unfortunately, a lack of literature on facilitative effects of Atriplex species makes it difficult to predict the outcome, but nonetheless, it is worth trying it out. Zone B covers 3,5 ha and the proposed planting density is 800 trees per ha. The rare Onosma tricerosperma is found in this area so field work should be done with caution and in the right time of the year.

Proposed site preparation methods:

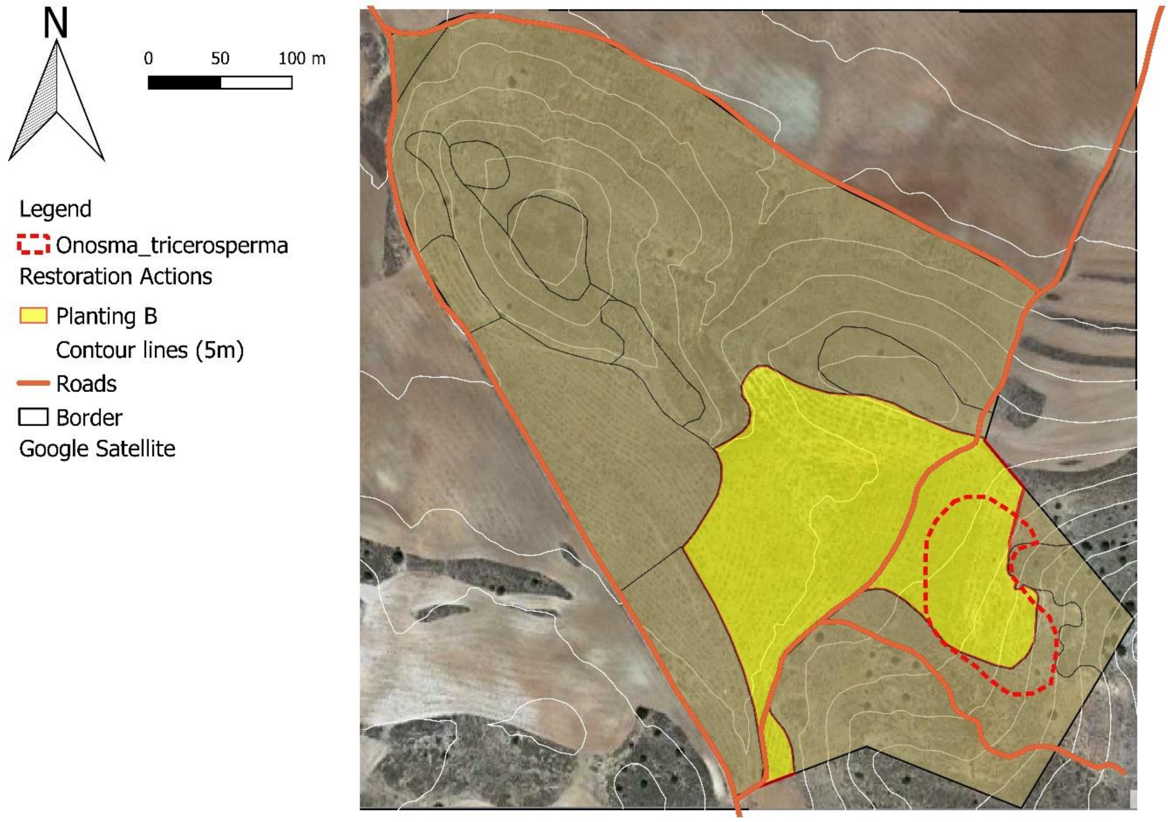
METHOD	DESCRIPTION
Digging	Mechanically if possible, regarding that disturbance is minimized
Deep holes	Holes with a depth of 60 cm. Dimensions of 40x40x60 or 60x60x60 are common
Use Atriplex as nurse plant	Dig a planting hole on the north side of an Atriplex bush, right next to the plant.
Compost	Add 0,75 kg of compost per hole. Mix it slightly with the earth in which the seedling is placed.
Cardboard Mulch	Place uncut cardboard around the seedling and cover it with rocks to keep it fixed. Approximately 0.75 m^2 per tree.
Microcatchments	On sloped land make small V-shaped diversion dams, each side of the V should be approximately 1 meter and the seedling should be at the bottom of the V.
Treeshelter	

Table 9 Site preparation methods Zone B

Species selection:

SPECIES	%	AMOUNT
Quercus ilex subsp. rotundifolia	65	1820
Pinus halepensis	5	140
Quercus coccifera	5	140
Juniperus phoenicea	5	140
Juniperus oxycedra	5	140
Retama sphaerocarpa	5	140
Rhamnus lycioides	5	140
Rosmarinus officinalis	5	140
SUM	**100**	**2800**

Table 10 Species selection Zone B



N
0 50 100 m
Legend
Onosma_tricerosperma
Restoration Actions
Planting B
Contour lines (5m)
Roads
Border
Google Satellite

Map 10 Zone B

Zone C - Shallow Soils

This 1 ha zone is made up of the hill tops and ridges which have in common that they are most likely to have shallow soils. Species selection is based upon the type of vegetation that would occur on these soils (see chapter on reference ecosystem). In addition, a relatively large amount of Rosemary is planted to support wild pollinator populations and to, on the long term, enable beekeeping on site. Proposed planting density is 1600 seedlings per ha. This is relatively high because survival rate is expected to be lower due to more extreme conditions.

Proposed site preparation methods:

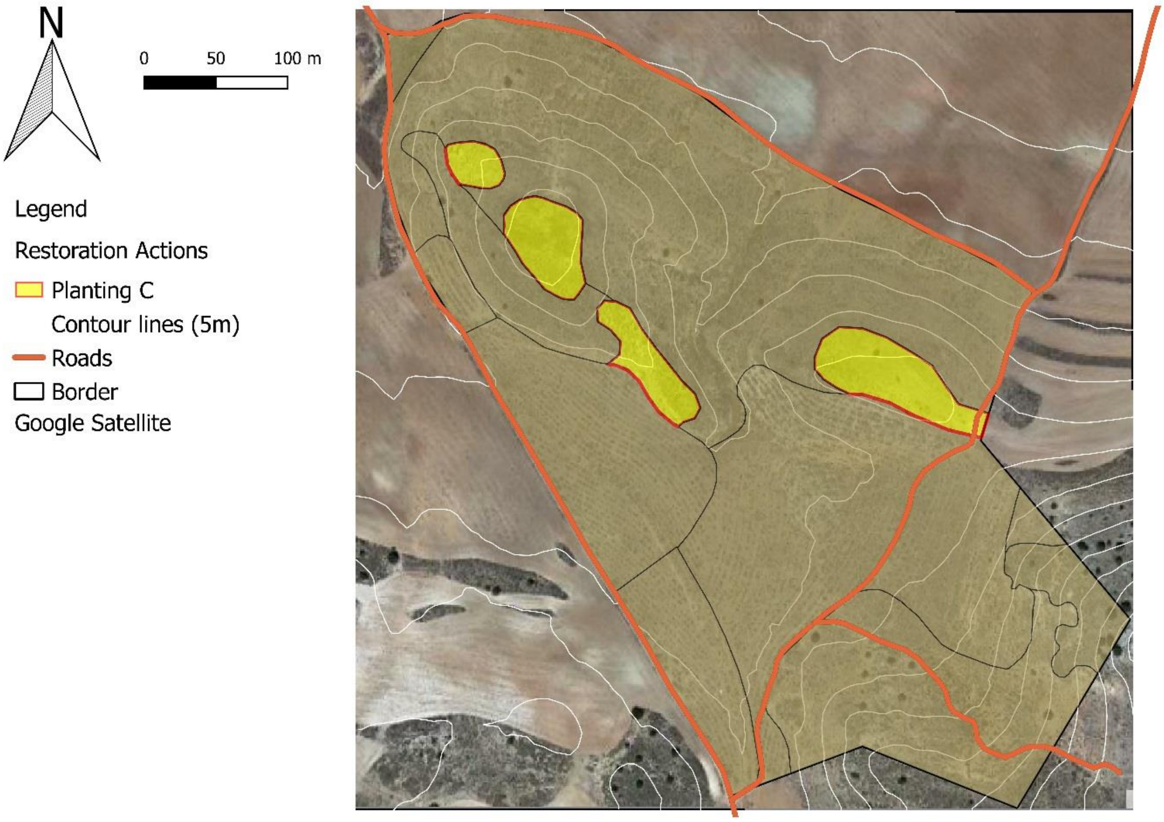
METHOD	DESCRIPTION
Digging	Mechanically if possible, regarding that disturbance is minimized. Possibly, digging in a too shallow soil will not be effective, or might even be counterproductive.
Deep holes	Dig holes as deep as possible. The preferred depth of 60 cm is most likely not possible in most cases.
Compost	Add 0,75 kg of compost per hole. Mix it slightly with the earth in which the seedling is placed.
Cardboard Mulch	Place uncut cardboard around the seedling and cover it with rocks to keep it fixed. Approximately 0.75 m² per tree.
Microcatchments	On sloped land make small V-shaped diversion dams, each side of the V should be approximately 1 meter and the seedling should be at the bottom of the V.
Treeshelter	

Table 11 Site preparation Zone C

Species selection

SPECIES	%	AMOUNT
Juniperus oxycedrus	22,5	360
Juniperus phoenicea	22,5	360
Quercus coccifera	25	400
Rosmarinus officinalis	30	480
SUM	100	1600

Table 12 Species selection zone C


N
0
50
100 m
Legend
Restoration Actions
Planting C
Contour lines (5m)
Roads
Border
Google Satellite

Map 11 Zone C

Zone D - Wetland

The wetlands occupy a very small surface on the site but they provide a unique habitat for plants and animals which makes them important out of a biodiversity perspective. I only recommend planting a few plants near the most northwest wetland. I recommend to plant **6 *Quercus faginea* and 6 *Berberis hispanica*** seedlings, relatively close to the pond. Planting should happen at the same time the pond is dug. If possible, these seedlings can be bought in large containers to help them establish.

Proposed site preparation methods:

METHOD	DESCRIPTION
Digging	Mechanically if possible, regarding that disturbance is minimized
Deep holes	Holes with a depth of 60 cm. Dimensions of 40x40x60 or 60x60x60 are common.
Compost	Add 0,75 kg of compost per hole. Mix it slightly with the earth in which the seedling is placed.
Cardboard Mulch	Place uncut cardboard around the seedling and cover it with rocks to keep it fixed. Approximately 0.75 m^2 per tree.
Treeshelter	

Table 13 Site preparation Zone D

Zone E - Seeding

Planting can be expensive and thus financially less attractive for those interested in implementing ecological restoration. Even though literature mentions that seeding is unpredictable and has low success rates, it still can be interesting to test whether the ease and low-cost of this method compensates lower survival rates. The species in the species list are all setting seeds on the farm and these can be readily collected and seeded. In addition, seedlings of the rare Ephedra nebrodensis are not sold by nurseries so seeding might help to establish this species more broadly. Survival can be improved by seeding at 15 cm deep and by protecting the seed with a protector tube (Oliet, Vazquez de Castro, & Puértolas, 2015). However, I propose to not use the tree shelter to keep costs low. The seeding zone covers 0,2 ha.

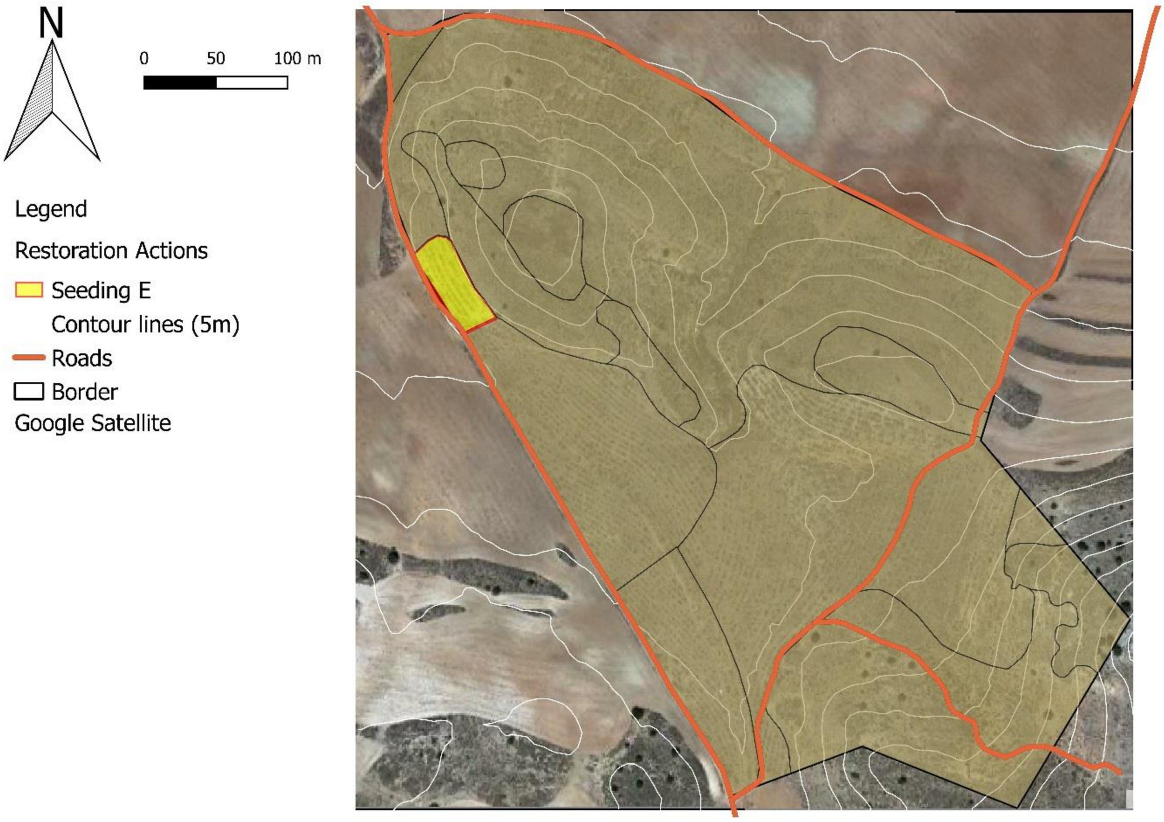
	STEPS
1	Collect seeds on the farm
2	Pre-germinate by soaking in water
3	Seeding: Dig small holes and put a handfull of seeds in. Moreover, during seeding, benefical microsites can be selected

Table 14 Preparation Seeding

Species selection

SPECIES
Quercus ilex subsp. rotundifolia
Quercus coccifera
Juniperus phoenicea
Juniperus oxycedra
Ephedra nebrodensis

Table 15 Species selection zone E



Map 12 Seeding zone

Cost estimation

The price per hectare for the different planting zones was calculated out of costs of machine rent, labour, seedlings and planting materials. These calculations can be found in the annex.

Some considerations concerning the cost estimation:

- In difficult terrain work, be it mechanical or manual, is generally slower and so costs are higher. This has not been accounted for strictly in this calculation.
- The use of compost and cardboard has not been included in the calculation based on the assumption that compost will come from the own farm's compost plant and the cardboard will be collected for free.
- Zone D, the wetland is not included in the cost estimation because the costs of the few seedling and little labour involved is insignificant.
- Zone E is also not included because I assume that this will be done by volunteers, by me or the client himself.

Restoration actions →	ESTABLISHING NATIVE SPECIES		
	Zone A	Zone B	Zone C
Total hectares	8	3,5	1
Man-hour per hectare	98	98	196
Planting density (trees/ha)	800	800	1600
Cost item			
SITE PREPARATION			
Digging	€ 568,32	€ 568,32	€ 1.136,64
MANUAL LABOUR			
Planting	€ 640,00	€ 640,00	€ 1.280,00
PLANTING MATERIAL			
Seedlings	€ 400,00	€ 400,00	€ 800,00
Treeshelters	€ 400,00	€ 400,00	€ 800,00
TOTAL PRICE PER HECTARE	€ 2.008,32	€ 2.008,32	€ 4.016,64
TOTAL PRICE (total hectare price * hectares)	€ 16.066,56	€ 7.029,12	€ 4.016,64

Table 16 Cost estimation for the different planting zones in prices per hectare.

Phased planting cost estimation

As survival rates are expected to lie between 30 to 50 %, it would be necessary to plant one area in two years in order to eventually reach the target density of 600 trees per hectare. For example, in year 1 Zone A is planted with 800 trees, then, with a survival rate of 50% only 400 survive. In the second year 400 new seedlings can be planted in the pre-dug holes, of which also 50% survives.

The cost per hectare for the phased planting is made up of seedling cost and planting labour. There are no new costs for treeshelters and holes because the ones from the previous year can be used. Basically, costs for seedlings and planting labour are halved when assuming that 50% will need to be replanted. This means that the following hectare costs are involved with the replanting.

Zone A & B → Planting labour + Seedlings /2 → 640 + 400 /2 = 520 €

Zone C → Planting labour + Seedlings /2 → 1280 + 800 /2 = 1040 €

4.1.3 Mixed zone

Client Alfonso explained the wish that the restoration site could also improve farm functioning in some way. Hereby I propose a few possibilities. For both the truffle and grazing area I propose to establish them close to the road to have good access for maintenance.

Truffle inoculated Holm oaks

Some local farmers have started to cultivate oaks that are inoculated with the Black truffle (*Tuber melanosporum*) (Olivera, Fischer, Bonet, Oliach, & Colinas, 2011). It is a crop that needs little care and sells for a very high price. However, local truffle cultivation is still in an experimental phase and plantation results vary a lot. Occasional irrigation might be needed in the first years to prevent that the oaks die in a summer drought. The selected location covers 0,75 ha. A typical planting density is 6 x 6 meters, which corresponds to 278 trees per ha (A. Chico de Guzman, personal communication).

	STEPS
1	Find a supplier of truffle-inoculated oak seedlings
2	Mark out the borders
3	Cut the Atriplex
4	Remove branches
5	Dig the holes
6	Plant the oaks
7	Irrigate in summer when necessary

Table 17 Steps for establishing truffle oak area

Grazing area

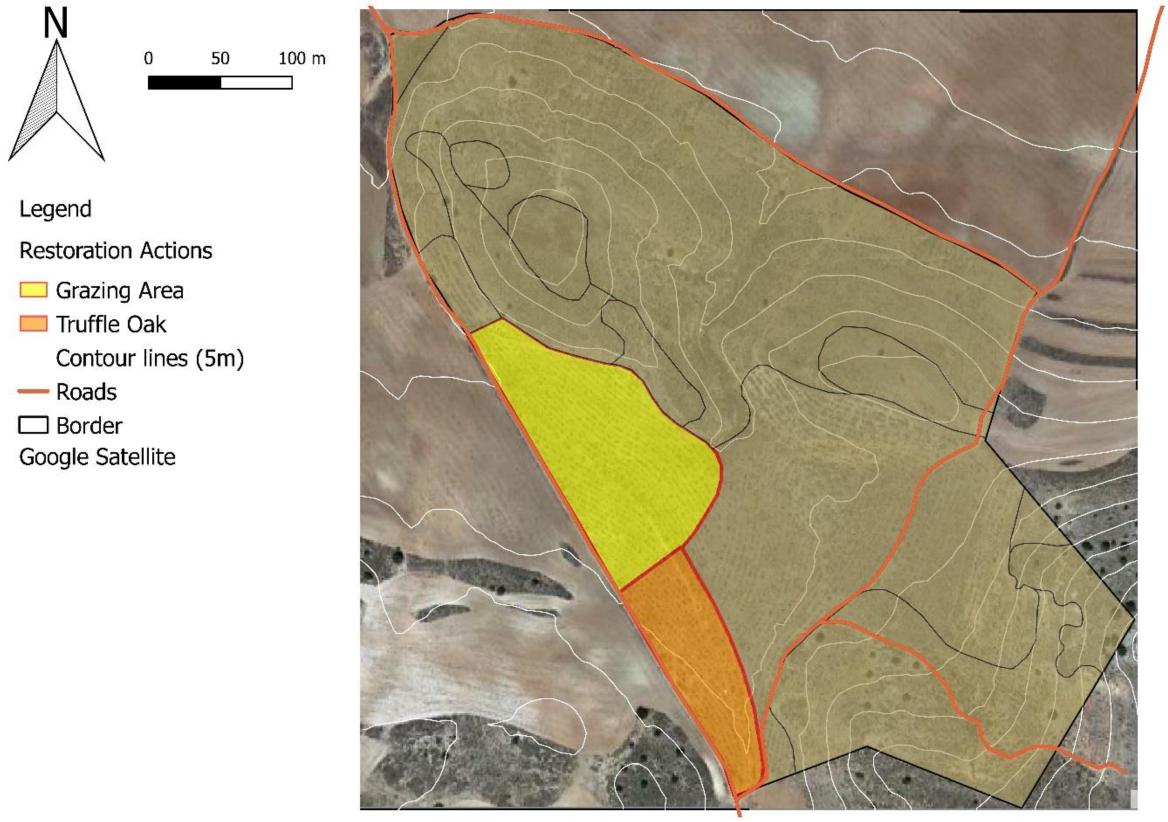
Currently there are about 6 cows of a rare Murcian breed at the farm and future plans include to breed the race and integrate them in the farming system by having a rotational grazing system on the farm. The flat field that is covered with Atriplex sp. holds potential for this purpose because it is easiy accessed and has nutritious plants like Alfalfa (Medicago sativa) and Atriplex. It comprises 1,5 ha.

	STEPS
1	Mark out the borders
2	Cut the Atriplex . The Atriplex will resprout with fresh leaves.
3	Remove branches
4	Seed (optionally fertilize lightly with manure). Use seedmix of nutritious and drought-tolerant herbs.

Table 18 Steps for establishing grazing area

Beekeeping

The current vegetation has many species that are frequently visited by honey bees and other pollinators. A wild bee nest that was found proves that the site can support a bee colony. Rosemary is an important plant for bees because it flowers early in the year and flowers long. It is one of the selected species and will especially be planted in higher quantities on shallow rocky soils. As more rosemary will be planted during the restoration, eventually, more bee-food will become available. The practical potential of beekeeping on this site should be examined with the help of a local beekeeper. Bees will also contribute to pollination of nearby agricultural crops, e.g. almonds.



Map 13 Location of Truffle and Grazing area

Cost estimation

The table below shows the hectare prices for the implementation of the grazing and truffle plots based on calculations that are found in the annex. The beekeeping is not included as no direct costs are involved.

Restoration actions →	**MIXED ZONE**	
	Grazing area	**Truffle**
Total hectares	1,5	0,75
Man-hour per hectare	5	37
Planting density (trees/ha)	-	278
Cost item		
SITE PREPARATION		
Digging	€ -	€ 197,12
Cutting Atriplex	€ 100,00	€ 100,00
Collect branches	€ 50,00	€ 50,00
Seeding	€ 100,00	€ -
MANUAL LABOUR		
Planting	€ -	222,4
PLANTING MATERIAL		
Seedlings	€ -	834
Treeshelters	€ -	139
TOTAL PRICE PER HECTARE	€ 250,00	€ 1.542,52
TOTAL PRICE (total hectare price * hectares)	€ 375,00	€ 1.156,89

Table 19 Price per hectare for establishing truffle and grazing area.

4.1.4 Pond

I propose to make a pond in the northeast corner of the site. A body of surface water provides habitat for many animals and increases biodiversity. Research points out that ponds increase beneficial insect populations, thereby improving pollination on adjacent farm lands (Stewart et al., 2017). This site is specifically chosen for a pond because groundwater is present (as indicated by the large *Scirpus holoschoenus* Bulrush). The groundwater will fill up the pond and will reduce the risk of the pond drying out (Barnes, 2017). The size of the pond will be around 800 m^2.

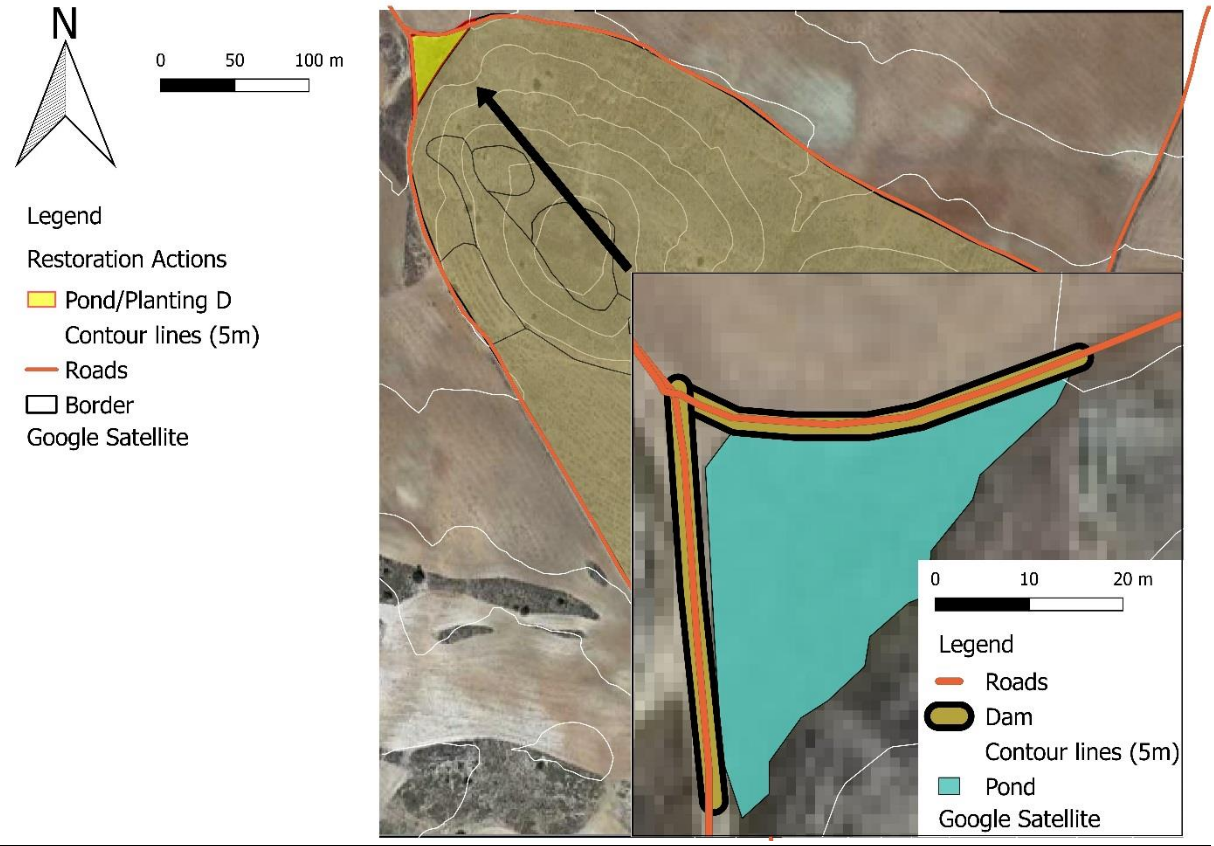
The proposed pond lies in between two roads that lie on the site borders. Both roads will have to be raised to maintain accessibility. Especially, in the case of the northern road, it will have to be raised and compacted to make it function as a dam so that, even during intense rain events, the pond can hold the water and let it slowly infiltrate.

Next to the pond are planted trees that eventually can help reduce evaporation. Species selection is explaining in the chapter on planting.

Proposed site preparation:

	STEPS
1	Mark out the pond's perimeter. On the north side this should be on contour, starting at the highest point of the road. This is where the elevated road will come. Mark contour with a laser level.
2	Excavate topsoil that is high in organic matter and put it aside. It can be used later to salvage damaged soil patches.
3	Excavate the pond. Use the excavated soil to heighten the roads. The slope of the pond should be 1:3, so 1 vertical for every 3 horizontal meters (Barnes, 2017). The average distance from edge to middle is 15 meters. So the middle of the pond would ideally be (15/3=) 5 meters deep, but because some edges lie closer to the centre, I propose a depth of 3,5 meter.
4	Compact the material that was deposited on the roads with the bulldozer.
5	Make a spillway on the dam/northern road, so that excess water can flow out and damage can be prevented.
6	Plant seedlings as described for Planting Zone D

Table 20 Steps for establishing the pond



Map 14 Location of pond

<u>Cost estimation</u>

Based on previous experience with pond excavation of client Alfonso, a pond of approx. 800m² needs 20 hours of work with a large excavator. The rent of a large excavator costs 50 € per hour. So:

- Required hours * machine rent per hour = cost → 20 * 50 = 1000 €

4.2 Monitoring plan

Monitoring is important to evaluate and learn from the restoration outcomes. Monitoring methods should be relatively easy and should not require much training or be too expensive to favour replicability. A monitoring baseline consisting of vegetation transects and photos has been done already. Soil samples have not been taken yet because they would be done in collaboration with a soil scientist of the university of Alicante, but the sampling was delayed. The sampling is now scheduled for this autumn. See the resulting plant species list and map of the photo monitoring points in the annex. The following monitoring methods are proposed for keeping track of the restoration development.

Monitoring	Description	Methods	Frequency
Seedling survival	Survival rate per ha measured with the same quadrat method as of the vegetation transect. Note all living and dead seedlings in the 20 x 10 quadrat (200m²). Record the species. In planting zone B, note whether the seedling was planted next to an Atriplex bush or not, so to be able to see whether the Atriplex facilitates seedling establishment. Quadrat locations are randomly assigned with GIS. Calculate survival and mortality percentages. Ideally, 3 quadrats are done per ha.	Quadrat sampling	Every year for the first 5 years after planting
Vegetation	Species composition, vegetation cover and species diversity. Use the quadrat method as described in the research methodology chapter. In time, a change in vegetation structure will create different habitats and can favour different species. Also, a change in vegetation cover can indicate the development of ecosystem functioning.	Quadrat sampling	Every 5 years
Photo	Take photos at fixed locations. Photos work well for showing general development of the landscape and vegetation structure. It is an easy, quick and cheap method.	Photos	Every 5 years
Soil	pH and organic carbon. Monitoring these kind of soil aspects will tell how ecosystem functioning recovers over time.	Unknown	Every 10 years

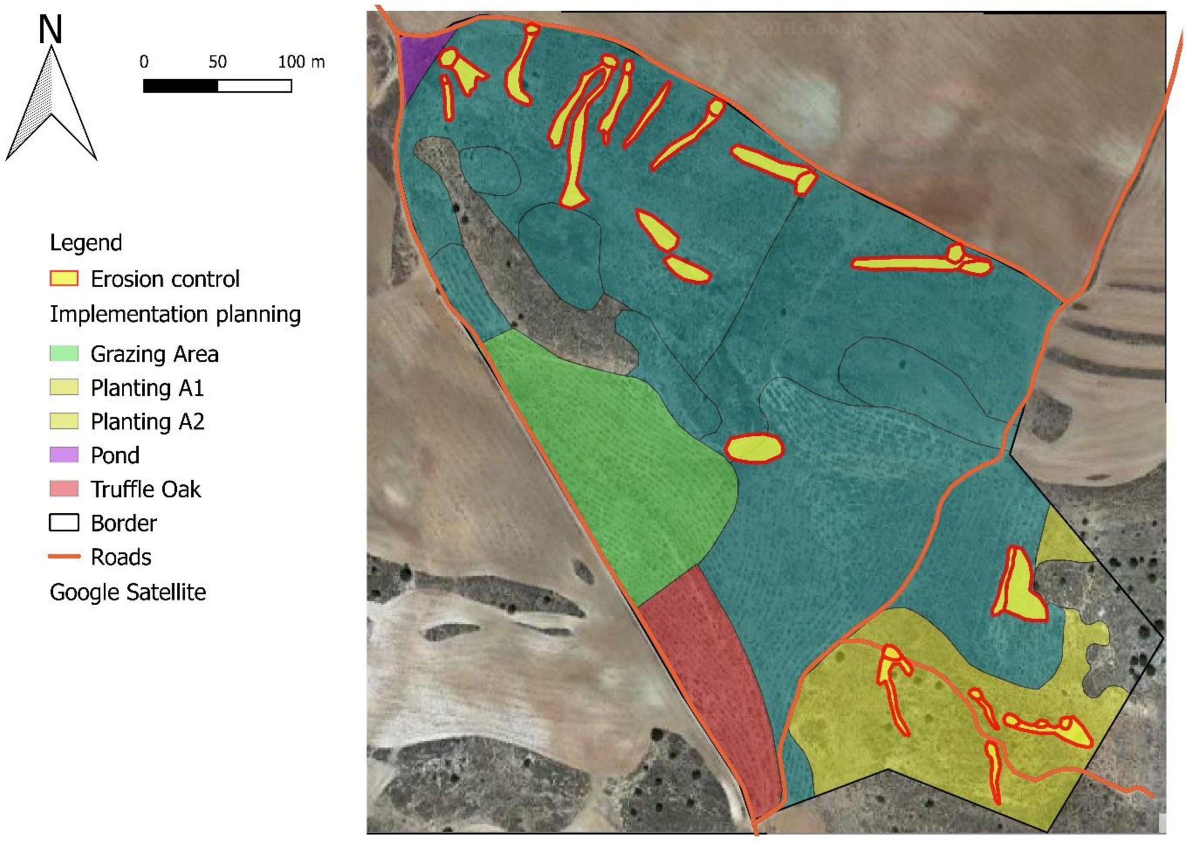
Table 21 Monitoring

4.3 Implementation & Management Planning

A planning is made for 30 years, starting in 2019. The implementation of the various restoration actions is done in the first 5 years. By doing so, costs and labour are spread more evenly over the years. It provides a greater manageability of the project and also the possibility of adapting to specific situations. Moreover, the risk of having a high mortality due to a very dry summer is reduced. In the table below are the implementation actions per year described. In the 30-year planning also the monitoring activities are planned on a regular basis.

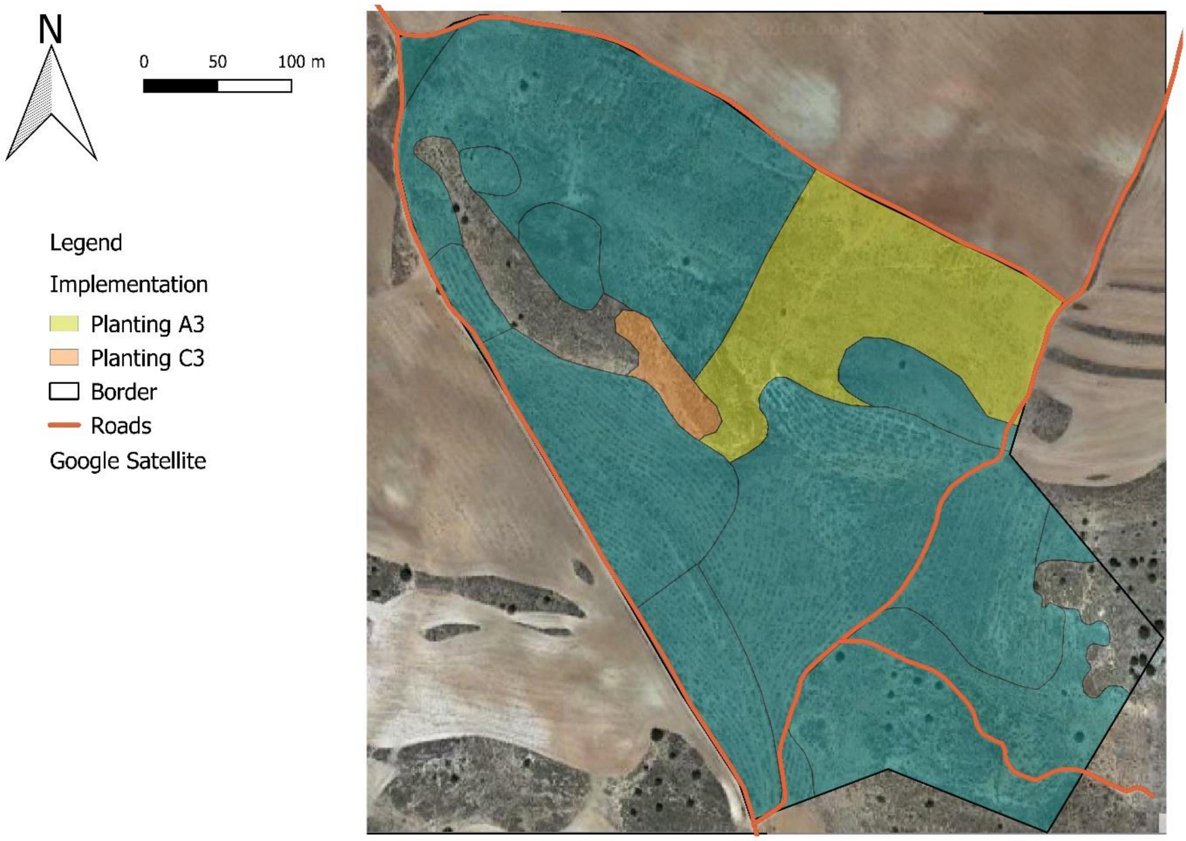
Year	Hectares	Mandays	Description
1	**4,5**	**44,7**	Priority is given to erosion control. Also the grazing area and truffle oak area are established and the cut Atriplex branches can be used for the erosion control measures. If possible, the pond is excavated. The planting of native vegetation happens on a part of Zone A, on the eastern slope of the site.
2	**6,1**	**64,3**	Zone B with the Atriplex and a part of Zone C on the shallow soils. Replanting of zones of year 1.
3	**6,5**	**56,2**	The northern part of the central hill is planted, consisting of Zone A and Zone C. Replanting of zones of year 2.
4	**6,5**	**66,7**	The western hill is planted, as well as the tops which are Zone C, and also zone A on the northern flank. Replanting of zones of year 3
5	**3,9**	**21,5**	Replanting of zones of year 4

Table 22 Restoration actions in the first 5 years



Map 15 Year 1

Map 16 Year 2



Map 17 Year 3

Map 18 Year 4

		WINTER	SPRING	SUMMER	AUTUMN
Year 1	2019	17, 13	17, 16, 13	1, 2, 11, 12, 13, 17	1, 2, 11, 12, 13, 17
Year 2	2020	15	15	5, 7, 14	5, 7, 14
Year 3	2021	15	15	3, 7, 14	3, 7, 10, 14
Year 4	2022	15	15	4, 6, 9, 14	4, 6, 9, 14
Year 5	2023	15	15	14	14
Year 6	2024	15	15, 16, 18	18	18
Year 7	2025	15	15		
Year 8	2026	15	15		
Year 9	2027	15	15		
Year 10	2028				
Year 11	2029	17	17, 16, 18	17, 18	17, 18
Year 12	2030				
Year 13	2031				
Year 15	2032				
Year 16	2033				
Year 17	2034		16, 18	18	18
Year 18	2035				
Year 18	2036				
Year 19	2037				
Year 20	2038				
Year 21	2039	17	17, 16, 18	17, 18	17, 18
Year 22	2040				
Year 23	2041				
Year 24	2042				
Year 25	2043				
Year 26	2044		16, 18	18	18
Year 27	2045				
Year 28	2046				
Year 29	2047				
Year 30	2048				

RESTORATION ACTION				MONITORING	
Planting Zone A1	1	Planting Zone C3	8	Survival	15
Planting Zone A2	2	Planting Zone C4	9	Vegetation	16
Planting Zone A3	3	Seeding Zone E	10	Soil	17
Planting Zone A4	4	Grazing Area	11	Photos	18
Planting Zone B	5	Truffle Oak	12		
Planting Zone C1	6	Pond	13		
Planting Zone C2	7	Replanting (optional)	14		

Table 23 30-year planning

4.4 Total budget

This budget shows the yearly and total costs of the restoration activities. It is based on the hectare prices which were calculated per restoration action.

YEAR 1	HECTARES	MANDAYS	COST PER HECTARE	COST
Planting A1 + A2	2,141	26,2	€ 2.008,32	€ 4.299,81
Truffle Oak	0,750	3,5	€ 1.542,52	€ 1.156,89
Grazing Area	1,500	2,5	€ 250,00	€ 1.000,00
Erosion control	-	10,0	€ -	€ 640,00
Pond	0,100	2,5	€ -	€ 1.000,00
YEAR TOTAL	4,491	44,7	€ 3.800,84	€ 8.096,70
YEAR 2				
Planting B	3,500	42,9	€ 2.008,32	€ 7.029,12
Planting C2	0,436	10,7	€ 4.016,64	€ 1.751,26
Replanting A1 + A2	2,141	10,7	€ 520,00	€ 1.113,32
YEAR TOTAL	6,077	64,3	€ 6.544,96	€ 9.893,70
YEAR 3				
Planting A3	2,327	28,5	€ 2.008,32	€ 4.673,36
Planting C3	0,239	5,9	€ 4.016,64	€ 959,98
Replanting B	3,500	17,5	€ 520,00	€ 1.820,00
Replanting C2	0,436	4,4	€ 1.040,00	€ 453,44
YEAR TOTAL	6,502	56,2	€ 7.584,96	€ 7.906,78
YEAR 4				
Planting A4	3,491	42,8	€ 2.008,32	€ 7.011,05
Planting C1 + C4	0,405	9,9	€ 4.016,64	€ 1.626,74
Replanting A3	2,327	11,6	€ 520,00	€ 1.210,04
Replanting C3	0,239	2,4	€ 1.040,00	€ 248,56
YEAR TOTAL	6,462	66,7	€ 7.584,96	€ 10.096,38
YEAR 5				
Replanting A4	3,491	17,5	€ 520,00	€ 1.815,32
Replanting C1 + C4	0,405	4,1	€ 1.040,00	€ 421,20
YEAR TOTAL	3,896	21,5	€ 1.560,00	€ 2.236,52
TOTAL	**27,428**	**253,4**	**-**	**€ 38.230,08**

Table 24 Budget

5. Reflection & Discussion

This plan meets the requirements as defined in the program of requirements to the extent of providing a clear substantiation of the choices that were made during the plan development, including; the locating of different restoration actions based on a site diagnosis, the species selection based on the investigated reference ecosystem, the choice for scientifically approved restoration methods. If the proposed restoration steps are followed and seedling establishment is favoured by good weather conditions, then, on the long term, it is to be expected that the planted trees will create a structurally diversified vegetation and provide a variety of habitats. In turn this will provide the opportunity for different species to inhabit the site and so species diversity is enhanced. Eventually, through the return of a forest structure and a denser vegetation cover, ecosystem functionality is recovered as well. In other words, a good outcome is achieved in terms of; the recovery of compositional, structural and functional ecosystem attributes.

The plan delivers substantiated guidelines for ecological restoration specifically applicable to this locality. However, a plan is not the same thing as its execution. Without doubt, ecological restoration is a long-term effort, and to which degree the objectives will be met depends on how it is implemented. Finding enough funding, finding the time, organizing the logistic and operational requirements can all be challenging, especially, if there is the responsibility of managing a large farm.

It was found that a good understanding of the local ecology, soils, climate, terrain and land use history is crucial for developing a research methodology, particularly for a site diagnosis methodology. Plainly, you need to know what you should look at. In this project, research methodology was determined mainly by literature, expert advice and common sense, and due to an initial lack of contextual knowledge, site diagnosis might have been less effective than it could be otherwise.

Related to the previous point, the lessons I learned will inform further restoration activities. In that sense, the research, and more general the allround learning of the people of La Junquera about ecological restoration is an iterative process. This process will keep finding better and quicker ways of doing site diagnoses and finding more suitable, (cost-)effective and efficient restoration methods.

Specifically regarding the methodology for defining the condition of the soil, soil erosion and degradation status I conclude that it could be refined and better structured to enable quantative analysis. The *Landscape Functional Analysis* (Tongway & Hindley, 2004) is, for example, an optional monitoring method that uses indicators of landscape processes to measure degradation. A more detailed method would allow to better prioritize and locate restoration actions.

Sustainability is high on the agenda of La Junquera. The client envisions the farm developing into an exemplary regenerative farm where many regenerative agricultural practices are put into action, where degraded land is restored and where the farm village is occupied by a lively community. Moreover, in this vision the farm also becomes a hub of knowledge and experience with regards to regenerative practices. This plan contributes to the farm's development towards sustainability, in that it takes the first step of building a knowledge and experience base of ecological restoration.

Furthermore, the plan would, depending on implementation, contribute to sustainability by restoring degraded land into a healthier ecosystem.

5.1 Recommendations

If ecological restoration is to be scaled up on the farm I would recommend to keep track of restoration activities, their costs, labour and time requirements, survival rates and general success. This enables to learn from past projects and improve future restoration work.

Moreover, I recommend to have a larger plan for ecological restoration; map out the areas that are most degraded and that need most attention. Also, strategize restoration actions, for example, by establishing a few patches of restored forest in patches that don't have any seed disperser so that natural regeneration is assisted.

At last, I recommend to build a network of people that have knowledge of, or want to help in, local ecological restoration projects. Also, collaborate with scientists that work in ecological restoration.

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7. Appendix

a. Plant species list

	SPECIES		SPECIES
1	Adonis aestivalis	81	Leuzea conifera
2	Aegilops geniculata	82	Linum narbonense
3	Alkanna tinctoria	83	Linum suffruticosum
4	Althaea hirsuta	84	Lithodora fruticosa
5	Alyssum serpyllifolium	85	Lolium rigidum
6	Alyssum montanum	86	Lotus corniculatus
7	Alyssum simplex	87	Lygeum spartum
8	Anacyclus clavatus	88	Mantisalca duriaei
9	Anarrhinum laxiflorum	89	Marrubium supinum
10	Androsace maxima	90	Mathiola fruticulosa
11	Andryala ragusina	91	Medicago minima
12	Anthyllis vulneraria	92	Medicago sativa
13	Aphyllantes monspeliensis	93	Melica minuta
14	Argyrolobium zanonii	94	Muscari comosum
15	Artemisia campestris	95	Neatostema apulum
16	Artemisia herba-alba	96	Onobrychis stenorhiza
17	Asparagus acutifolius	97	Ononis minutissima
18	Asphodelus cerasiferus	98	Onopordon acaulon
19	Astragalus glaux	99	Ononis fruticosa
20	Astragalus incanus	100	Onosma tricerosperma
21	Astragalus monspessulanus subsp. gypsophylus	101	Ophrys lutea
22	Astragalus sesameus	102	Ophrys scolopax
23	Astragalus stella	103	Pallenis spinosa
24	Atractylis humilis	104	Papaver hybridum
25	Avenula bromoides	105	Papaver rhoeas
26	Biscutella auriculata	106	Paronychia aretioides
27	Biscutella valentina	107	Paronychia capitata
28	Bombycilaena discolor	108	Paronychia suffruticosa
29	Brachypodium retusum	109	Phlomis herba-venti
30	Bromus aff. matritensis	110	Phlomis lychnitis
31	Bupleurum fruticescens	111	Picnomon acarna
32	Carduncellus sp.	112	Pinus halepensis
33	Carduus bourgeanus	113	Piptatherum miliaceum
34	Carduus platypus subsp. granatensis	114	Plantago albicans
35	Carex halleriana	115	Plantago lanceolata
36	Carlina corymbosa	116	Poa bulbosa
37	Centaurea ornata	117	Polygala rupestris
38	Cerastium pumilum	118	Quercus coccifera
39	Chaenorrhinum origanifolium subsp. crassifolium	119	Quercus rotundifolia
40	Convolvulus lineatus	120	Rapistrum rugosum
41	Coronilla scorpius	121	Reseda lutea

42	Crepis albida	122	Reseda phyteuma
43	Crepis vesicaria	123	Reseda undata
44	Crupina crupinastrum	124	Rhamnus lycioides
45	Cuscuta campestris	125	Roemeria hybrida
46	Cuscuta epithymum	126	Rosmarinus officinalis
47	Cynodon dactylon	127	Rubia peregrina
48	Dactylis glomerata	128	Rumex pulcher
49	Desmazeria rigida	129	Salvia lavandulifolia subsp. oxyodon
50	Dorycnium pentaphyllum	130	Salvia verbenaca
51	Echinaria capitata	131	Sanguisorba minor subsp. verrucosa
52	Echium sp.	132	Santolina chamaecyparissus
53	Erinacea anthyllis ?	133	Satureja obovata subsp. obovata
54	Ephedra nebrodensis	134	Scabiosa turolensis
55	Elymus sp.	135	Scirpus holoschoenus
56	Eruca vesicaria	136	Scorzonera angustifolia
57	Eryngium campestre	137	Scorzonera hispanica
58	Euphorbia flavicoma	138	Scorzonera laciniata
59	Euphorbia serrata	139	Sedum acre
60	Fumana procumbens	140	Sedum album
61	Fumana thymifolia	141	Serratula flavescens subsp. leucantha
62	Fumaria parviflora	142	Sideritis leucantha subsp. incana
63	Galium fruticescens	143	Silene vulgaris
64	Genista pumila subsp. mugronensis	144	Sisymbrium crassifolium
65	Genista scorpius	145	Sonchus oleraceus
66	Helianthemum cinereum subsp. guadiccianum	146	Stipa parviflora
67	Helianthemum hirtum	147	Stipa tenacissima
68	Helianthemum salicifolium	148	Tamarix sp.
69	Helianthemum violaceum	149	Taraxacum obovatum
70	Helianthemum violaceum x H. hirtum	150	Telephium imperati
71	Helichrysum italicum subsp. serotinum	151	Teucrium pseudochamaephytis
72	Helictotrichon filifolium	152	Teucrium similatum
73	Hippocrepis bourgaei	153	Thesium divaricatum
74	Hordeum leporinum	154	Thymus vulgaris
75	Juncus maritimus	155	Tragopogon crocifolius
76	Juniperus oxycedrus	156	Turgenia latifolia
77	Juniperus phoenicea	157	Vaccaria hispanica
78	Koeleria vallesiana	158	Vallerianela discoidea
79	Lamium amplexicaule	159	Verbascum rotundifolium
80	Leuzea conifera	160	Vicia sp.

b. Species composition of fauna

The fauna in oak forest can be very diverse and depends on many factors such as climate, the forest's structure and age, the mosaic of different ecosystems and fragmentation of natural areas (Ferrán et al., 2009). The acorns of the *Q. rotundifolia* forms an important food source for many animals. Typical of the holm oak, just like many oak species, is their mast-seeding which is defined as the seeding of a population synchronized at the same time. It creates an abundance of seeds in one year whereas in other years significantly less seeds may be produced. These kind of irregular seeding events affect all animal populations that depend on the acorns.

In a more closed thick *Q. rotundifolia* forest the following species may be abundant:

Wild boar (*Sus scrofa*)
Red fox (*Vulpes vulpes)*
European roe deer (*Capreolus capreolus*)
Common genet (*Genetta genetta*)
Beech marten (*Martes foina*)
European badger (*Meles meles*)
Wood mouse (*Apodemus sylvaticus*)
Garden dormouse (*Eliomys quercinus*)
Eurasian sparrowhawk (*Accipiter nisus*)
Northern goshawk (*Accipiter gentilis*)
Brown owl (*Strix aluco*)
Band-tailed pigeon (*Patagioenas fasciata*)
Eurasian jay (*Garrulus glandarius*)
Common blackbird (*Turdus merula*)
Short-toed treecreeper (*Certhia brachydactyla*)
Long-tailed tit (*Aegithalos caudatus*)
Common firecrest (*Regulus ignicapilla*)

The presence of reptiles is limited in dense oak forest due to more shade. In more open forests and more mosaic-like landscapes with other types of ecosystems (rocky, shrubland, grassland, agricultural fields), you can find many of the above species and, in addition:

Wolf (*Canis lupus*)
Red deer (*Cervus elaphus*)
Fallow deer (*Dama dama*)
Iberian ibex (*Capra pyrenaica)*
European rabbit (*Oryctolagus cuniculus*)
Spanish imperial eagle (*Aquila adalberti*)
Bonelli's eagle (*Aquila fasciata*)
Short-toed snake eagle (*Circaetus gallicus*)
Common buzzard (*Buteo buteo*)
European turtle dove (*Streptopelia turtur*)
Wood lark (*Lullula arborea*)
Woodchat shrike (*Lanius senator*)
Dartford warbler (*Sylvia undata*)
Iberian magpie (*Cyanopica cooki*)
Montpellier snake (*Malpolon monspessulanus*)

Also, invertebrate diversity is high in holm oak forests.

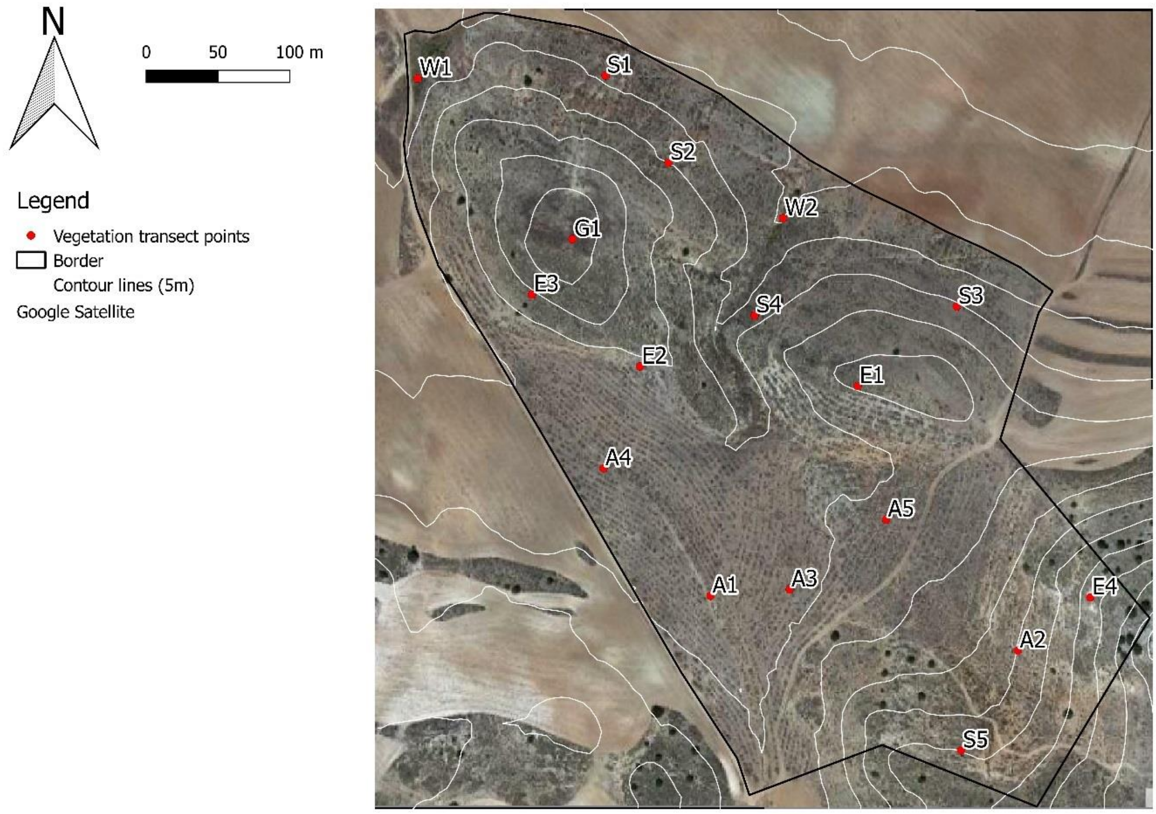
On La Junquera the following animals have been observed: Wild boar (*Sus scrofa*), Red fox (*Vulpes vulpes),* Red deer (*Cervus elaphus*), European wild cat (Felis silvestris), European badger (*Meles meles*), Iberian ibex (*Capra pyrenaica),* Hare *(Lepus sp.),* Iberian lynx *(Lynx pardinus)*, and many species of predatory birds (including different species of vultures).

7.3 List of Local experts

Local expert	Occupation	Organization	Contact
Jordi Cortina	Professor restoration ecology	University of Alicante	jordi@ua.es
Pedro Sánchez Gómez	Botanist	University of Murcia	psgomez@um.es

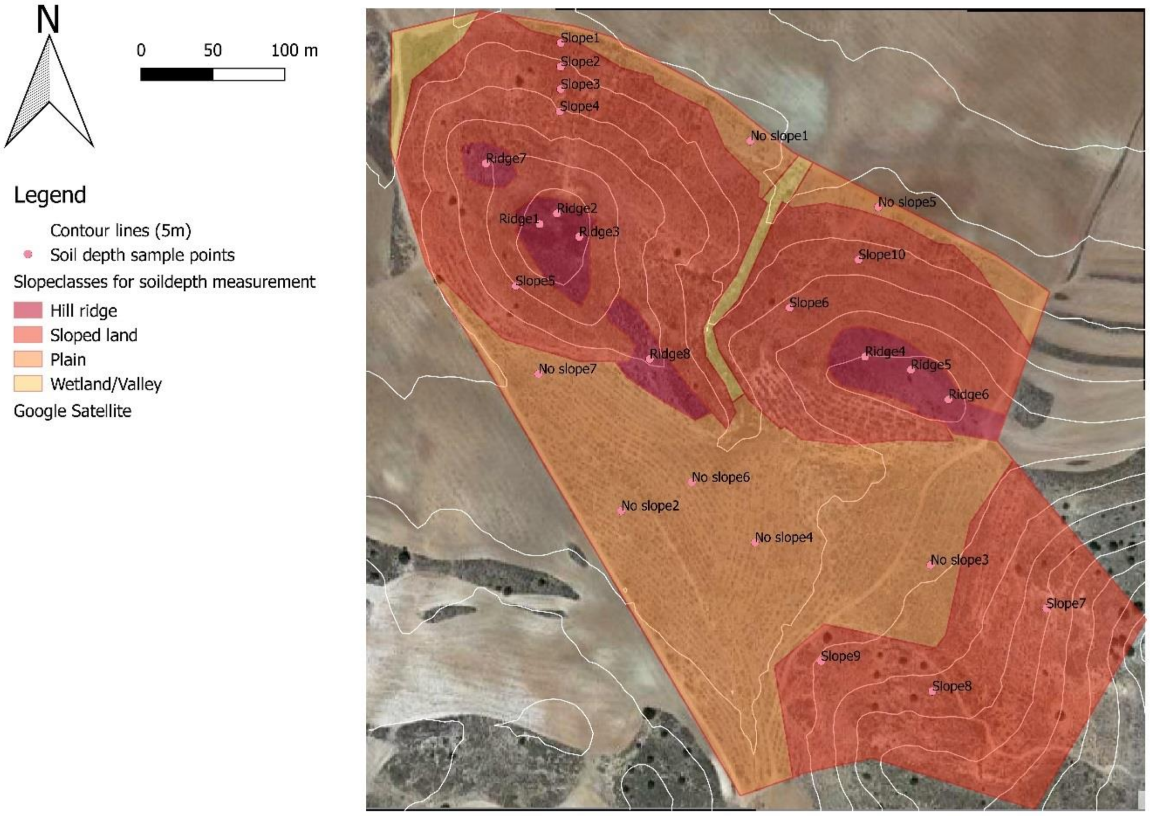
Juan Francisco Jiménez	Botanist	University of Murcia	-
Miguel Angel Esteve Selma	Professor ecology	University of Murcia	maesteve@um.es
Alfonso Chico de Guzman	Farm owner and manager	La Junquera	achicodeguzman@gmail.com

7.4 Vegetation transect points

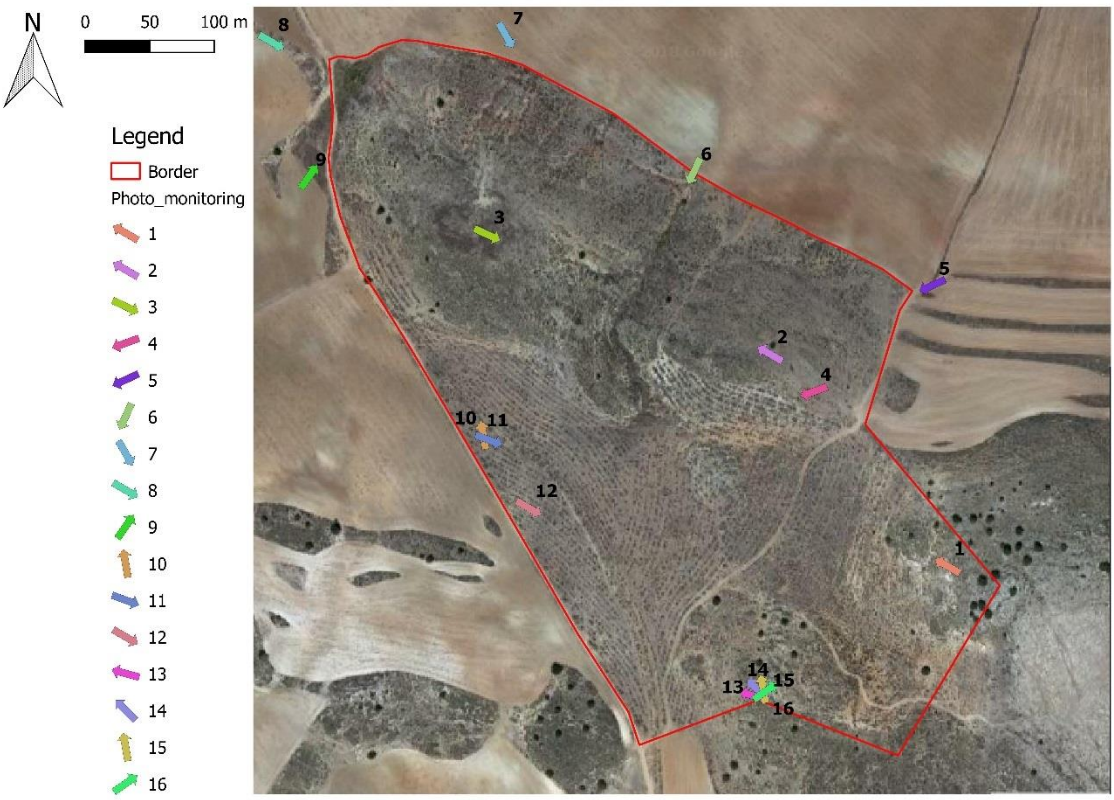


7.5 Soil depth sampling data + map

Slope type	#	Depth	Notes	Average per slope type
No slope	1	40		
No slope	2	50		
No slope	3	50		
No slope	4	50		
No slope	5	50		
No slope	6	50		
No slope	7	50		48,6
Ridge	1	30		
Ridge	2	40	Rock outcrops closeby	
Ridge	3	30		
Ridge	4	30		
Ridge	5	50		
Ridge	6	10		
Ridge	7	30		
Ridge	8	34	Rock outcrops closeby	31,8
Slope	1	50		
Slope	2	50		
Slope	3	50		
Slope	4	50		
Slope	5	50		
Slope	6	50		
Slope	7	50		
Slope	8	50		
Slope	9	50		
Slope	10	50		50



7.6 Photo monitoring



7.7 List of Local experts

LOCAL EXPERT	OCCUPATION	ORGANIZATION	CONTACT
Jordi Cortina	Professor restoration ecology	University of Alicante	jordi@ua.es
Pedro Sánchez Gómez	Botanist	University of Murcia	psgomez@um.es
Juan Francisco Jiménez	Botanist	University of Murcia	-
Miguel Angel Esteve Selma	Professor ecology	University of Murcia	maesteve@um.es
Alfonso Chico de Guzman	Farm owner and manager	La Junquera	achicodeguzman@gmail.com
Fernando Bautísta Expósito	Biologist and reforestation manager	Alvelal	fernando.bautista.exposito@gmail.com

7.8 Calculations of cost estimations

Here are given the calculations with which the prices per ha for the different restoration actions were calculated. These were calculated based on the data in the table below. Most of these are based on work experience of farmer and client Alfonso.

MACHINES (RENTAL, WORK CAPACITY)
Small excavator digs 45 holes per hour on normal terrain
Small excavator digs (45 * 8) 360 holes per day
Small excavator costs 32 euro per hour (including labour costs)
Small excavator costs (32 * 8) 256 per day (including labour costs)
Large excavator costs 50 euro per hour (including labour costs)
Large excavator costs 400 euro per day (including labour costs)
Machine for cutting, collecting branches and seeding is 50 euro per hour (including labour costs)
LABOUR
worker's wage is 8 euro per hour
worker's wage is 64 euro per day.
I assume that one worker can plant 80 trees on a day, including doing all the extra measures (adding compost, making microcatchment, etc)
PLANTING MATERIALS & SEEDLINGS
one seedling costs on average 0,50 euro
one treeshelter costs 0,50 euro
An oak seedling inoculated with truffle costs 3 euro

Erosion control

Is calculated without hectare price because it is a small area. Labour will be done manually due to bad accessibility. I estimate a total of 800 metres of erosion channels will need to be covered with check dams. Check dams are 10 metres apart so (800 / 10 =) 80 dams will have to be made. I assume it takes 1 person 1 hour to make a dam, so 8 dams can be built in a day. 10 days are then required to build all dams. If two persons work together, they need 5 days.

1. Costs are then: 5 * 2 * 64 = 640 €

Establishing native vegetation – Planting Zone A & Zone B

The planting density for this zone is 800 trees per hectare.

Digging

A small excavator is used. The hectare price for digging with a small excavator:

1. Planting density per ha / work capacity = required days for completing 1 hectare → 800 / 360 = 2,22 days
2. Days necessary for digging holes on 1 hectare * price for machine rent (included labour) = cost per hectare → 2,22 * 256 = 568,32 €

Planting

I assume one worker can plant 80 trees in a day.

1. Planting density per ha / planting capacity of 1 worker = amount of days needed for planting one hectare → 800 / 80 = 10 days
2. Amount of days needed for planting one hectare * wage per day = cost for planting one hectare → 10 * 64 = 640 €

Planting materials

800 seedlings per ha. → 800 * 0,50 = 400 €

800 treeshelters per ha → 800 * 0,50 = 400 €

Establishing native vegetation – Planting Zone C

The planting density for this zone is 1600 trees per ha.

Digging

A small excavator is used. The hectare price for digging with a small excavator:

1. Planting density per ha / work capacity = required days for completing 1 hectare → 1600 / 360 = 4,44 days
2. Days necessary for digging holes on 1 hectare * price for machine rent (included labour) = cost per hectare → 4,44 * 256 = 1136,64 €

Planting

I assume one worker can plant 80 trees in a day.

1. Planting density per ha / planting capacity of 1 worker = amount of days needed for planting one hectare → 1600 / 80 = 20 days
2. Amount of days needed for planting one hectare * wage per day = cost for planting one hectare → 20 * 64 = 1280 €

Planting materials

1600 seedlings per ha. → 1600 * 0,50 = 800 €

1600 treeshelters per ha → 1600 * 0,50 = 800 €

Establishing native vegetation –Zone D & E

The work involved in planting the wetland plants is insignificant and thus not accounted for. Seeding will be done by volunteers.

Mixed zone – Truffle inoculated Holm oaks

The planting density is 278 per ha.

Cutting

Farmer Alfonso estimated that cutting Atriplex would take 2 hours per ha. The cutting machine costs 50 euro per hour. So, the hectare price is (50 * 2=) 100 euro per hour.

Removing branches

Removing cut Atriplex branches is estimated to take 1 hour per ha. The collecting machine costs 50 euro per hour. So, the hectare price is 50 euro per hour.

Digging

A small excavator is used. The hectare price for digging with a small excavator:

1. Planting density per ha / work capacity = required days for completing 1 hectare → 278 / 360 = 0.77 days
2. Days necessary for digging holes on 1 hectare * price for machine rent (included labour) = cost per hectare → 0.77 * 256 = 197.12 €

Planting

I assume one worker can plant 80 trees in a day.

1. Planting density per ha / planting capacity of 1 worker = amount of days needed for planting one hectare → 278 / 80 = 3.475 days
2. Amount of days needed for planting one hectare * wage per day = cost for planting one hectare → 3.475 * 64 = 222.4 €

Planting materials

278 seedlings per ha. → 278 * 3 = 834 €.

Treeshelters → 278 * 0.50 = 139 €

Mixed zone – Grazing area

Cutting

Farmer Alfonso estimated that cutting Atriplex would take 2 hours per ha. The cutting machine costs 50 euro per hour. So, the hectare price is (50 * 2=) 100 euro per hour.

Removing branches

Removing cut Atriplex branches is estimated to take 1 hour per ha. The collecting machine costs 50 euro per hour. So, the hectare price is 50 euro per hour.

Seeding

Seeding cost two hours per ha. The seeding machine costs 50 euro per hour. So, the hectare price is (50 * 2=) 100 euro per hour.

Pond

Is calculated without hectare price because it is a small area. Based on the experience of client Alfonso, a pond of approx. 800m² needs 20 hours of work with a large excavator.

1. Required hours * machine rent per hour = cost → 20 * 50 = 1000 €