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Article

Decision Pattern for Changing Polluted Areas into Recreational Places

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Abstract: There are many enclaves in the Mediterranean basin with soils contaminated with heavy metal(loid)s, most of these in natural areas of great beauty that have suffered the consequences of industrial and mining activity for years. These soils pose a risk to human and animal health due to the transfer of metal(loid)s condemning these areas to isolation. The rehabilitation by means of phytoremediation is one of the most used techniques, but phytoremediation must be part of a comprehensive strategy of steps that guide owners and administrations in the recovery of ecosystem services. An easily replicable decision-making methodology is defined, considering the initial conditions, the preferences of the decision makers or typologies from among six possibilities and the different models of use, typified in 13 categories. As a result, a landscape is obtained that integrates phytostabilization and areas with recreational and/or educational uses. Two case studies from the southeast of Spain are presented as validation, a deposit of mining sludge residues and the channel of a river contaminated by industrial discharges. Both enclaves are included in the tourist and cultural offer of their area, thus achieving an environmental and socioeconomic benefit and have been visited by more than 1000 people in a two-year period.

Keywords: phytostabilization; mine rehabilitation; metal(loids); aid decision support system

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1. Introduction

It is known that around five million sites are contaminated by heavy metals and metalloids worldwide [1] caused by human activities, of those sites 250,000 are found in Europe. Regarding the sources, the contamination existing in the Mediterranean basin is a clear fact due to the mining and industrial activity developed for decades, which have contaminated soils and waters of heavy metal(loid)s, persistent xenobiotics and dangerous substances. We can observe in the review by Raffa et al. [2] such as the Mediterranean coasts, principally in Spain, France, Egypt, Italy, Morocco, Turkey, Libya and Greece the presence of heavy metals found in soils in high amounts. Intervention on them should be urgent and follow the guidelines given by the EU directive 2004/35/EC [3], which establishes that the best of the possible rehabilitations must be sought from among the contaminated areas.

In the bibliography, numerous works have been found referring to models related to the landscape management of contaminated environments, such as those defined in the United States and Australia, among others [4–7], which are quite complex and difficult to implement since they require a lot of previous data collection, and in some of them complex calculation models that are difficult to approach outside the scientific field, for example the work of Yu and Yang [8] that use a predictive algorithm of plant restoration in polluted areas. They highlight the need to seek multifunctionality in the recovery of degraded landscapes, so that the benefit obtained reverts to an improvement in ecosystem services [7,9,10]. In many cases, an alternative source of income is also sought for areas that have had to diversify their economic activity due to the abandonment of the activity causing the contamination. This is the focus in multicriteria decision problems that need complex decisions models [4,7,11,12]. These complex models were used by the same modelers and not by the real actors and executors of the restoration [13]. In any case, it is a reality that decision models must be easily defined and implemented [14], and like Chazdon et al., summarize [13], "the plan can be a framework or a progression of steps and activities to guide a long-term implementation and adaptive management" such as the proposal defined in urban landscape by Wilschut et al. [15]. Likewise, it must be considered that the EU prioritize landscape protection while preserving and maintaining the significant or characteristic features of a landscape, as well as to seek sustainable development, in order to guide and harmonize the changes caused by social, economic and environmental processes, as well as planning these activities and seeking long-term landscape policies for present and future generations. Therefore, with the intervention on these areas, in addition to promoting the immobilization or removal of metal(loid)s and favoring the establishment of vegetation in degraded spaces, the integration of all resources, biotic, abiotic and cultural, can be achieved to attain ecological and cultural rehabilitation and restoration of ecosystem services [9,10,16].

However, there is no doubt that the first step is the recovery of the soil in order to be used in a safe way for the health of the general population. There are many techniques for the recovery of soils contaminated by heavy metal(loid)s, but most of these techniques are expensive and invasive for the environment [1,17]. Phytoremediation techniques are based on the use of plants to aid decontamination, and are the most widely used given their viability, with phytoextraction and phytostabilization being the most common [17–20]. The recovery of contaminated soils through these techniques is based on achieving the optimal conditions for the growth of the appropriate plants by improving the physical, chemical and biological characteristics of the soil by using different amendments, if necessary [21–24]. Phytoextraction is the uptake of a pollutant by plant roots from the environment and its translocation to the plant biomass, which, if cut later, generates a residue from the metal/metal-contaminated plant. However, phytostabilization presents the establishment of a stable vegetation cover, and is considered an adequate option when we find high volumes of contaminants [25–28]. Phytostabilization has been known for decades and has been widely shown to reduce the bioavailability of metals by retaining them in the immediate vicinity of the roots or in non-transferable parts of the plant, also avoiding drift caused by wind and rain [25,29,30].

As a general rule, to create a self-sustaining landscape with the help of phytostabilization, it is preferable to use adapted native species that are suitable and ensure continuity. Likewise, the introduction of non-native and potentially invasive species that can alter the regional diversity of plants and endanger the harmony of the ecosystem must be prevented [17,31]. Therefore, plant selection is an important requirement for successful revegetation and most studies have described the aptitude of herbaceous species for phytostabilization [21,32–34]. Additionally, for the Mediterranean realm, the species guide prepared by Parra et al., can be followed according to different option criteria of tolerance and association [35]. Likewise, it will be advisable to look for those species that have colonized spontaneously, if there are any in the area, and that are adapted to these contaminated environments and the local weather. According to Conesa et al., (2007) [34], in the southeast of Spain, spontaneous vegetation is adapted to toxic metals and to low pH in soils, so they must be a priority to reduce wind and water erosion and mitigate the contamination that derives from nearby areas. In this way, the establishment of vegetation cover will serve as a barrier to the erosive effects of wind and water that prevents the loss of soil particles, as well as the reduction of risks associated with the spread of heavy metal(loid)s, leaching and runoff. Therefore, those native plant species adapted to local climatic conditions, high potential evapotranspiration, salinity, and the presence of heavy metal(loid)s should be selected, avoiding the use of bio-accumulative plants in highly palatable organs, which could cause the movement of metals through the food chain.

For all these reasons, since there are common features in the Mediterranean basin from a climatological point of view, plant species and industrial and mining activities, common guidelines and recommendations for action can be established, since in many cases not having a simple guide on how to act, leads to the non-action of entrepreneurs and government officials when considering rehabilitation.

In this work, the definition of an action model is presented, in which variables and restrictions are organized in steps in order to rescue natural areas polluted by anthropogenic activities. The development of the best solution, among the possible ones, will be identified for each area, using phytoestabilization techniques for metal(loid)s stabilization, and finalized with educational and recreational use, which are most common for natural areas. Two case studies are presented for areas contaminated, one, by mining activities, and the other by industrial activities in order to validate the simple and useful implementation of each.

2. Materials and Methods

A decision-making methodology is proposed to assist private developers and public organizations when establishing and organizing actions to be considered for the rehabilitation of natural spaces degraded by industrial activities (Figure 1). Beginning with the compilation of information and arriving at the definition of a usable space from a recreational and educational point of view, as well as the maintenance and stability of a contaminated area. We can say, therefore, that we are facing a classic case of decision making, we are faced with a problem to be solved, the rehabilitation of the contaminated site, a series of alternatives, defined at various levels, and some restrictions or criteria, which they are going to make us prioritize one alternative over another.

The model is structured at different levels (Figure 1), a first level of information gathering in which the promoter or the agents in charge of the rehabilitation must identify the project restrictions, marked by legislation in any of the areas to which that is subject, local, regional, national and/or European, as well as urban, environmental, etc. In this case, we can find areas that are either privately or publicly owned, but in any of these cases, the legislation will define the actions to be carried out.

The determining factors of each project become more evident in the second level of the model, in which the decision makers must select the model of action, Mn, according to its typology or the preferences of the promoter or users. It may be the case, especially in the context of publicly owned projects, that neighborhood consultations or groups of future users are carried out, in order to define the different uses or even, the proposal of surveys that enrich the possibility of alternatives to pose.

Taking into account our experience, as a first approximation of performance models, Mn, the following six are proposed, but they could be extended considering the decision makers or the users through a survey:

- M1: Revegetation project, only plants would be placed, with aesthetic function.
- M2: Stabilization project, elements (plants, containments, etc.) would be placed to stabilize the soil
- M3: Project of high landscape interest
- M4: Project of high cultural interest.
- M5: High social interest project
- M6: Mixed
- M7: Other projects

In reality, we are going to find ourselves, in most cases, with mixed projects in which several of the characteristics of the other projects are combined. However, as we have mentioned, it is interesting to carry out a public consultation, in order to consider the preferences of the end users of the environment.

In the third level, a delimitation of the existing areas is made, which depends on the type of model chosen, Z f(M). In this phase it is recommended to define and delimit the zones in detail, both at the level of extension and location in plans, as well as any characteristic that will later serve to make decisions, associated in most cases with edaphic and inventory characteristics of existing flora, which will determine, among other things, the plant species to be used.

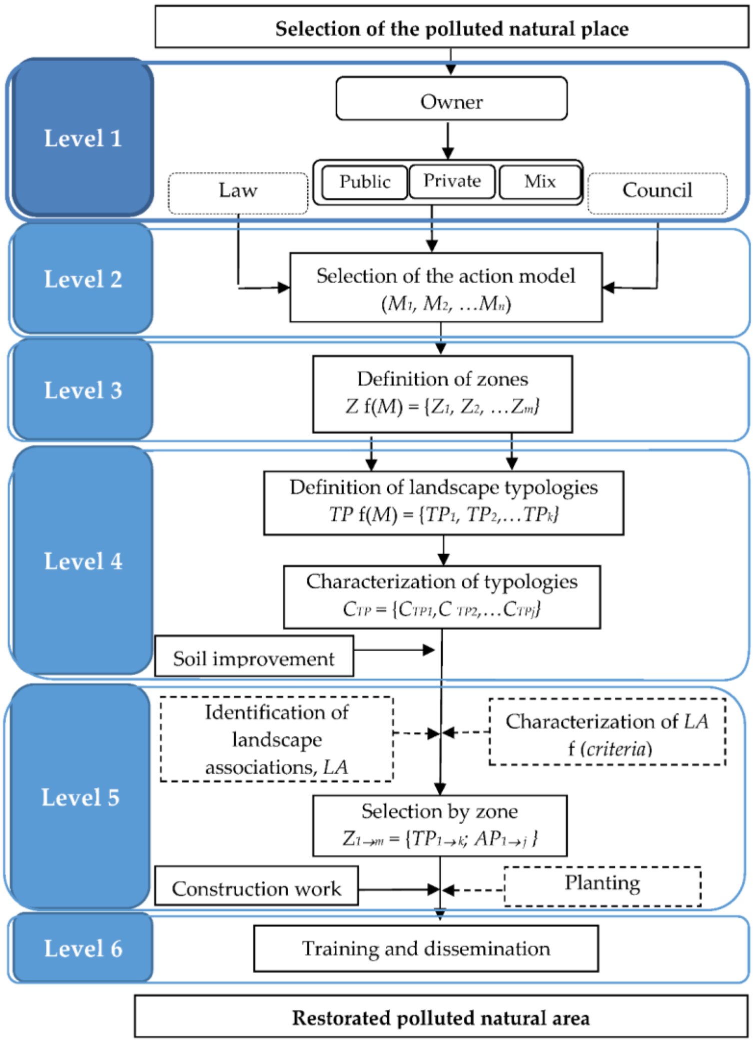


Figure 1. Outline of an action model for the rehabilitation of degraded natural areas when the pollution area is known. (---) actions related to plants. (M: action model; Z: zones depending of the model; C_{TP}: Characterization of typologies; LA: landscape associations; $Z_{1\text{-}m}$: selection of landscape associations for landscape typologies).

Although it could vary, considering our experience, the areas Z that are most common that we are going to find are:

- Z1: Plain
- Z2: Slope
- Z3: Access areas
- Z4: Transition zones
- Z5: Existing trails and recreational areas (viewpoints, etc.)
- Z6: Highly polluted soil areas
- Z7: Existing cultural landmark (castle, interpretation centers, views, etc.)

- Z8: Others

After finishing this level, we would go to the fourth level of design or decision making, in which, initially what we have called landscape typologies will be defined, which, will clearly be conditioned by the chosen model of action, TP f(M). In short, we are referring to the end use of each area, since they will have a specific function in the future, and therefore will depend on whether we have chosen a model of action of social or cultural interest, etc.

A series of typologies are proposed at this level, TP, considering our experience and the typologies that have been most successful over time, being able to be extended if necessary:

- TP1: Access
- TP2: Parking
- TP3: Transit area
- TP4: Interpretation centers.
- TP5: Cultural landmarks (e.g., castillete, oven, etc.)
- TP6: Thematic milestones (ex: botanical itineraries, etc.)
- TP7: Limited or prohibited access area
- TP8: Slopes
- TP9: Lookouts
- TP10: Footpath
- TP11: Recreation area (e.g., picnic areas, benches, etc.)
- TP12: Existing vegetation areas (trees and bushes)
- TP13: Areas to revegetate
- TP14: Other areas

Of course, at this level it is recommended to take advantage of the existing boundaries and elements, see elements of cultural interest, ancient roads, etc., identified in the previous level.

Subsequently, sometimes within the rehabilitation proposal, soil improvement should be carried out, if necessary, to ensure the growth and survival of the plants. Generally, in metal(loid)s contaminated soils, it is necessary to:

- Condition pH and immobilize the heavy metal(loid)s present in the contaminated area. This will achieve a reduction in the contamination of nearby waters and soils, as well as a decrease in the transfer of metals to the food chain. By immobilizing metal(loid)s, they are no longer washed with water, nor are they absorbed and retained by vegetation, thereby reducing the risks of transfer of contamination to animals and humans. The soils of the Mediterranean basin are mostly basic, as Mann et al., (2015) [36] show in their work; although the existence of acid soils must also be considered, depending on the rock on which they have been developed and the pluviometry of the area. In order to provide materials that ensure the ecological sustainability of the system, the use of calcium carbonates from remains and washes of marble quarries is suggested for increasing the pH in acid soils [22,37,38]. For the decrease in pH in alkaline soils, more and more acidified or unaltered biochar are used, such as those described in the work of Sadegh-Zadeh et al., (2018) [39].
- Increase the organic matter content to create a soil with good structure (adequate porosity and therefore water retention) and rich in nutrients and microorganisms, to favor the conditions for the establishment of vegetation, as shown in the works of Zornoza et al., (2013) [38] and Parra et al., (2014) [22], which provide animal manure, widely available in Mediterranean areas or the application of effective microorganisms to generate Technosols [40].

Once the soils have been improved and after a period of stabilization of the organic matter, each one of the zones or typologies must be characterized from the physical and chemical point of view and thus see the final suitability.

The fifth level represents the choice for each area of the binomial landscape typology and association of plant species to plant, Z (TP, AP), as well as its physical execution, including, depending on each case, the civil works, the rehabilitation of slopes, roads, picnic areas, viewpoints, etc., and finally the plantation.

This level is where all aspects related to the plant are studied and defined. Firstly, the existing landscape associations are identified since they spontaneously occur in the area and must be prioritized. In the same way, other typical species of the Mediterranean basin that can be used are characterized and studied.

Regarding the characterization of species, apart from the characteristics of growth and phenology, the parameters that have been considered most suitable to be decisive when discriminating between the use of one plant or another are those collected in Table 1 and those considered by Laghlimi et al., (2015) [29]. As a basis are the species sheets defined in Parra et al., (2019) [35] that provide useful information about scrub species of the Mediterranean climate. One of the most important factors is to look for species with a high phytostabilizing character. These species immobilize metals by accumulating them in aerial parts of the plant, roots, or by retaining these metals in the soil, close to the roots. These plants also retain the soil, preventing erosion and the transport of contaminated material, as well as the stability of the soil, preventing landslides. With all this we managed to alleviate many of the environmental problems identified in these areas.

Table 1. Parameters to consider for the choice of species based on tolerance values [35].

Parameter	Tolerance Values		
Soil Type	Acid soils	Basic or alkaline soils Limestone soils (pH 7.3–8.5) - Chalky soils	Edaphic indifference
Weather	Moderately rainy (500–2000 mm)	Arid (250–500 mm)	Desert (<200 mm)
Salinity	Sensitive <1 dS m^{-1}	Moderately tolerant 1–3 dS m^{-1}	Tolerant >3 dS m^{-1}
Phytostabilization	Yes	No	

In a sixth level the final use of the area would be defined. When we are in natural spaces, which is the majority of those that present contamination by industrial or mining spills, we will opt to create an educational environment that is also recreational, in order to spread the benefit generated to society. However, in the case of finding urban environments, we can allocate them to a variety of uses, such as, for example, parking or public gardens, but always with the intention of dissemination of the change made.

3. Results and Discussions

3.1. Development of the Action Model: Study Cases

The described action model has been validated in two contaminated areas of the Murcia Region in the southeast of Spain (Figure 2a) that present a climatic average of the last 10 years of 259 mm per year of precipitation, absolute T_{max} of 38.6 °C and absolute T_{min} of −1.2 °C, being able to be replicated in any contaminated area and more especially in the areas of the Mediterranean arc contaminated by heavy metals and with similar climate and vegetation. The case studies used are:

- Case study 1, is an area contaminated by mining activity, the Santa Antonieta mining deposit, which is located to the southeast of the Autonomous Community of the Region of Murcia in the Municipal Term of Cartagena. It is close to population centers, at approximately 4 km from the city of La Unión and 9.5 km from that of Cartagena. Their geographic coordinates are 37°35′38″ N and 0°53′11″ W; it has an altitude of 170 m and an area of 14,095 m^2 (Figure 2B).

- Case study 2, is an area contaminated by industrial activity, more specifically in the Guadalentín riverbed, as it passes through the municipality of Lorca, where discharges of leather tanning and nearby agricultural production were carried out (Figure 2C). With a total surface of 96,550 m^2, located in the geographic coordinates 37°40′32.5″ N 1°41′20.4″ W.

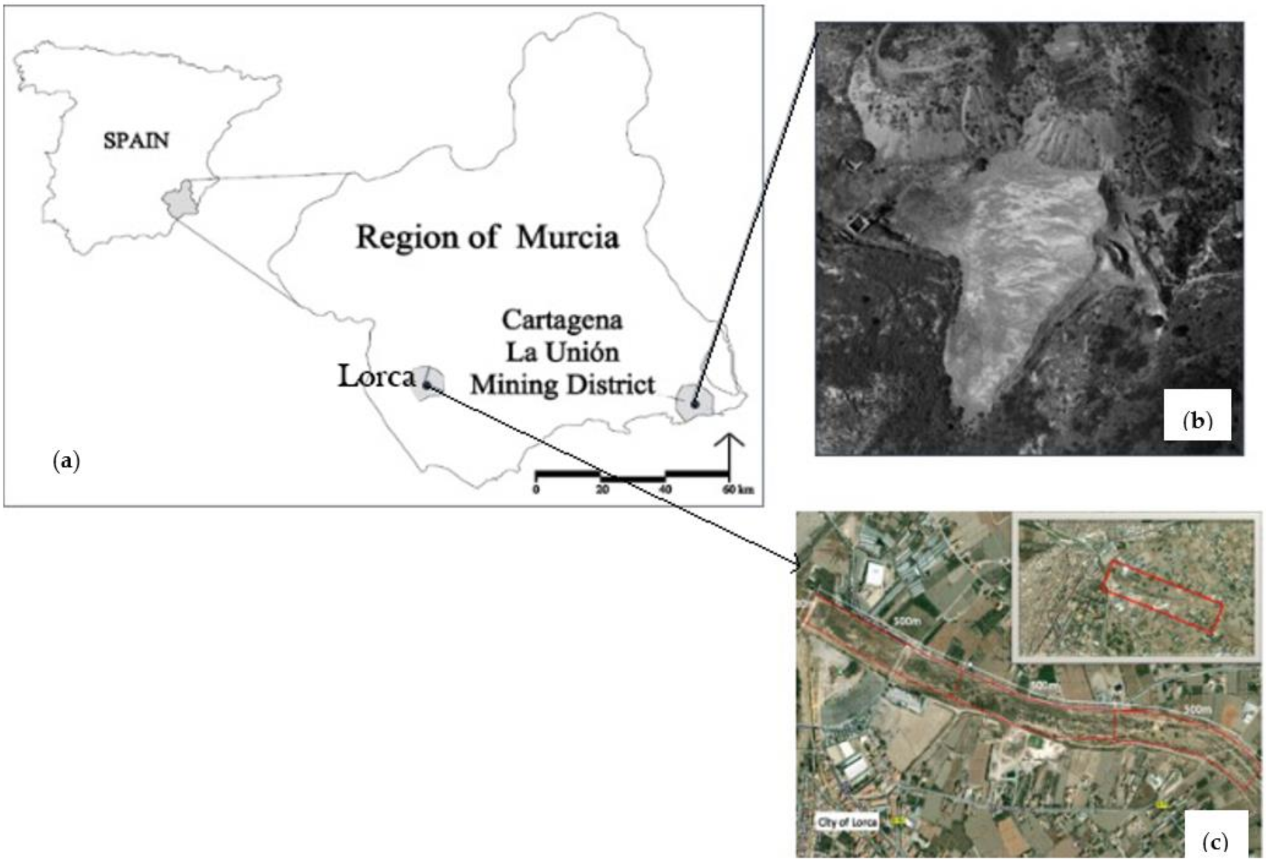


Figure 2. Situation of: (**a**) the Region of Murcia with location of the two case studies, and the case studies' situation, (**b**) the Santa Antonieta mining deposit in Cartagena, and (**c**) section of the contaminated Guadalentín river in Lorca.

Once the areas have been identified, the results of the definition of the different levels of the proposed action model are shown.

3.2. Level 1: Data Mining

3.2.1. Case Study 1

Santa Antonieta mining deposit, located in a ravine, between mountain slopes, generated by the deposition of sludge residue from mineral washing.

Location: Cartagena municipality

Ownership: Private

Skills: Private company, Cartagena City Council, Autonomous Community of the Region of Murcia

Environmental problems. The Santa Antonieta deposit has been generated by the activity of a mining operation that dumped its mineral washing residues in an old ravine with a steep slope that ended at the Avenque boulevard, producing its filling and silting. The state of deterioration can be seen in Figure A1a of Appendix A. The environmental problems of the deposit come from the presence of significant volumes of mining waste, which present severe environmental impacts, such as:

- Absence of organic matter and nutrients.

- Great compaction of the material and high acidity.
- High concentration of heavy metal(loid)s such as As and high salinity (Table 2).
- Little or no vegetation cover and biodiversity. Although there are very few plants capable of growing in the tank, those that grow can accumulate high contents of heavy metals in their tissues, which can be transferred to the food chain.
- Water and wind erosion, which transport the materials contaminated by heavy metals to other areas (especially to the *Rambla del Avenque*).
- In the western area of the deposit, the so-called "Acid Mine Drains" are formed, with high acidity, salinity and high content of dissolved metals.
- It is an unstable structure, which ends in a pronounced slope, which favors erosion.
- Loss of the historical-cultural heritage linked to mining; the industrial buildings of the Santa Antonieta deposit are in a state of ruin.

Cultural heritage. The Santa Antonieta tank features a six-legged castle with metal pulleys and an access ladder. Its state of conservation is acceptable; it maintains the two large pulleys, although the wood of its structure is degraded in some areas. Next to this is the powerhouse that is built in plastered masonry (Figure A2). Currently it does not preserve the roof.

Other relevant mining elements can be seen from the Santa Antonieta deposit, such as the *San Francisco Javier mine*, where the boulevard widens, with a machine house, steam chimney and calcination oven. The chimney of the *Oportunidad Mine* and the facilities of the *Innocent Mine* in the surroundings complete this mining nucleus (Figure A1).

3.2.2. Case Study 2

A section of the Guadalentín river as it passes through the municipality of Lorca contaminated by the dumping of waste from the tanning industry and agricultural production. Dry channel due to water retention in reservoirs located upstream.

Location: Lorca municipality

Ownership: public

Competences: Lorca City Council, Segura Hydrographic Confederation, Autonomous Community of the Region of Murcia

Environmental problems. In the city of Lorca, the problem arises for the extension of contaminated sediments by heavy metals (mainly Cu, Zn and Cr) along the Guadalentín riverbed (Figure A1b). No permanent water flows along the riverbed, carrying water after rainfall events. The transfer of dissolved metals in water and contaminated sediments contributes to the contamination of the Segura River, which is used for irrigation of croplands. The source of the contamination was the spill of tannery wastes (rich in Cr) and pig slurries from close farms (rich in Cu and Zn) in the last century.

The main environmental problems can be summarized in:

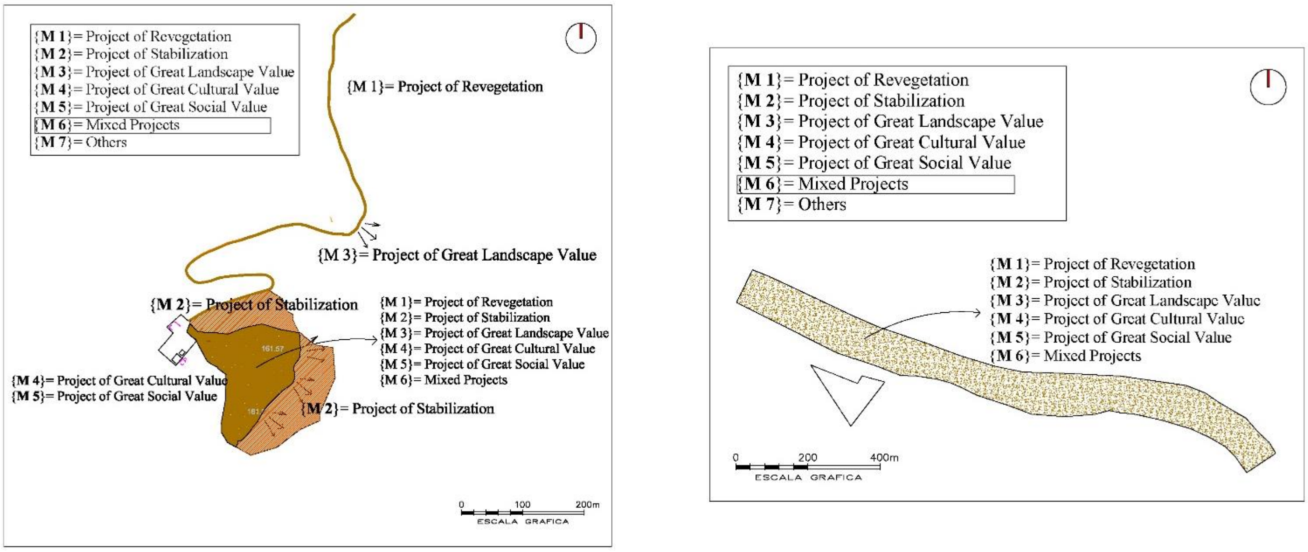
- Absence of organic matter and nutrients.
- High concentration of heavy metals and salinity (Table 2).
- Water and wind erosion, which transport materials contaminated by heavy metals to other urban areas. The riverbed serves as transportation for polluted waters that in times of torrential rains generate runoff, dragging metals downstream and even into aquifers.
- Danger of having a polluted area within easy reach of children.

Regarding the elements to be visually highlighted and the surroundings of the area to be recovered, there are to the south several mansions and historical buildings, to the north the *Sierra de la Tercia* and to the west the old town of Lorca and the *Castle of Lorca named Fortress of the Sun*.

3.3. Level 2: Selection of the Action Model

With all this, in both cases a mixed action model is proposed, owing to the characteristic and extension of the preferences of the owner, reflected in Figure 3. As can be seen in

Case Study 1, the inclusion of the access road makes the model mixed, and we find ourselves differentiated areas with different projects. In Case Study 2, the different models are located on the same surface, the riverbed.

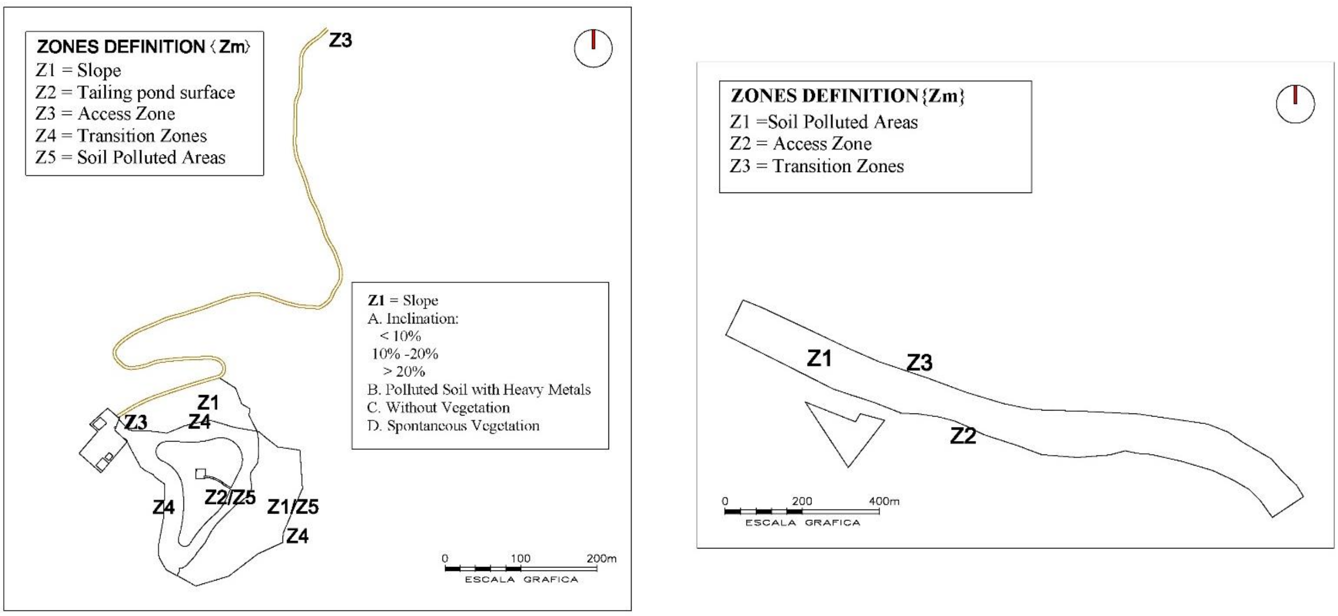


(**a**) (**b**)

Figure 3. Model of action selected and location in map for: (**a**) Case Study 1, and (**b**) Case Study 2.

3.4. Level 3: Definition of Zones

After the detailed study of the area, the project areas have been defined, these are described in Figure 4.

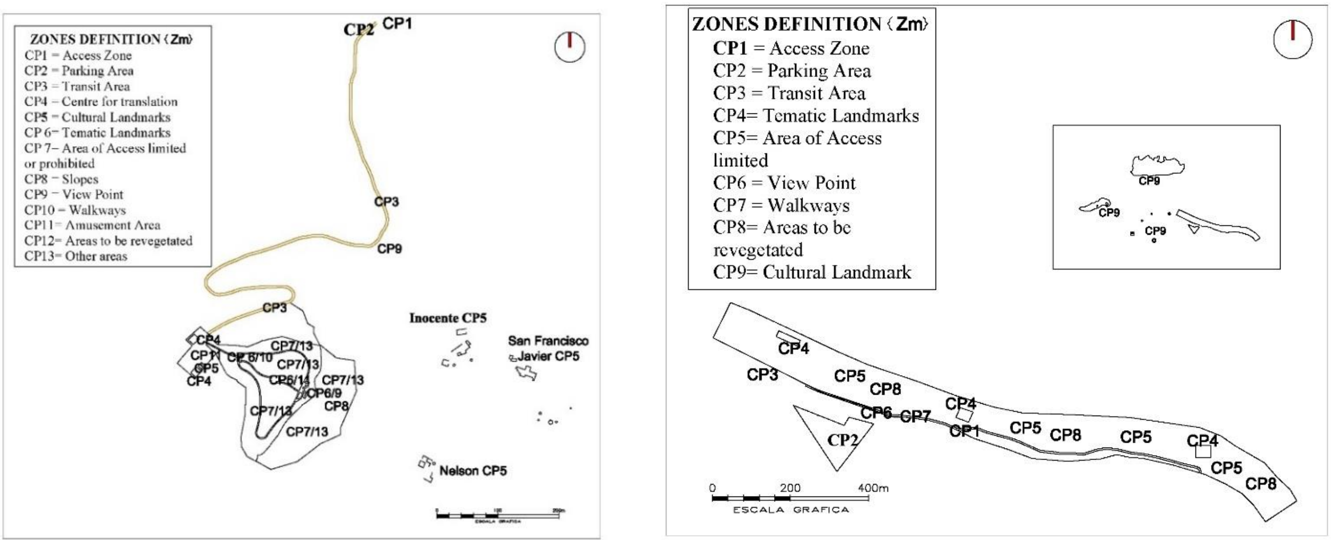


(**a**) (**b**)

Figure 4. Definition of zones selected and location in map for: (**a**) Case Study 1, and (**b**) Case Study 2.

3.5. Level 4: Landscape Definition

In the fourth decision-making level, the landscape typologies have been defined first, conditioned by the selected action model. These zones will have a specific function in the future, and therefore depend on the model chosen for each zone (of social, cultural interest, etc.). In this way, a series of typologies will be established (Figure 5), which will then be defined in detail to establish the vegetation or the civil works necessary to carry them out. For example, we must know the metal content to know if it is an area to be phytoremediated and thus establish the plants to be used or the location of the cultural landmarks (Figure A4) to guide the viewpoints or the slope of the land to define the paths, etc.



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

Figure 5. Definition of landscape typologies selected and location in map for: (**a**) Case Study 1, and (**b**) Case Study 2.

Greater detail of these areas is presented in Figures 6 and 7, thus being able to quantify the extension and location of the project. We therefore identify the areas with slopes to stabilize, viewpoints, parking and pathways and areas of educational interest, among others, that will form part of the interpretive itinerary to be created.

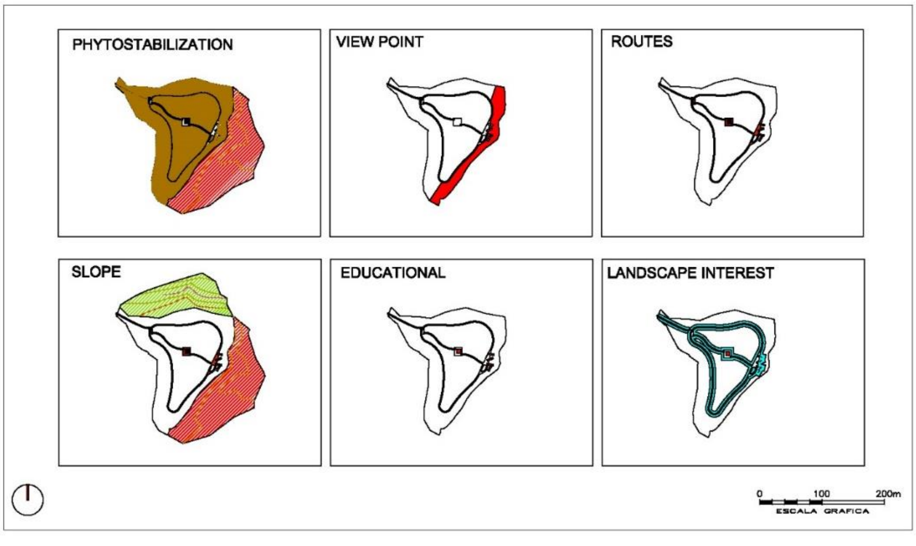


Figure 6. Detailed location of the landscape characterizations by uses, for Case Study 1.

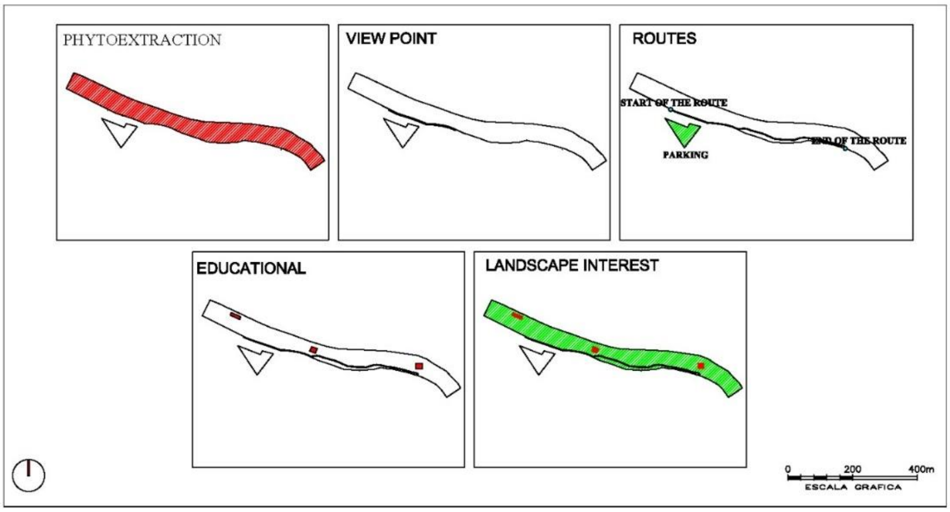


Figure 7. Detailed location of the landscape characterizations by uses, for Case Study 2.

From the characterization of the areas made for Case Study 1, it was possible to identify areas of water accumulation, areas of high salinity and areas with a high content of metals that are practically the entire plain (Figure A3), i.e., information that will be necessary to act on and that is detailed in the complementary information.

The analysis of the initial soils of both case studies, as well as the limits established for plant growth, are presented in Table 2.

Table 2. Initial soil analysis of the case studies (EC: electrical conductivity; OC: organic carbon; Nt: total Nitrogen, organic and inorganic).

Element	Case Study 1	Case Study 2	Soil Salinity and Metal Toxicity Limit *
pH	2.87	7.8	
EC (dS m^{-1})	2.3	2.5	2.0
OC (g kg^{-1})	1.78	0.9	
Nt (g kg^{-1})	0.21	0.13	
Cr (mg kg^{-1})	-	790	66
Cu (mg kg^{-1})	91	43	200
Zn (mg kg^{-1})	1587	63	400
Pb (mg kg^{-1})	1762	-	100–500
Cd (microg kg^{-1})	21	-	3
As (mg kg^{-1})	384		

* Based on concentrations of metals generally toxic to plant growth [37–39].

As we can see in Case Study 1, we have acidity, salinity and high toxicity problems, especially in Zn and Pb. In Case Study 2, the most notable is the salinity of the soil and its high toxicity in Cr.

In Case Study 1, to achieve the physical and chemical improvement of the soil as well as the immobilization of metals, the contribution of two by-products was made, one generated in the marble processing industry (8 kg m^{-2}), to increase the pH to 6.89 and another in livestock activity, such as pig slurry (7 kg m^{-2}), to increase soil quality and microbial activity (OC = 4.35 g kg^{-1}), a detail of the contribution can be seen in Figure A5 and it is described in depth by Parra et al., and Rosales et al. [22,28]. In the case of study 2, the contribution of amendments was not necessary. Pardo et al., (2011) [37] in reclamation works also concluded that the use of pig slurry improved soil properties in organic material and microbiology activity.

3.6. Level 5: Characterization and Selection of Species: Construction and Plantation

3.6.1. Work Construction

In Case Study 1, the civil works carried out followed the landscape design generated and were divided into the following parts:

- Access area: this space includes the access road from the N-345 road between La Unión and Portman, which did not exist.
- Network of trails: a network of trails has been designed that fulfills the function of environmental itineraries. This network is made up of a perimeter path and a central one.
- Draining perimeter ditch, which prevents the accumulation of water in the east and west of the reservoir at the foot of the slopes of the mountains.
- Slope regeneration area: stabilization of the slopes surrounding the reservoir, by placing heather sashes, amendments and plants to stabilize.

At the beginning of the project of Case Study 2 and for its correct implementation, it was necessary to remove all kinds of debris, wastes, rubbish, etc., accumulated in the selected stretches of the Guadalentín riverbed and banks to be able to access for site preparation and increasing their aesthetic value. In the case of the riverbed, it is not allowed to act with any type of civil work, since the geometry of the riverbed cannot be altered, so only the following has been carried out:

A. 1.50 m wide wooden walkway in the first 200 m of the route, parallel to the riverbed, with a raised ramp point, to facilitate access to the start of the route for people with motor disabilities, facilitating visits to this environmental regeneration project for this group.

B. The works necessary for the stabilization of slopes: carrying out a union of concrete walls of the first 500 m of the channel with the earth slope, the reconstruction, conditioning and re-profiling of slopes and the elimination of invasive species.

3.6.2. Selection of Species by Zone

The vegetation of the area was studied and existing species and landscape associations of species that spontaneously grew together were identified. This section was defined by following the recommendations of Parra et al., (2019) [35] where the species data sheets can be consulted, obtaining the information set forth in Table 1, as well as the aspects of botanical classification, structure, appearance, morphology, ecology and timing of the phenological states in the year. Based on this and linked to the needs of each area, the plantation was defined, the details of the characteristics of each species, as well as the plantation plans are found in the complementary information. Regarding the selected vegetation, the metal (oils) accumulation rates were discussed in Parra et al. [20] for Case Study 1 and in Beltra et al. [41] for Case Study 2.

In Case Study 1, several planting areas were defined:

- Zones A and B that surround viewpoints (2077 m^2) and a network of trails (2493 m^2), in which plant species with landscape interest were selected and whose development did not block views from these points. These being: *Lavandula dentada*, *Rosmarinus officinalis*, *Cistus albidus*, *Ligeum spartum* and *Cynodon dactylon*. Seven-hundred and sixty-one units of each species were planted with a planting frame of 1 unit m^{-2}.
- Central zones C and D of the deposit and surroundings, with high needs for phytostabilization (3219 m^2 and 4264 m^2), we sought phyto-stabilizing species that had moderate growth in this environment, did not block views and allow us to create landscape-interesting volumes. *Atriplex halimus*, *Ligeum spartum*, *Helichrysum decumbens*, *Phagnalon saxatile*, *Piptatherum miliaceum*, *Zygophyllum fabago*, *Dittrichia viscosa* and *Hyparrhenia hirta* were selected. Six-hundred and eighty-seven units of each species have been planted in a planting frame of one plant per m^2.
- Transition zones: it includes the zone bordering the mining deposit, with a total area of 3144 m^2. Within this unit, plant species with landscape interest have been selected,

among which we find the following plant species: *Pistacea lentiscus*, *Tetraclinis articulata*, *Chamaerops humilis*, *Tamarix canariensis*, *Atriplex halimus*, 126 units of each species were planted with a planting frame of 1 plant m^{-2}.

- Slopes regeneration zone with risk of landslides. Five thousand heath sashes and species (Figure A11) with greater root development were placed to give stability: *Atriplex halimus*, *Ligeum spartum*, and *Zygophyllum fabago*. One hundred and twenty units of each species.

For Case Study 2, when all the models and typifications were found in the same environment, plants with phytostabilization capacity, resistant to salinity and with edaphic indifference for growth were chosen for the riverbed, using a total of 39,989 plants in three plantations over two years. The species used were:

- Riverbed area: 1 plant m^{-2} plantation. Species: *Atriplex halimus*; *Hyparrhenia sinaica*; *Lygeum spartum*; *Piptatherum miliaceum*; *Salsola oppositifolia*; *Suaeda vera*; *Silybum marianum*; *Tamarix fricana*; *Dittrichia viscosa*; *Foeniculum vulgare*; *Stipa tenacissima*; *Phagnalon saxatile*; *Nerium oleander*.
- Slope stabilization zone: 1 plant m^{-2} plantation. Species: *Atriplex halimus*; *Lygeum spartum*; *Salsola oppositifolia*; *Suaeda vera*; *Stipa tenacissima*; *Nerium oleander*; *Tamarix fricana*.

Some planting maps can be seen in Figures A6–A10 in Appendix A.

Among the limiting factors of viability (Table 1), their growth habit was also considered, which determined their placement in the plantation, so that they did not overlap and cover. We have selected plants already used in the area, such as *Piptatherum miliaceum* and *Dittrichia viscosa*, that were shown as a good accumulator of Pb in the *Sierra Minera* [42]; or the case of *Lygeum spartum*, which under optimal cultivation conditions is capable of phytostabilizing high amounts of metals [34]. In the case of accumulation of Cd and Zn, works by Gómez-Ros et al. [14] show good values for *Dittrichia viscosa*, *Tetraclinis articulata* and *Hyparrenia.* All these coincide with what was found in the two case studies and can be consulted in Parra et al. [22] for Case Study 1 and Beltra et al. [41] for Case Study 2.

3.7. Level 6: Definition of End Use

Since we are in natural environments and considering the chosen mixed model, the end use of both areas is didactic and recreational. Being open-air areas, in both cases a training and dissemination strategy is adopted, with the development of explanatory posters of itineraries and technology used in decontamination, as well as explanations of the history of the enclave and the industrial activity that has led to it being contaminated, in order to educate present and future generations on how human activity can contaminate a place that we can maintain today, but never return to its original state. Figure 8 shows the final state of both case studies, after rehabilitation.

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

Figure 8. Final state of rehabilitation: (**a**) in Case Study 1, and (**b**) Case Study 2.

In Case Study 1, the environmental itinerary is made up of a network of paths that run in a circular direction with a central path that divides it. This itinerary allows visitors to observe plants used for plant stabilization purposes and the native plants associated with them with landscape interest. Along these roads, signs and interpretive panels have been placed to explain the tasks carried out, the history and heritage of the place, the risks linked to mining, the main characteristics of the ecosystem, as well as the description of the species used, the details of these panels is presented in Appendix A (Figure A12). On the central path, a platform has been defined where the didactic plots are located, consisting of four flower beds containing different types of soil, allowing visitors to observe the growth of plant species in the original soil of the mining deposit, in original floors with a mixture of amendments (pig slurry and marble sludge), an original floor with a single contribution of marble sludge and original floor with a single contribution of pig slurry, together with a panel explaining the amendment and phytostabilization process used. In addition to the itinerary, the following have been defined:

- Three viewpoints, which allow visitors to observe an extraordinary panoramic view of the mining area, being able to compare the regenerated Santa Antonieta mining deposit with other abandoned and degraded deposits.
- A recreational area that coincides with the esplanade where the buildings that constitute the architectural heritage of the deposit are located. From this esplanade the itinerary begins. In this area, the inclusion of urban furniture and shade trees is planned, which will invite the visitor to rest.
- It is planned to define a museum area in order to develop new future economic opportunities, turning the industrial architectural heritage into a museum area for educational use and that serves as a link between nature and human heritage.

The visit to Santa Antonieta is planned to be included in the recreational cultural offer of the Cartagena City Council and is included in the hiking and cycling routes of various sports clubs.

In Case Study 2, a didactic itinerary has been defined in which the characteristics and most relevant aspects of the route are detailed through posters, considering stops at the most interesting points of interest, the detailed plan and sample poster are in the supplementary information (Figure A13). With this, the aim is to disseminate the environmental values of the environment and our role as individuals and as a group in its improvement and conservation, develop the curiosity and interest of users, value the resources offered by the natural environment and give learning opportunities on the different actions carried out in this area to achieve the complete environmental regeneration of the banks of the Guadalentín river.

It is a 1000 m long, open linear and self-guided route, where the route is marked, and along which are nine panels in which the following is included:

- Panel 1. Brief description of the environmental project, map, regulations for use and precautions, and technical information on the itinerary.
- Panel 2. Overview of Lorca from the performance area. Description of the problem of pollution, its history and origin.
- Panel 3. Description of the techniques used. Results of the actions carried out.
- Panels 4, 5, 6 and 7 (placed at different points on the itinerary). Description of the most representative plant species.
- Panel 8. Biodiversity of the river ecosystem.
- Panel 9. End of route.

Regarding the direct repercussion that could be accounted for in both rehabilitations, it is possible to say that there have been numerous guided technical visits with secondary schools and universities; in two years, there have been more than 600 visits in the case of study 1 and 300 in the case of study 2. More than 10 courses, conferences and workshops and club visits are hiking and cycling. Particularly notable is that both the population of the area and technical visits were conducted with a survey, thereby confirming that the people answered favorably to the surveys and to the questionnaires at the end of the training activities and they admit that the knowledge they have acquired can be applied to their municipality and can be put into practice in a future.

Concerning the proposed model, this agrees with Chazdon and Guaruguata [13] about their conclusions that a tool for prioritization, spatial planning and species selection must be used to build and repair elements and must contain a clear objective in mind and a plan of action as we have proposed. Additionally, we should add that using the wrong tool can be counterproductive and wasteful in both time and money. The ecosystem service approaches have also been a priority as argued by Ruckelshaus et al. [16] and clearly the model proposed has to move from a scientific standpoint to real-world decision making.

4. Conclusions

A methodology has been defined that is intended to help owners and managers for the rehabilitation of contaminated areas. The methodology has been validated in two cases (in the mountains and in an urban nucleus) and in both, it has been verified that the follow-up of the steps described, grouped into five levels, makes it possible. The proposed model combines the previous study of the area, the soils, the surrounding vegetation, and the associations of species that exist naturally in the area. The solution seeks to neutralize metal contamination in these areas, through phytostabilization with specific plant species. So, the projects go from an isolated and dangerous enclave to a recreational area to be enjoyed safely by schools, athletes and families, and providing learning about history, botany and ecology. The establishment of the vegetation has proliferated in the area, together with the high number of registered visits and the impressions collected demonstrate the social and environmental benefit obtained.

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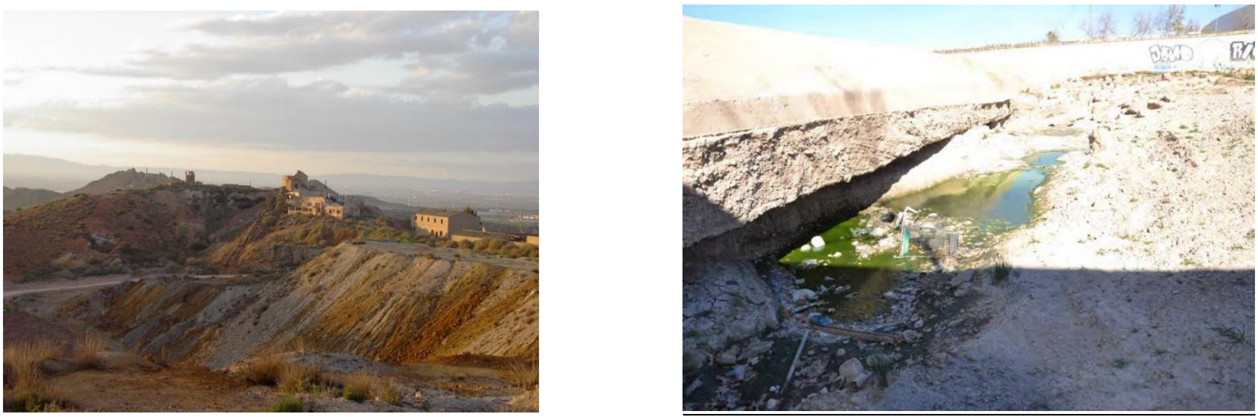
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A



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

Figure A1. Deterioration of the study areas: (**a**) Waste materials generated by the mining activity in La Unión (MU, Spain), (**b**) industrial discharge and rubble in the Guadalentín riverbed in Lorca.

Figure A2. General view of castle and engine room in Case Study 1.

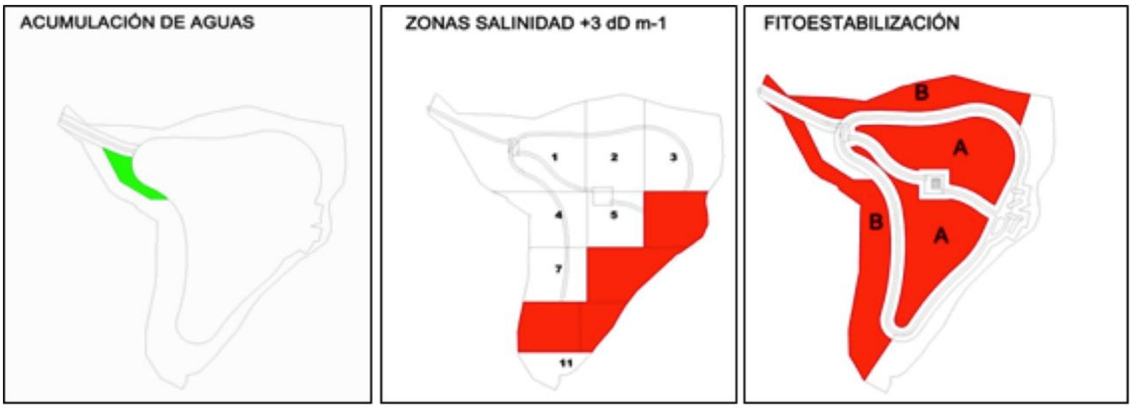
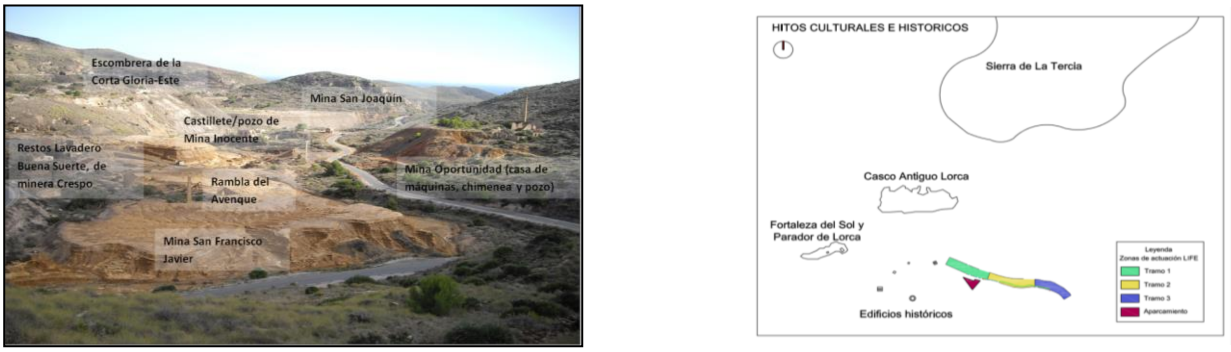


Figure A3. Characterization of areas with environmental problems, for Case Study 1.



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

Figure A4. Definition of nearby cultural and historical landmarks for: (**a**) Case Study 1, and (**b**) Case Study 2.

Figure A5. Detail of the application of amendments in Case Study 1.

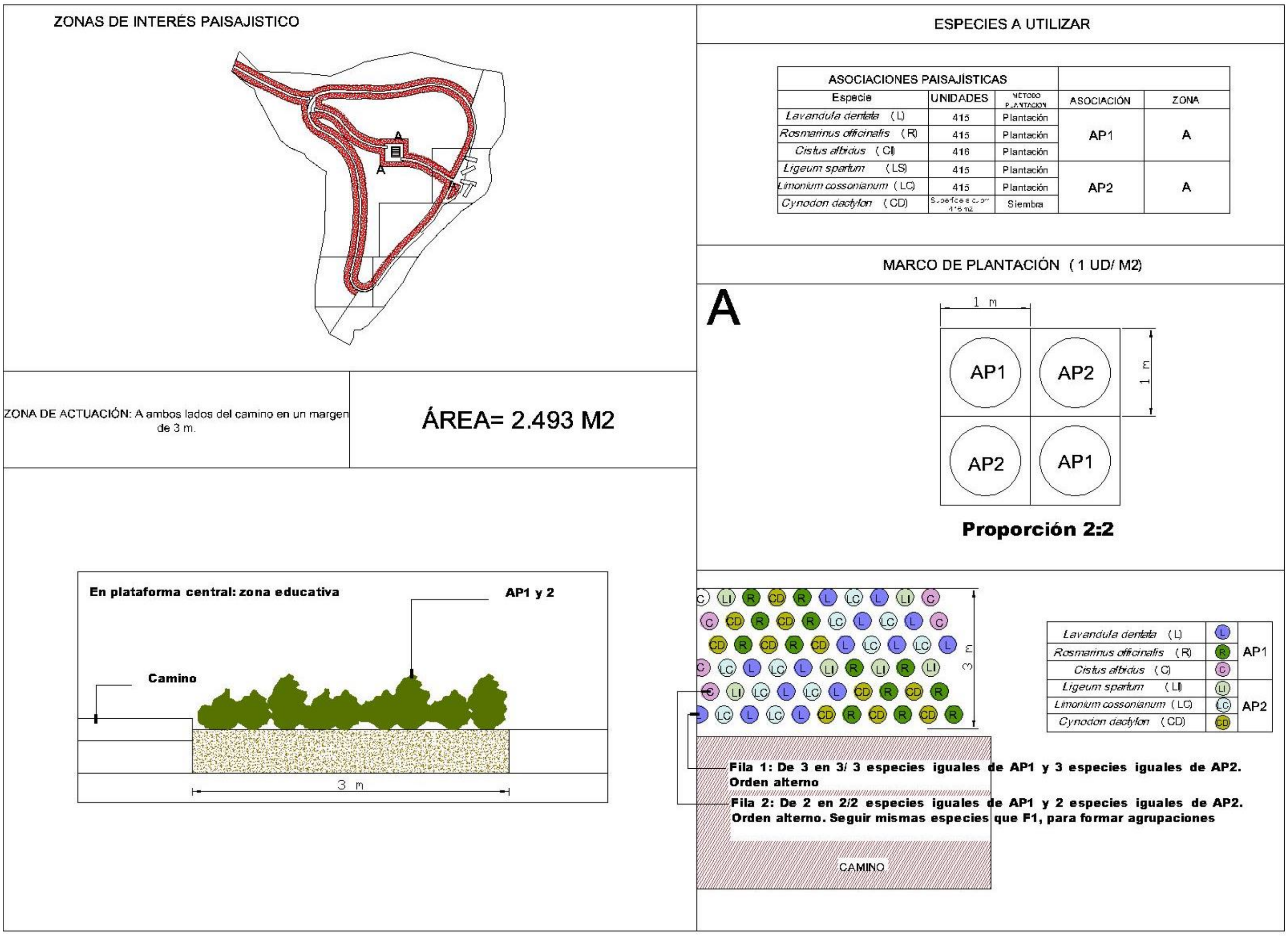


Figure A6. Planting map for zone A of Case Study 1.

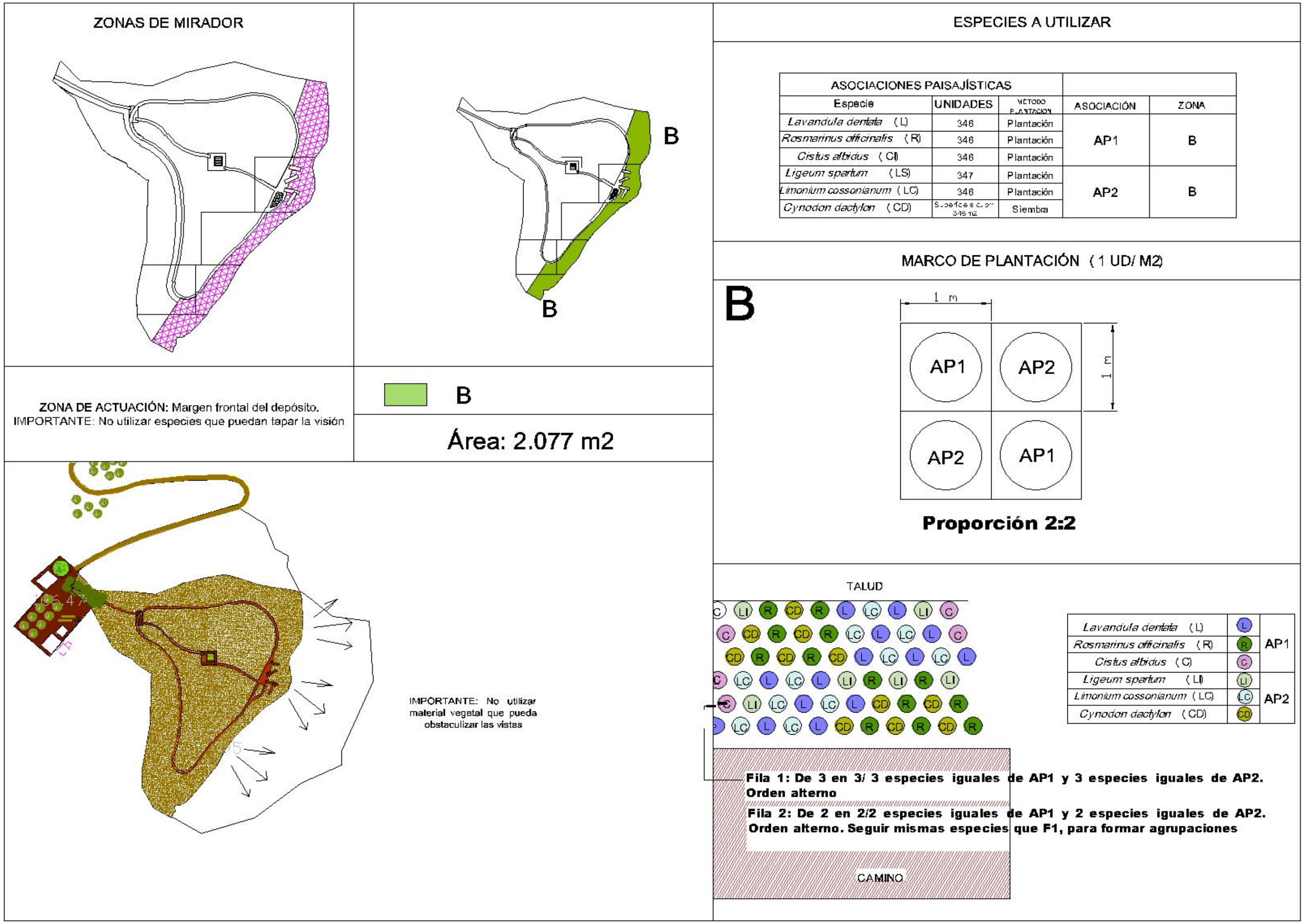
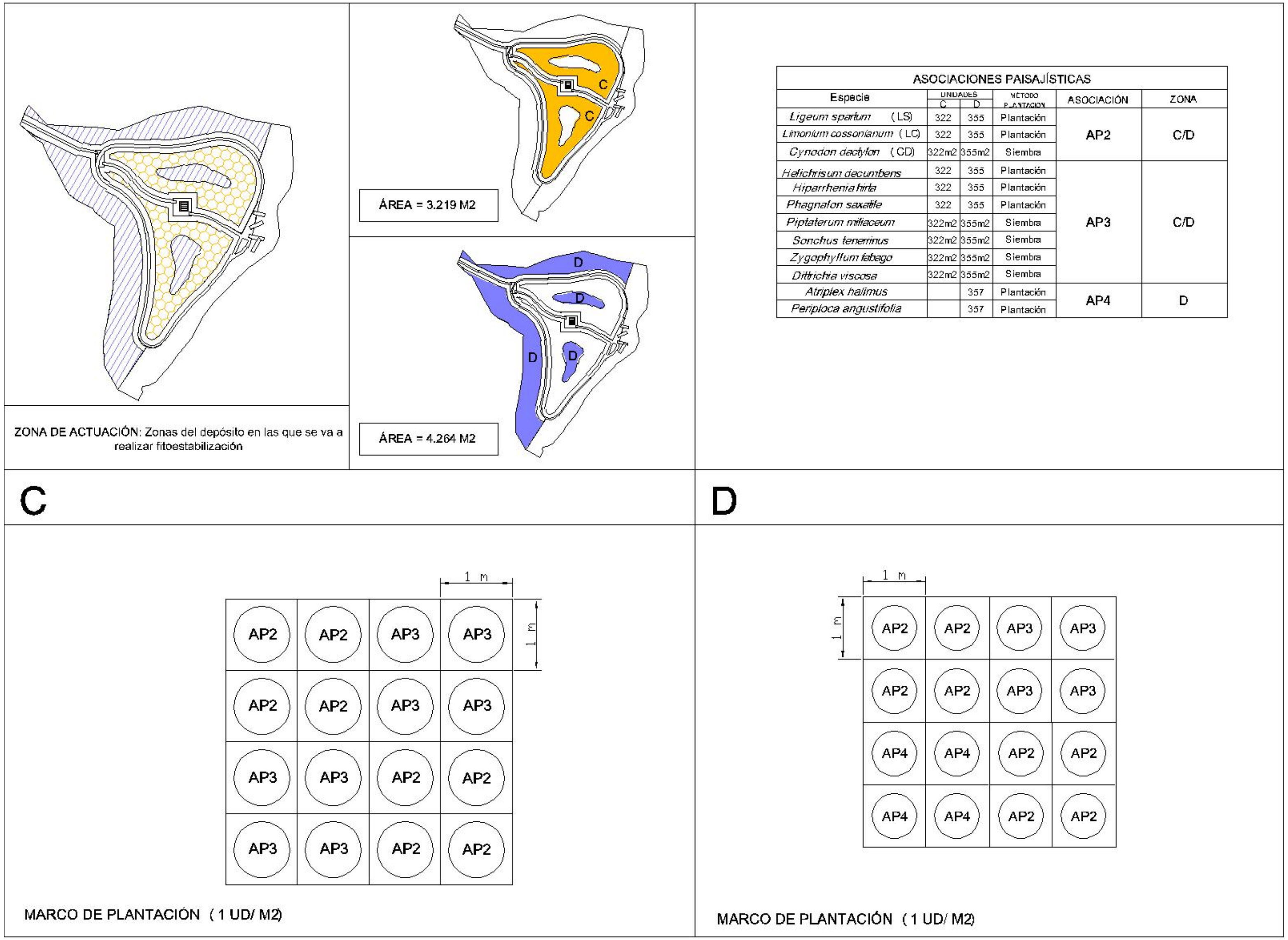


Figure A7. Planting map for zone B of Case Study 1.



ASOCIACIONES PAISAJÍSTICAS					
Especie	UNIDADES C	UNIDADES D	MÉTODO PLANTACIÓN	ASOCIACIÓN	ZONA
Ligeum spartum (LS)	322	355	Plantación	AP2	C/D
Limonium cossonianum (LC)	322	355	Plantación		
Cynodon dactylon (CD)	322m2	355m2	Siembra		
Helichrisum decumbens	322	355	Plantación	AP3	C/D
Hiparrhenia hirta	322	355	Plantación		
Phagnalon saxatile	322	355	Plantación		
Piptaterum miliaceum	322m2	355m2	Siembra		
Sonchus tenerrinus	322m2	355m2	Siembra		
Zygophyllum fabago	322m2	355m2	Siembra		
Dittrichia viscosa	322m2	355m2	Siembra		
Atriplex halimus		357	Plantación	AP4	D
Periploca angustifolia		357	Plantación		

Figure A8. Planting map for zones C and D of Case Study 1.

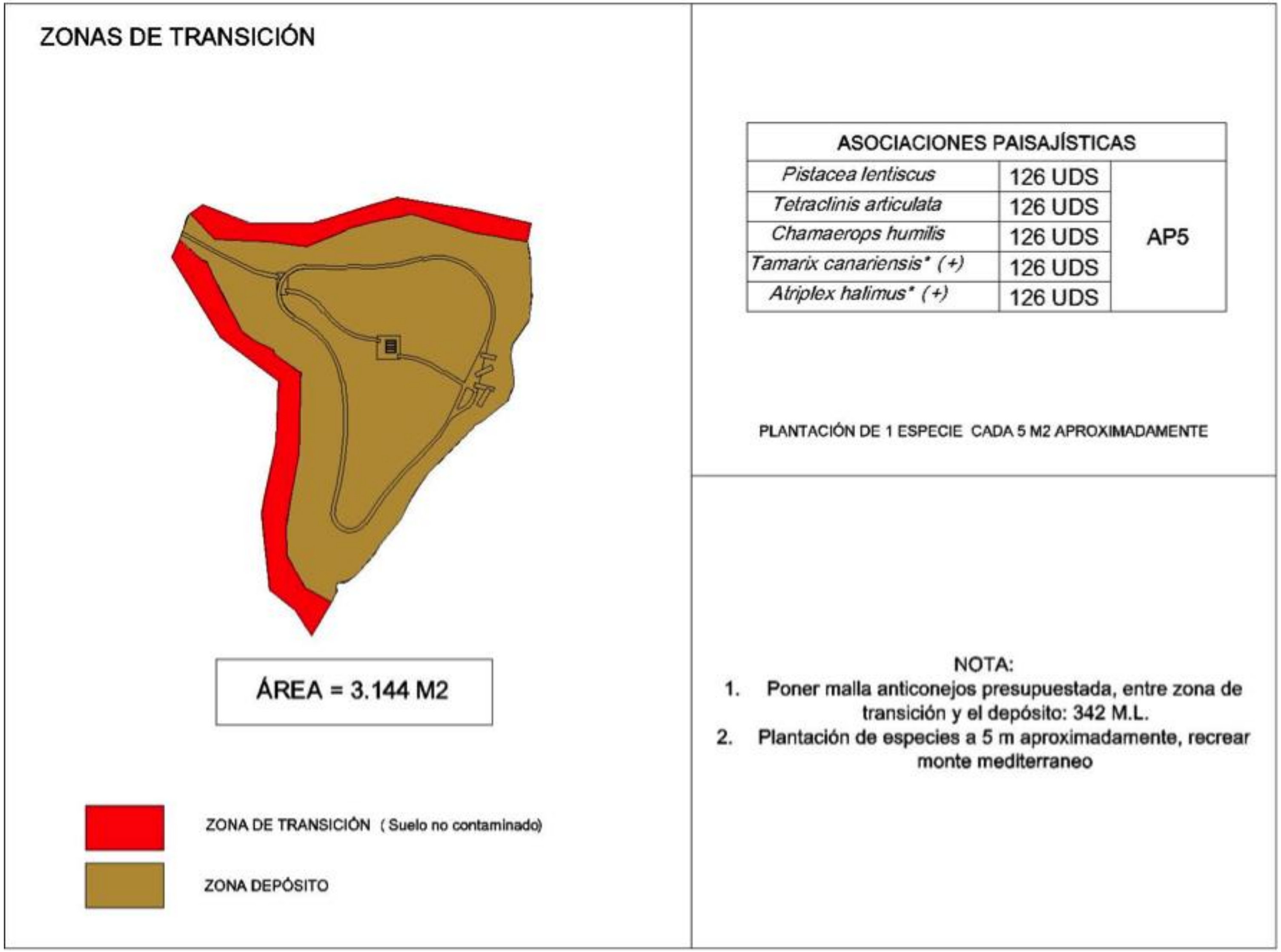
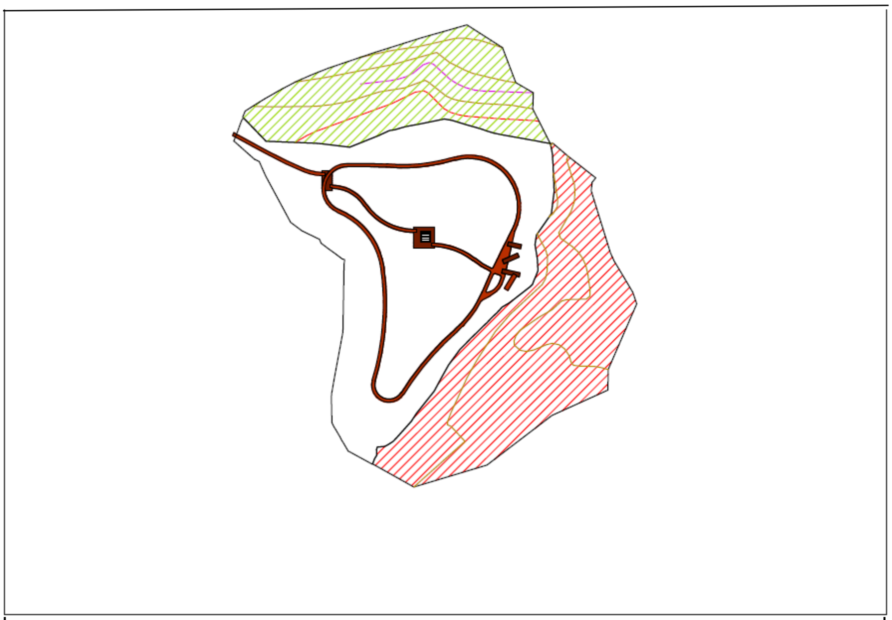


Figure A9. Planting map for the transition zone of Case Study 1.



TALUD	
Fajinas	**Unidades**
Talud camino+ Talud depósito	5.465
Especies	**Unidades**
Atriplex halimus L.	185
Lygeum spartum (L.) Kunth.	120
Zygophyllum fabago L	Siembra en Octubre

Figure A10. Planting plan for the stabilization of slopes of Case Study 1.

Figure A11. Detail of stabilization of slopes with heather sashes in Case Study 1.

Figure A12. Definition of location of panels of the itinerary and example of panel in Case Study 1.

Figure A13. Example of a panel in Case Study 2.

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