Deliverable on establishment success of plantations:

Survival and Growth

LIFE16 ENV/ES/000159

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1. Introduction

Open-pit mining results in profound modifications on different environmental scales that may persist for very long time periods, or even indefinitely. The ability to recover these highly degraded areas is reduced due to environmental limitations (Carrick and Kruger, 2007; Valladares and Gianoli, 2007; Hardegree et al., 2011), especially in areas where the natural vegetation has been completely removed and the original soils have disappeared (Bainbridge, 2007). In this sense, the setting objectives for restoration must aimed at considering a combined processes from geomorphological recovery to multilayered and diverse vegetation cover according to the soils and bioclimatic conditions of each area (Martin-Duque et al., 2020; Jorba et al., 2011; Turrión et al., 2021).

The ecological recovery of degraded lands, that involves the introduction of species or the natural colonization of native species, should implement field techniques to maximize water availability and nutrients to ensure seedling establishment, survival and growth (Vallejo et al., 2012). In this sense, the diversity of selected species and the use of native species with a high colonizing capacity and high resiliency against disturbances and stress conditions is a key issue (Montero de Burgos and Alcanda, 1993; Vilagrosa et al., 1997). Contrarily, if selected plants are not suitable for the restoring area, the consequences may involve high mortality rates, reduced growth rates, low competitiveness and poor seed production during the following years (Thomas et al., 2014).

After restoration, to establish a continuous monitoring and analysis of revegetated areas will help to assess restoration success and could warning of possible critical deficiencies at early stages (Vickers et al., 2012). In this regard, important parameters such as survival rates and seedlings growth must be considered.

2. Approach and objectives

The main goal of the present document is to analyze the survival and growth data obtained during the monitoring period (i.e., 1-3 years after outplanting) in the LIFE TECMINE Project. Complementarily, the reforestation quality control and the identification of limiting steeps will improve the results and recommendations for future restorations.

These generic objectives have been developed within the following tasks:

1) Analysis on the climatic data registered in the meteorological station located in the restored area, during the following years after planting.
2) Data analysis of the soil water content dynamics in the planting holes across the monitoring period.
3) Survival assessment of the introduced seedlings in the main Restoration Units.
4) Growth analysis (height, basal diameter) of the reforested species.
5) Plant performance analysis: reproductive effort and natural recruitment.

3. Material & Methods.

3.1 TECMINE area and Restoration Units

In the TECMINE Project we identified 3 different Restoration Units (see Sub-Action A4.2 Gemorphological restoration for further information): 1) Platform mine area that included the Geofluv West area (5.20 ha), 2) the Permanent Pond and surrounding areas (0.9 ha) and, 3) Talus-berm areas (1.44 ha) (Figure 1, Table 1).

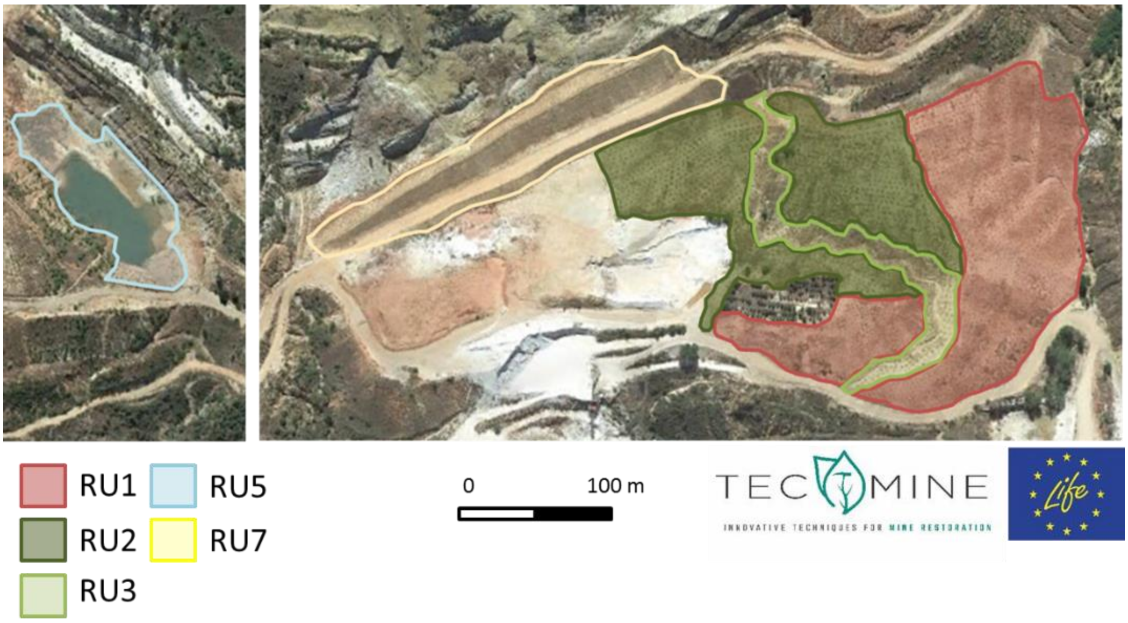


Figure 1. Aerial images showing the Restoration Units (RUs): 1) Platform mine area subdivided into RU1, RU2, and RU3. 2) Permanent Pond area, RU5. 3) Talus-Berm area, RU7.

Table 1. Description of the main characteristics of each Restoration Unit: surface area, aspect and slope

Area	Restoration Unit (RU)	Main characteristics
Platform Mine area	RU1 (ca. 2.79 ha)	Drier (sun-exposed), some localized areas with slopes exceeding 30%
	RU2 (ca. 1.98 ha)	Dry–mild areas, moderate slopes (15%–30%)
	RU3 (ca. 0.46 ha)	Wetter areas, bottom and valley areas, flow accumulations, flat areas, slopes <15%
Permanent Pond	RU5 (ca. 0.9 ha)	Semi-natural wetland
Talus-Berm area*	RU7 (ca. 1.44 ha)	Adjacent flat “berm” areas with uniform steep slopes “talus”.

* No initially planned.

3.2 Species selection in each Restoration Unit

We introduced a combination of species according to Deliverable, Action A.4. Sub-action 3 (August 2018) and Midterm Report (November 2017). To analyze survival and growth, we considered each combination of habitats and species introduced in the whole restored area (Table 2).

Table 2. List of the introduced species according to Natura 2000 Habitats, number of seedlings and percentage of presence, in brackets, of each species in each Restoration Unit. In the table heading the plantation density and unit surface area of each Restoration Unit are specified.

		Geofluv West Platform area			Permanent Pond area (RU5)		Talus-Berm area (RU7)
Habitat	**Species**	**RU1 (1000/ha; 2.9 ha)*** **	**RU2 (600/ha; 2.0 ha)**	**RU3 (600/ha; 0.4 ha)**	**Surroundings (600/ha; 0.3 ha)**	**Flooded area (1200/ha; 0.1 ha)**	**Talus (1000/ha; 0.9 ha)**
Habitat *6220 Pseudo-steppe with grasses and annuals of the Thero-Brachypodietea with shrubs (Rosmarino-Ericon)	*Brachypodium retusum*	220 (7)					
	*Brachypodium phoenicoides***	220 (7)					600 (67)
	Psoralea bituminosa	290 (10)					
	Lavandula latifolia	290 (10)					
	Rosmarinus officinalis	290 (10)					
Habitat 9340 Quercus ilex and Quercus rotundifolia forests	*Quercus ilex*		360 (30)				
	Rhamnus lycioides	580 (20)	240 (20)				
	Rhamnus alaternus	230 (8)	170 (14)				
	Colutea arborescens	230 (8)	105 (9)				
	Dorycnium pentaphyllum	289 (10)	105 (9)				300 (33)
Habitat *9530 Sub-) Mediterranean pine forests with endemic black pines	*Pinus nigra ssp salzmanii*			34 (14)	17 (14)		
	Amelanchier ovalis			24 (10)	12 (10)		
	Prunus spinosa			24 (10)	12 (10)		
	Lonicera etrusca			8 (3)	4 (3)		
	Pistacia terebinthus			16 (6)	7 (6)		
	Crataegus monogyna			17 (7)	8 (7)		
Habitat 5210 Arborescent matorral with Juniperus spp.	*Juniperus oxycedrus*	58 (2)	45 (4)		12 (10)		
	Juniperus phoenicea	200 (7)	105 (9)	10 (5)	12 (10)		
Habitat 9240 Quercus faginea and Quercus canariensis Iberian Woods	*Quercus faginea*			35 (15)	18 (15)		
	Sorbus domestica			24 (10)	12 (10)		
Habitat *9560 Endemic forests of	*Juniperus thurifera*		70 (6)		6 (5)		

Juniperus spp.							
Habitat 92A0	*Populus alba*				30 (25)		
Salix alba and	*Fraxinus angustifolia*				30 (25)		
Populus alba	*Salix atrocinerea*				30 (25)		
galleries	*Salix purpurea*				30 (25)		
	Tamarix canariensis				30 (25)		
Habitat 6420	*Typha domingensis***					270 (25)	
Meditteranem tall	*Phragmites australis*					86 (8)	
humid herb	*Scirpus holoschoenus*					312 (29)	
grasslands of the	*Molinia caerulea*					214 (20)	
Molinio-	*Juncus inflexus*					163 (15)	
Holoschenion	*Juncus subnodulosus*					26 (2)	
Total	6428	2897	1200	240	240	951	900

Note: *Habitats listed as priority habitats. ** Species no initially planned.***Final density (seedling/ha); total area (ha).

3.3 Climatic variables: Temperature and precipitation assessment

We installed a meteorological station located in the restored area to assess climatic conditions. The meteorological station specifically placed at 40°11’21.81’N’, -1°15’99.54’’W and 966 m.a.s.l., was provided with a rain gauge (EML model ARG100), temperature and relative humidity sensors (E Elektronik model: EE08-PFT1V11D6 / T48), a solar radiometer pyranometer (Kipp & Zonen model CMP3), a barometer for Wind speed and direction sensor (Geoves model CS BAR-I 3Wire) and, soil humidity and temperature probes (Campbell Sci model CS655-DS 12CM Water Contect Reflectometer). A data logger (Campbell Scientific model CR1000X) and a communication system (Matrix / Siemens communication modem MTX-3G-JAVA FW 3.00 / 199801388, with embedded MTX-Tunnel v9.18) sent the recorded data to the receiving center at CEAM research center. This equipment provided daily climatic data on total and maximum precipitation, maximum, minimum and mean temperature, maximum wind-speed and, soil water content at 10 cm in depth. (Figure 2).

Figure 2. General view of the meteorological station installed in the restored area.

3.4 Soil Moisture monitoring in the planting holes

We monitored soil moisture dynamics in the planting holes to assess the water availability for the seedlings in each Restoration Unit. In addition, this evaluation allowed us to control levels of available water after critical periods such as the summer months characterized by prolonged drought. We monitored soil water availability by discrete measurements (TDR probes) and by continuous recording system (10HS sensors). We installed TDR (Topp and Davis 1985) soil moisture probes (0-30 cm depth) upslope of 12 target seedlings per Restoration Unit (RU1, RU2 and RU3). We used a TDR100 device (Campbell Scientific, Inc., Lo Installgan, USA) to registered soil moisture as an integration of volumetric soil water content through the software PCTDR100 (Figure 3, left). We measured monthly during the summer season and bimonthly the rest of the year. In addition, we installed soil moisture sensors 10HS (Decagon dev., Pullman, USA) at 30 cm depth horizontally in eight target seedlings by Restoration Unit (RU1, RU2 and RU3). These sensors provided hourly soil moisture data. We recorded continuous data for the entire monitoring period, and we downloaded bimonthly the data using the software ECH20 Utility (Figure 3, right). In total, we followed the soil moisture dynamics in 60 recording points with both types of measurements (Table 3).

Figure 3. Detailed image of soil moisture samplings. Left image shows discrete measuring by the TDR100 Campbell device. Right image shows the downloading of continuous data through the software ECH20 Utility from Decagon.

Table 3. Summary information about the distribution of TDR soil moisture probes (discrete measurements) and soil moisture sensors 10HS (continuous measurement) installed in the target seedlings.

Restoration unit	Discrete (TDR) 4 plot (100 m^2)	Continuous (10HS) 2 plot (100 m^2)
RU1	12	8
RU2	12	8
RU3	12	8
Total	36	24

Note: TDR probes were installed in four groups of three seedlings distributed in each RU. The 10HS sensors were installed in two groups of four seedlings per each RU.

3.5 Initial seedling characterization

To evaluate seedling stock quality, we carried out a morphological characterization for a set of 10 seedlings per cultivated species, at the end of the nursery period. We measured height, stem basal diameter and, both above- and below-ground biomass. We also determined the root/shoot ratio as an indicator of the balance between root capacity to absorb water and aboveground parts development, as well as of plant quality (Gil, Pardos 1997).

3.6 Seedling survival and growth

Once the plantation was carried out, we monitored seedling survival and height and diameter growth, during two years after outplanting (from July 2019 to July 2021), including an additional sampling in December 2021. We sampled twice a year (at the end of Spring and Autumn). To identify each monitoring seedling, we labeled the selected individuals with a numbered metal tag in a representative percentage for each species (Table 4). In the different Restoration Units, we selected a total of 1447 (about 22% of introduced plants) and 710 (about 11% of introduced plants) seedlings for survival and growth assessment, respectively. Regarding changes in height and basal diameter, for the less abundant species, we selected a lower number of seedlings. We selected a subset of seedling to determine basal diameter due to the difficulty for measuring this parameter because of the treeshelters and the meshes installed (Table 4).

To determine survival rates, we assessed if a seedling was alive or dead when clearly it was dry with no leaves, and there were no signs of resprouting. To avoid mistakes, we paid special attention to distinguish between deciduous species and wilted plants. Regarding growth, we measured the total height from the ground, at the base of the main stem in case of shrubs, up to the top of the canopy avoiding branches, leaves or flowers sticking out of the majority of the canopy and look for the height of the plant as a whole (Figure 4). Using an electronic caliper we measure the basal diameter of the stem as close as possible to the ground, avoiding any thickening at the base (Figure 5). In some specific species such as *Brachypodium* sp. and *Dorycnium pentaphyllum,* we estimated the canopy cover instead of the basal diameter due to their growing habit (Figure 6). In the Permanent Pond area (RU5), we monitored all the introduced plants except those planted in flooded areas. In the Talus-Berm area (RU7), we monitored the survival on all introduced seedlings.
Initially, during spring- early summer 2019, it was applied two complete irrigation treatments to the seedlings because of the extreme dry conditions consequence of lack of precipitations (see Mid-term report for a detailed explanation).

Table 4**.** Number of monitored seedlings and percentage of plants evaluated within each Restoration Unit, in brackets. Acronyms correspond to Survival (S), total height (H) and basal diameter (D) of each species within each Restoration Unit.

Species	**RU1**			**RU2**			**RU3**			**RU5**			**RU7**
	S	**H**	**D**	**S**	**H**	**D**	**S**	**H**	**D**	**S**	**H**	**D**	**S**
Brachypodium retusum	38(10)	16(5)	10(12)*										
Brachypodium phoenicoides	16(4)	24(8)	7(8)*										196(67)
Psoralea bituminosa	20(5)	11(3)	9(10)										
Lavandula latifolia	41(11)	38(12)	8(9)										
Rosmarinus officinalis	43(12)	40(13)	9(10)										
Quercus ilex				75(21)	34(18)	6(5)							
Rhamnus lycioides	76(20)	68(22)	10(12)	78(21)	33(17)	9(8)							
Rhamnus alaternus	37(10)	20(6)	10(12)	74(20)	30(16)	8(7)				10(4)			
Colutea arborescens	48(13)	47(15)	12(14)	39(11)	26(14)	10(9)							
Dorycnium pentaphyllum	41(11)	40(13)	8(9)*	38(10)	22(12)	9(5)*				12(4)			98(33)
Pinus nigra ssp salzmanii							18(12)	14(11)	5(9)	10(4)			
Amelanchier ovalis							22(15)	17(13)	11(19)	28(10)	10(13)	7(20)	
Prunus spinosa							23(16)	20(15)	7(12)	8(3)	1(1)	1(3)	
Lonicera etrusca							4(3)	4(3)	5(9)				
Pistacia terebinthus							14(9)	13(10)	9(16)				
Crataegus monogyna							9(6)	9(7)	6(11)	27(10)	6(8)	5(14)	
Juniperus oxycedrus	3(1)	3(1)	1(1)	16(4)	10(5)	6(5)							
Juniperus phoenicea	8(2)	8(2)	2(2)	27(7)	18(10)	6(5)	5(3)	5(4)	3(5)				
Quercus faginea							32(22)	29(22)	10(18)				
Sorbus domestica							21(14)	20(15)	7(12)	2(1)	2(3)	2(6)	
Juniperus thurifera				16(4)	12(7)	6(5)							
Populus alba										36(13)	5(11)	4(11)	
Fraxinus angustifoilia										5(2)	3(4)	0	
Salix atrocinerea										8(3)	7(9)	6(17)	
Salix purpurea										85(31)	10(13)	4(11)	
Tamarix canariensis										40(15)	34(43)	12(34)	
Seedlings measured	**371**	**315**	**72**	**363**	**185**	**60**	**148**	**131**	**63**	**271**	**79**	**41**	**294**

Note: *Canopy cover analyzed instead of basal diameter.

Figure 4. Height measurement in the main stem of *Sorbus domestica* (left) and in the multi-stem *Lavandula latifolia* (right).

Figure 5. Detailed image of an electronic caliper measuring the stem basal diameter of a seedling.

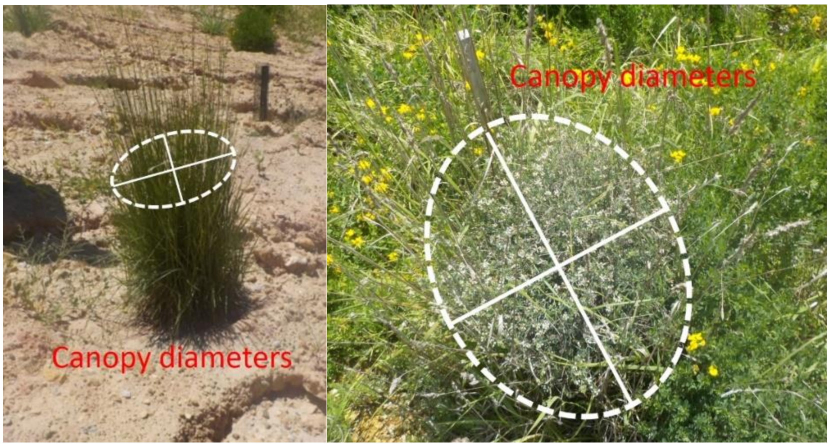


Figure 6. Canopy cover estimation through canopy diameter measurements for *Brachypodium phoenicoides* (left) and *Dorycnium pentaphyllum* (right).

3.7 Monitoring Timeline

Figure 7. Monitoring timing for survival, growth, and soil moisture sampling across 2019, 2020 and 2021.

4. Results

4.1 Climatic conditions assessment and soil moisture analysis

4.1.1 Precipitation and Temperature

The climate in the TECMINE restored area showed a typical Mediterranean intra and inter-annual variation. The interannual variation coefficient considering the historical data for the TECMINE area was 30-34% for precipitation (https://www.aragon.es/-/atlas-climatico-de-aragon). The analysis of the climatic parameters registered in the meteorological station installed in the TECMINE area showed an intra and inter-annual variation typical of the Mediterranean climate for the monitoring period (Table 5, Figure 8). Compared to historical values and the closest weather stations, Tecmine station registered average values within the normal ranges for this area (Table 5).

Table 5. Annual precipitation (P) and mean temperature (Tª) for the following years: 2019, 2020 and 2021 in the three closest meteorological stations and in Tecmine station. The reference station for this area is Torrebaja (Avamet, 40° 7' 10.56" N, 01° 15' 25.20" W), which reported an historical mean precipitation about 431 mm with an average temperature of 16.2ºC.

Station	Parameter	2019	2020	2021
Ademuz	P (mm)	293.5	477.8	440.2
	Tª (°C)	13.8	14.2	13.9
Castielfabib	P (mm)	333	375.1	373.8
	Tª (°C)	16.1	13.6	13.2
La Pobla de San Miguel	P (mm)	453.1	515.3	564.6
	Tª (°C)	12.6	12.9	12.3
TECMINE	P (mm)	265*	449	409
	Tª (°C)	13.7*	13.5	11.9

* Data for 2019 only corresponds to a half of the year, after the station installation.

During the monitoring period, the main climatic traits were (Table 6):

- The following summer season after outplanting (summer 2019) was considerably dry, with a total precipitation of 52 mm. During June and July 2019, the accumulated rainfall registered was only 6 mm from three different rain events.
- The values of the accumulated precipitation during the spring 2020 was 178 mm, distributed in continuous rain events throughout the season. This value slightly exceeded the average rainfall range for this season, which is 150-175 mm. As a result, the value of precipitation in Spring 2020 resulted in 40% over the total accumulated precipitation for 2020.
- Summer 2020 was also very dry with a total precipitation value of 40 mm; the precipitation values recorded for each month were below the estimated range for this period in the TECMINE area.
- The last year of the monitoring period was characterized by a particularly rainy summer, with values of accumulated precipitation (288 mm) much higher than historical values for the months of June and July (40-50 mm and 30-40 mm, respectively). In addition, the average temperatures recorded in this final monitoring period were warmer (18.5 ºC) than those evaluated in previous years.

Table 6. Variation in climatic total precipitation P and average in mean, maximum and minimum

temperature (Tmean, Tmax and Tmin, respectively) for each annual season and each month along the monitoring period.

Year	Season/months	P(mm)	T(°C)	Tmax (°C)	Tmix (°C)
2019 (265mm, 13.7°C)	**Spring**	**62**	**14.2**	**21.0**	**7.2**
	from 16 April	41	10.5	16.0	5.3
	May	18	14.0	21.3	7.0
	to 20 June	3	18.1	25.8	9.3
	Summer	**52**	**22.3**	**30.5**	**14.3**
	from 21 June	0	24.1	33.4	14.1
	July	6	23.9	32.1	15.2
	August	13	22.9	31.3	14.8
	to 20 September	32	18.4	25.3	12.9
	Autumn	**147**	**11.3**	**17.5**	**5.9**
	from 21 September	38	18.0	25.9	10.5
	October	38	14.1	21.1	8.3
	November	26	7.4	11.8	3.2
	to 20 December	45	5.9	11.0	1.9
	Winter	**139**	**6.8**	**14.2**	**1.3**
	from 21 December	4	5.4	13.4	0.7
2020 (449mm, 13.5°C)	*January*	66	4.2	10.6	-0.6
	February	1	8.3	17.2	1.6
	to 20 March	68	9.3	15.7	3.7
	Spring	**178**	**12.5**	**18.9**	**6.7**
	form 21 March	30	5.6	10.2	1.5
	April	103	10.9	16.8	6.4
	May	39	16.1	23.6	9.1
	to 20 June	7	17.3	24.9	9.8
	Summer	**40**	**22.3**	**31.4**	**13.4**
	from 21 June	2	22.9	32.1	13.1
	July	15	23.8	33.3	14.8
	August	16	23.3	32.5	14.4
	to 20 September	6	19.1	27.6	11.2
	Autumn	**104**	**11.9**	**19.6**	**5.7**
	from 21 September	1	15.1	22.9	8.3
	October	11	11.6	19.7	4.8
	November	81	10.6	18.5	4.6
	to 20 December	11	10.1	17.4	5.0
	Winter	**39**	**4.8**	**11.2**	**-0.1**
	from 21 December	1	5.5	13.9	0.1
2021 (409mm, 12.7°C)	*January*	7	4.7	10.6	-0.1
	February	29	2.0	7.0	-2.3
	to 20 March	2	6.8	13.4	1.8
	Spring	**105**	**9.6**	**16.6**	**3.8**

form 21 March	2	6.8	13.4	1.8
April	15	7.3	14.7	1.3
May	75	9.8	16.6	4.5
to 21 June	13	14.5	21.6	7.5
Summer	**288**	**18.5**	**25.9**	**11.6**
from 21 June	162	18.2	25.5	11.3
July	126	18.9	26.3	11.9
August	6	23.0	32.2	14.8
to 20 September	10	19.3	26.9	12.5
Autumn	**76**	**9.6**	**16.1**	**3.8**
from 21 September	10	16.2	19.1	8.5
October	27	13.2	21.4	6.6
November	38	6.0	10.8	1.6
to 20 December	1	4.9	11.8	-0.1
Winter	**7**	**8.4**	**14.6**	**4.2**
from 21 December	7	8.4	14.6	4.2

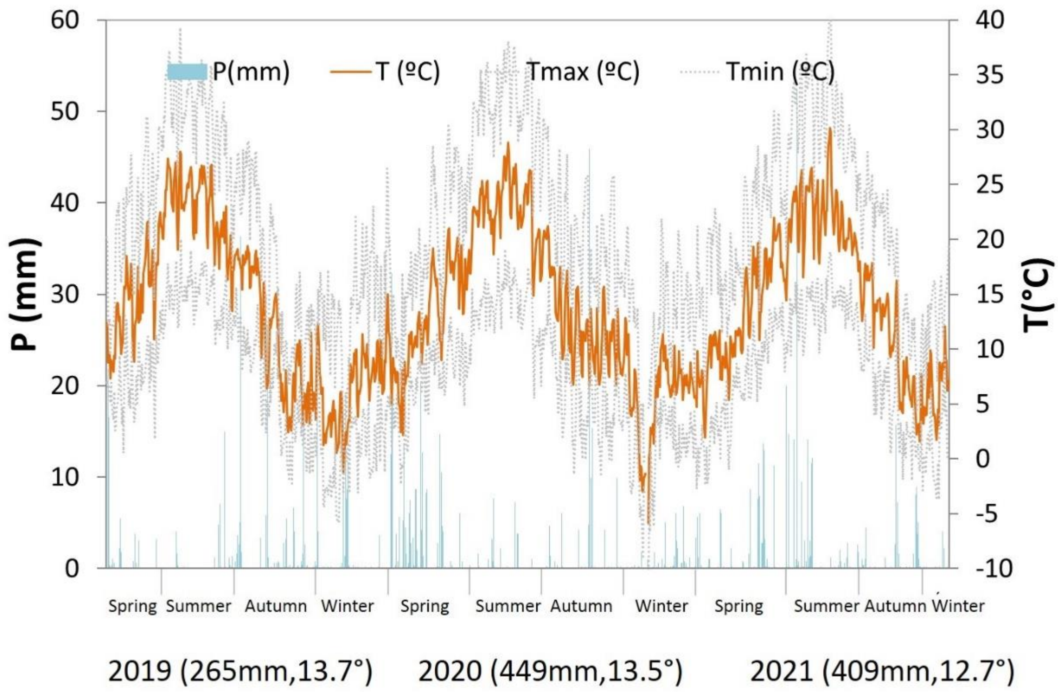


Figure 8. Daily variation on climatic parameters (from April 2019 to December 2021). Blue bars show the total precipitation P in the left axis. Lines show mean temperature (orange straight line) and maximum and minimum temperature (black dashed line) in the right axis. All data were provided by the meteorological station installed in the restored area.

4.1.2 Soil moisture dynamics

The analysis of volumetric soil moisture dynamics registered by TDR probes (30cm long) in the planting holes showed high annual variability, ranging from the maximum values around 0.5 $m^3 \cdot m^{-3}$ in autumn-winter 2019 to less than 0.1 $m^3 \cdot m^{-3}$ during summer months (Figure 9). In general, no major differences were found among Restoration Units. The RU1 showed the lowest values during all monitoring period, especially during the rainy periods in spring and autumn, compared with RU2 and RU3.

The continuous soil moisture recorded by multiple 10HS sensors installed at 30 cm depth in the planting holes and a soil moisture probe installed at 10 cm depth, close to the weather station, provided detailed information about soil moisture dynamics in relation to precipitation regime (Figure 10). Soil moisture recorded at 10 cm soil depth showed averaged values around 0.12 m^3/m^3 across the monitoring period. These probes also highlighted that precipitation values lower than 5 mm produced small or almost null variations in soil water content, when soil was dry as in summer (see period June-October 2020). Regarding 10HS at 30 cm depth sensors and for rain events with values above 20 mm (autumn 2019, winter 2019, spring 2020 and autumn 2020) or continuous rainy periods (winter-spring 2020 and winter-spring 2021), the soil water content reached the maximum values indicating the field capacity of the soils in this area (Figure 10).
We found differences in the soil moisture registered among Restoration Units. Thus, the RU2 was the area with the mean highest soil moisture values while the RU1 showed the lowest recorded soil moisture values. The RU3 showed fluctuating values between those reached in RU2 and RU1, being closer to RU2 when the soil moisture was high (above 0.30 m^3/m^3) and closer to RU1 when the soil moisture was minimum. The fact that RU2 was the Unit with higher soil moisture values may be due to the combination of the presence of shallow slopes as well as the effect of the implemented micro-catchment that captured soil runoff water, redirecting it towards the planting hole. The poorly structured soil and high slopes in the RU1 were probably the determining factors to generate surface runoff resulting in higher water losses and the lowest soil water content values. For the RU3, the position in the bottom parts of the Geofluv West area may have conditioned the runoff water and reduce soil water content to some extent compared to the RU2.

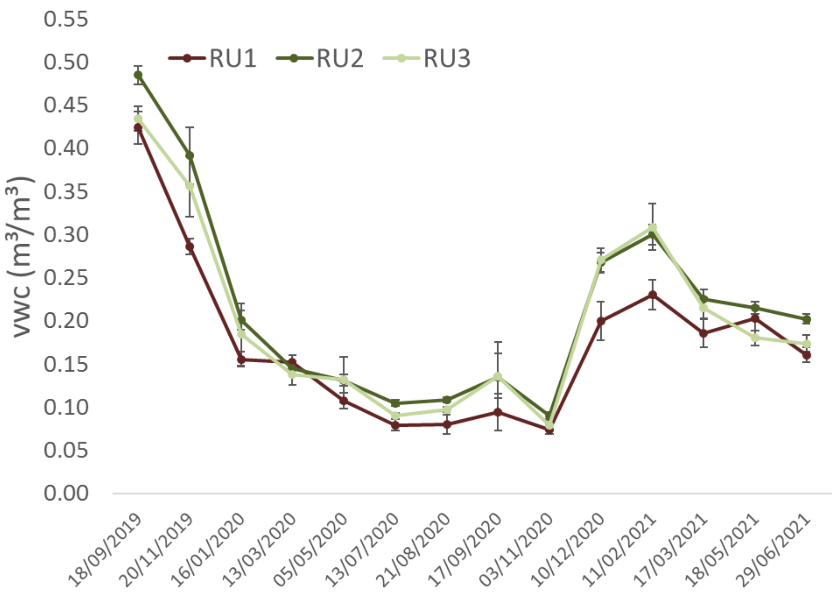


Figure 9. Volumetric soil water content dynamics (mean±SE) for several dates according to the RUs along the monitoring period. Data shown range from September-19 to June-21.

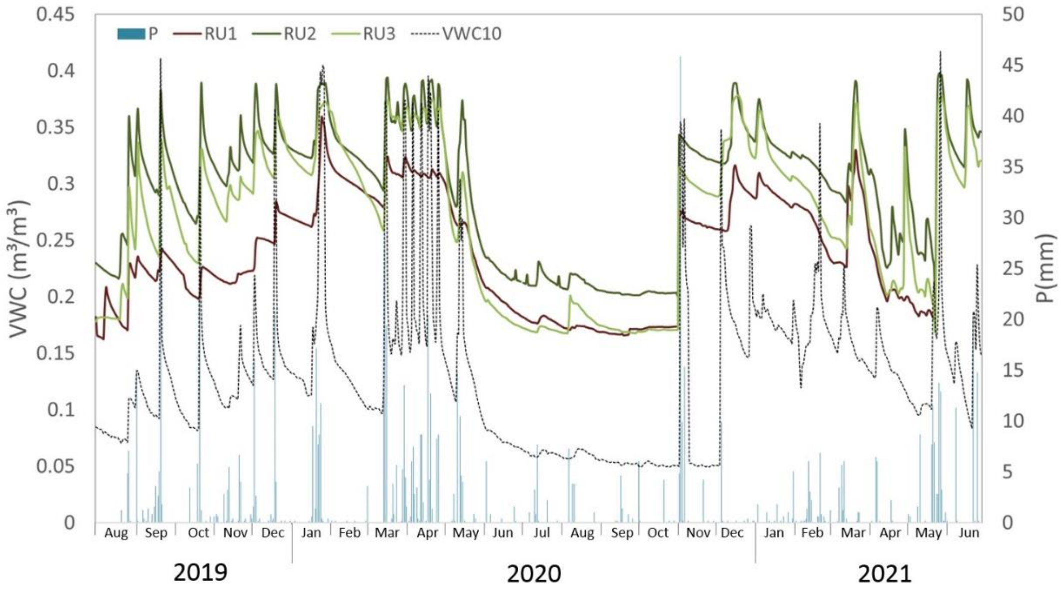
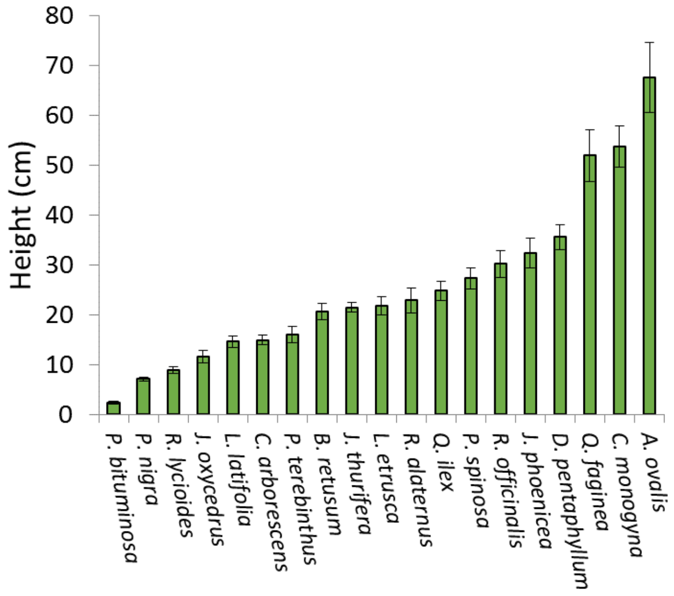


Figure 10. Daily Volume Water Content dynamics (VWC) (Left axis) at the different Restoration Units (RU, RU2, RU3) at 30 cm depth and for the meteorological station registers at 10 cm (dashed lines). The vertical blue bars represent the precipitation recorded by the meteorological station installed in the TECMINE area (Right axes). Plot shows data from August-19 to June-21. Some value increments at the beginning (June-August-19) are the result of watering treatment to avoid the extremely dry period after outplanting.

4.2 Initial seedling characterization

One of the most important factors for the plantation success is the stock quality of the seedlings. The initial characterization of the seedlings showed different mean size values depending on the species. The bigger species were *Amelanchier ovalis*, *Crataegus monogyna* and *Quercus faginea*, while the smallest species were *Pinus nigra*, *Rhamnus lycioides* and *Juniperus oxycedrus* (Figure 11). In Mediterranean plants, height values ranged between 10 -30 cm would result in maximum efficiency in the seedling establishment. Seedlings with above or below values are considered of lower quality and could lead to failures in structural development of the plants once introduced (Vallejo 1996). Considering the size of the introduced species in the restored area before planting, most of the seedlings were within the range of maximum efficiency. Exceptionally, species such as *Psoralea bituminosa* and *Pinus nigra* were extremely small. However, only *Pinus nigra* showed poor development and high mortality rates during monitoring (Table 7). Some species such as *Rosmarinus officinalis*, *Amelanchier ovalis* or *Dorycnium pentaphyllum* showed lower root development than aerial part development (Root/Shoot ratio) which is related to functional species strategy.



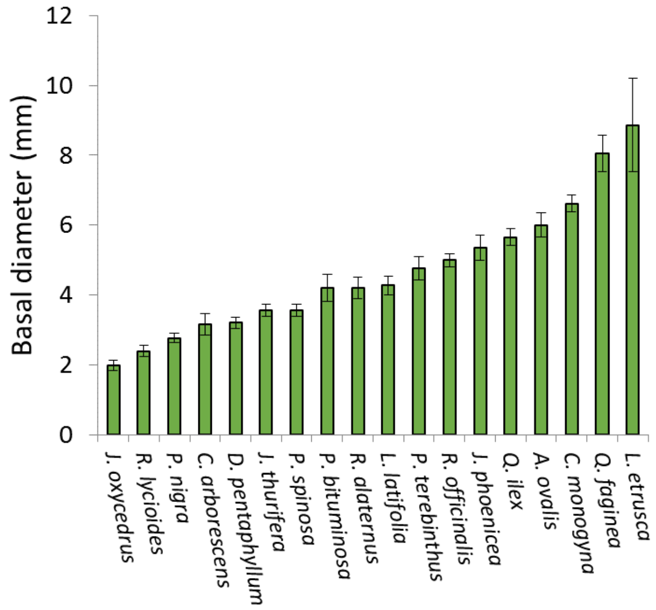


Figure 11. Seedling size (mean ±SE) according to species, before planting (March-19). The upper plot shows the total height values and the bottom plot the basal diameter.

Table 7. Initial seedling characterization of the main species. Values show de mean ± SE of height, diameter, above and below ground biomass, and root to shoot ratio.

Species	Height (cm)	Diameter (mm)	Above-ground biomass (g)	Below-ground biomass (g)	Root/shoot ratio
Amelanchier ovalis	67.7 ± 7.0	6.0 ± 0.3	6.1 ± 1.0	1.9 ± 0.4	0.31
Brachypodium retusum	20.6 ± 1.7	----	3.3 ± 0.7	1.6 ± 0.5	0.48
Colutea arborescens	14.0 ± 1.0	3.2 ± 0.3	0.7 ± 0.1	1.3 ± 0.3	1.84
Crataegus monogyna	53.8 ± 4.1	6.6 ± 0.2	6.8 ± 0.5	7.1 ± 0.3	1.04
Dorycnium pentaphyllum	35.6 ± 2.6	3.2 ± 0.2	4.4 ± 0.6	1.3 ± 0.2	0.29

Juniperus oxycedrus	11.6 ± 1.2	1.9 ± 0.1	0.6 ± 0.1	0.4 ± 0.1	0.68
Juniperus phoenicea	32.4 ± 2.9	5.4 ± 0.4	8.6 ± 1.3	3.4 ± 0.6	0.40
Juniperus thurifera	21.5 ± 1.0	3.6 ± 0.2	4.0 ± 0.4	1.5 ± 0.3	0.36
Lavandula latifolia	14.6 ± 1.1	4.3 ± 0.3	3.5 ± 0.5	0.5 ± 0.1	0.14
Lonicera etrusca	21.8 ± 1.8	8.9 ± 1.3	6.7 ± 1.2	3.2 ± 0.7	0.48
Pinus nigra var. salzmanii	7.1 ± 0.4	2.8 ± 0.1	0.9 ± 0.1	0.8 ± 0.1	0.90
Pistacia terebinthus	16.1 ± 1.7	4.8 ± 0.3	0.7 ± 0.1	1.5 ± 0.3	1.90
Prunus spinosa	27.4 ± 2.1	3.6 ± 0.2	1.0 ± 0.1	1.8 ± 0.3	1.69
Psoralea bituminosa	2.3 ± 0.2	4.2 ± 0.4	0.2 ± 0.1	0.4 ± 0.1	2.13
Quercus faginea	52.0 ± 5.2	8.1 ± 0.5	7.0 ± 0.8	10.0 ± 1.0	1.43
Quercus ilex	24.8 ± 2.0	5.7 ± 0.2	4.0 ± 0.6	4.0 ± 0.5	1.01
Rhamnus alaternus	22.9 ± 2.5	4.2 ± 0.	3.1 ± 0.3	1.8 ± 0.3	0.57
Rhamnus lycioides	8.95 ± 0.7	2.4 ± 0.2	0.5 ± 0.1	0.8 ± 0.2	1.62
Rosmarinus officinalis	30.2 ± 2.6	5.0 ± 0.2	5.7 ± 0.5	1.1 ± 0.1	0.20

4.3 Survival analysis

4.3.1 Restoration Units within the Geofluv West area

The mean global survival for all introduced seedlings 2.5 years after planting (June 2021) in the Geofluv area was 75%. We did not find great differences among Restoration Units. The specific survival values for RU1, RU2 and RU3 at the end of the monitoring period were 76, 79 and 71 %, respectively (Figure 12).

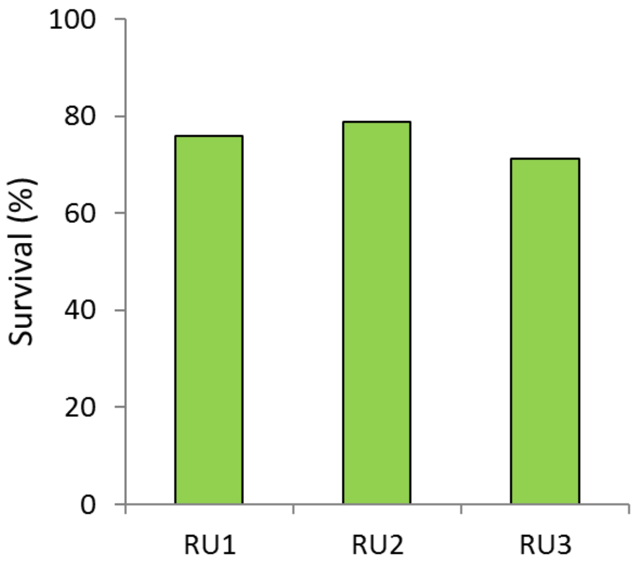


Figure 12. Global survival values at each Restoration Unit (RU1, RU2 and RU2) at the end of monitoring period (June-21).

During most of the monitoring period, survival values for the RU1, RU2 and RU3 were above 80% (Figure 13). The most important mortality period in RU1 and RU2 was during the early establishment, in spring 2019, with a survival decrease about 12-15%. Later, after the first summer, survival rates in the RU1 and RU2 gradually decreased until the end of the monitoring period. Survival rates in RU3 decreased gradually, but an important mortality event was detected after the second summer season, with a decrease about 16% in survival (Figure 13).Previous experiences monitored by CEAM showed similar survival dynamics, with higher mortality rates during the first years after outplanting, and later slightly decreasing until stabilization.

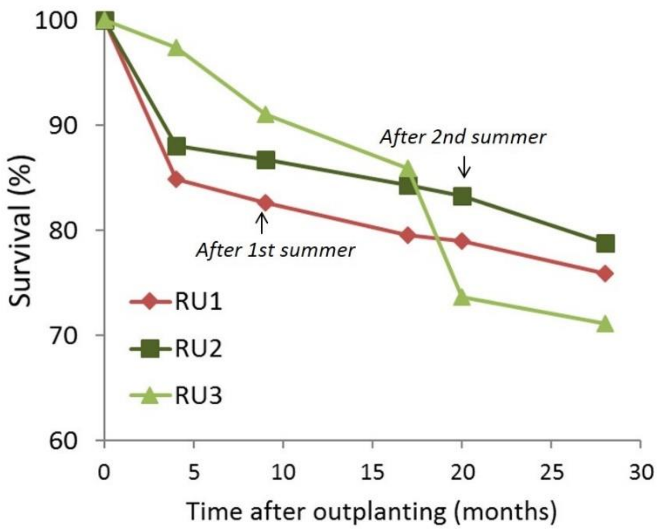


Figure 13. Survival rates dynamics (%) during the monitoring period (February 19 – June 2021) at each Restoration Unit (RU1, RU2 and RU3).

Regarding species success, most of the introduced species in the Geofluv West area showed high survival rates (i.e., 62% of the species above 80% of survival, and 90% of the species above 60%; Figure 14). Only *Pinus nigra*, showed very low survival (below 11%). In the RU1 where conditions were more limiting, some of species such as *Dorycnium pentaphyllum*, *Brachypodium phoenicoides* and *Rosmarinus officcinalis* had survivals rates above 90%. Within this RU, *Rhamnus alaternus* was the species with lowest survival values (57%) (Figure 14, upper plot). Survival of slow-growing species such as *Juniperus oxycedrus*, *Juniperus phoenicea* and *Juniperus thurifera* introduced in the RU2 was above 80%. Within this RU, *Rhamnus alaternus* was also the species with lowest survival (66%) (Figure 14, middle plot). In the RU3, species such as *Quercus faginea*, *Pistacia terebinthus* and *Crataegus monogyna* with low tolerance to water stress showed survival values above 80%. The low survival showed by *Pinus nigra* (11%) resulted in an important decrease on the mean survival for the whole RU (Figure 14, bottom plot).

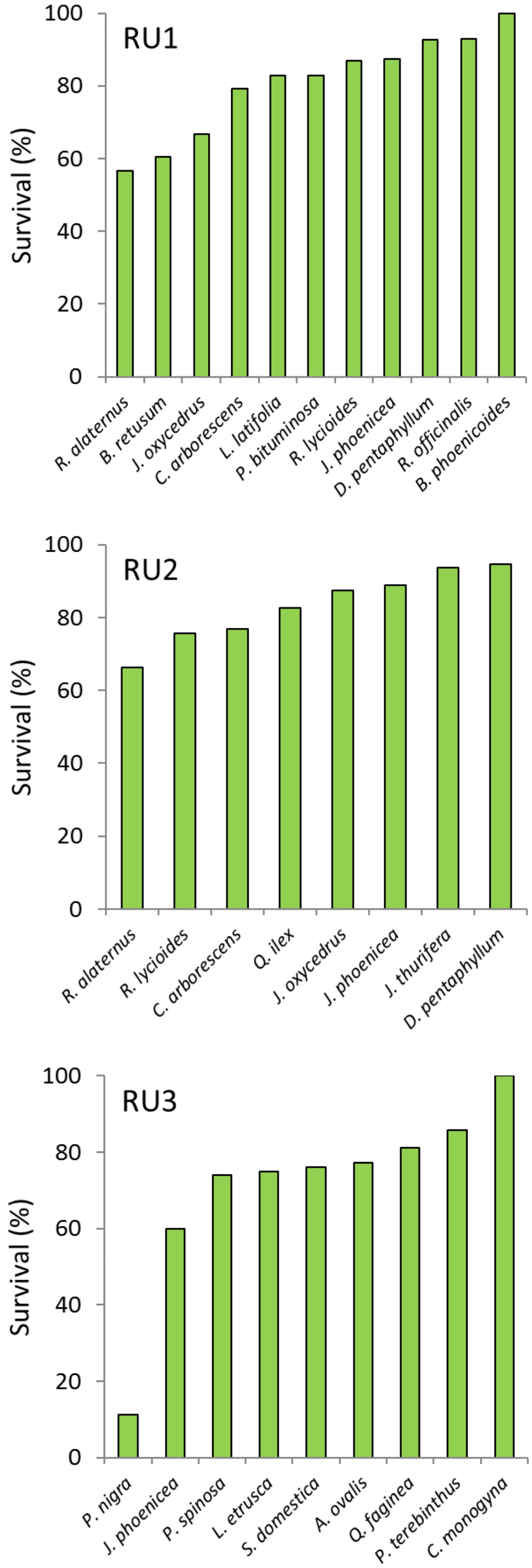


Figure 14. Survival rates (%) according to species at the end of the monitoring period (June, 2021) at each Restoration Unit: RU1 (upper plot), RU2 (middle plot) and RU3 (bottom plot).

4.3.1.1 Comparison of common species among Restoration Units

At the end of the monitoring period, the response in survival of common species introduced in several RUs varied according species (Figure 15). The species *Dorycnium pentaphyllum*, *Colutea arborescens* and *Juniperus phoenicea* introduced in the RU1 and RU2, showed similar survival rates among RUs, varying less than 2%. *Rhamnus alaternus* introduced in all RUs showed lower survival values in the RU3 (~28%) than in the other two RUs. *Rhamnus lyciodes* showed higher survival rates in the RU1 than in the RU2. Finally, *Juniperus oxycedrus* seedlings survived more in the RU2 than in the RU1. However, the differences among RUs for each species are small meaning that no important limitations were found for any species.

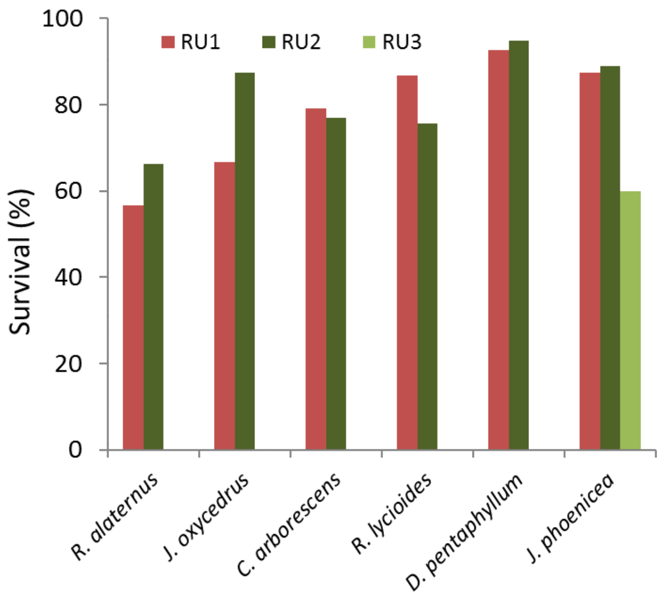


Figure 15. Survival rates (%) according to common species at each Restoration Unit (RU1, RU2, RU3) at the end of the monitoring period (June -21).

4.3.2 Other restoration units

4.3.2.1Permanent Pond area (RU5)

The highest mortality in the Permanent Pond area was reached after the first summer season (9 months after planting). Then, the mean survival rates for the area stabilized around 40% (Figure 16).

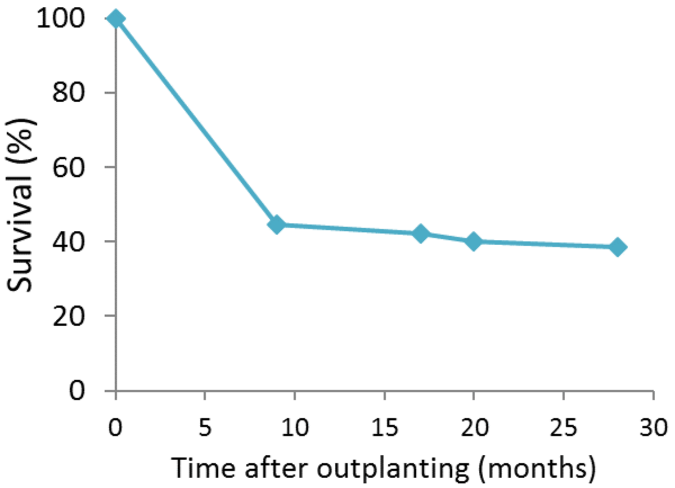


Figure 16. Survival rates dynamics (%) during the monitoring period (February, 19–June, 21) on the Permanent Pond area (RU5).

Regarding species success, *Prunus spinosa*, *Salix atrocinera*, *Rhamnus alaternus, Dorycnium pentaphyllum* and *Sorbus domestica* showed survival rates above 80%, at the end of the monitoring period (Figure 17). However, some other species such as *Pinus nigra*, *Populus alba* and *Salix purpurea* had survival rates below 20%. The high mortality rates registered in this RU was the consequence of a combination of factors. Firstly, a certain delay in the seedling plantation timing due to reforestation works in the other RUs, which took longer than expected. It resulted in a planting date closer to the summer season. Secondly, the substrate had high clay content with the associated problems for the seedlings to obtain water and nutrients from the soil. And finally, it was the last RU watered during the post-planting irrigation. All these factors, resulted in mortality rates higher than expected.

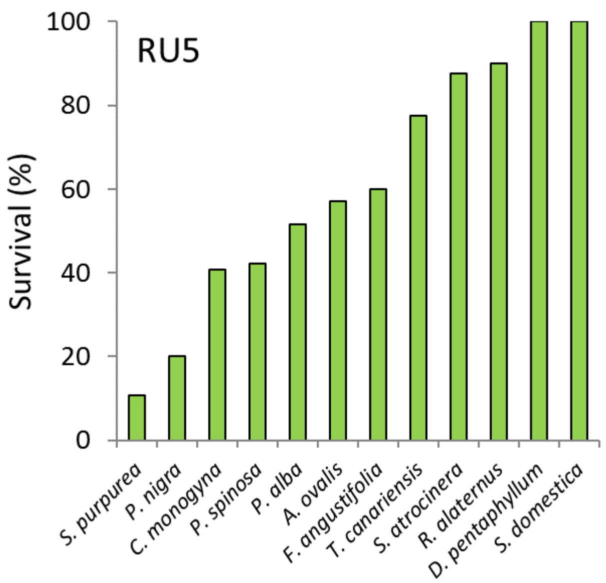


Figure 17. Survival rates (%) according to species, at the end of the monitoring period (June-21) in the Permanent Pond area (RU5).

4.3.2.2 Talus-Berm area (RU7)

Survival in the talus areas of this RU (RU7) were very high. Introduced seedlings had survival values higher than 90%, and only showed a small decrease (3%) after the second summer season (Figure 18). Both species here introduced, *Dorycnium pentaphyllum* and *Brachypodium phoenicoides*, showed high survival rates (Figure 19). The mulching effect of the applied organic meshes probably increases the soil water content, preventing evaporation and thus increasing the survival chances.

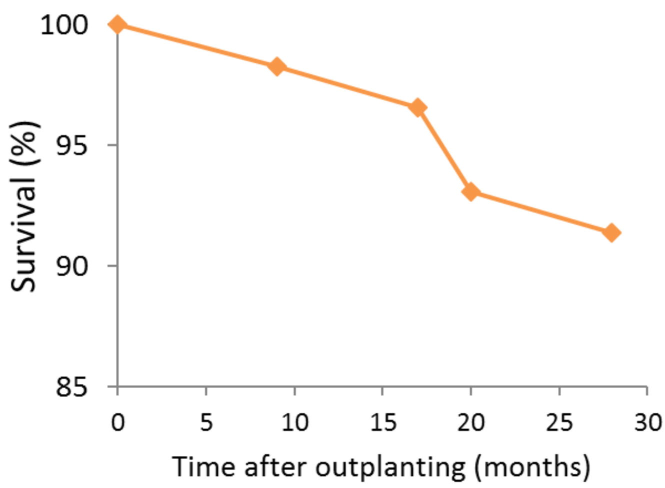


Figure 18. Survival rates (%) during the monitoring period (February-19 to June-21) on a talus of the Talus-Berm area (RU7).

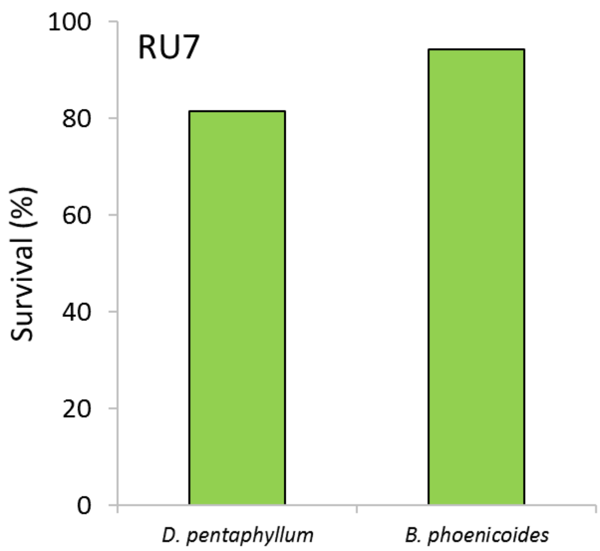


Figure 19. Survival rates (%) according to species, at the end of the monitoring period (June 2021) in a talus of the Talus-Berm area (RU7).

4.4 Growth data analysis

4.4.1 Restoration Units in the Geofluv West area

4.4.1.1 Seedling height

Globally, seedlings had suitable growth rates with an averaged seedling height around 0.8 m at the end of the monitoring period (June 2021). Regarding RUs, there were no large differences in height between the RU1 and RU2. However, the average seedling height in the RU3 was higher than the values found in the RU1 and RU2. The seedlings height varied across time with larger growth rates after the establishment period (Table 8), especially the seedlings introduced in RU1. However, at the end of the monitoring period (after spring 2021), the seedlings in the RU2 grew the most. At this period, the seedlings in RU1 barely varied in height respect to the previous samplings.

Table 8. Seedling height values (mean ± SE) across time, for the three Restauration Units

Restoration Unit	Nursery Initial period (m)	Spring 2019 Establishment period (m)	Spring 2020 Intermediate period (m)	Spring 2021 Final Period (m)
RU1	0.19 ± 0.03	0.30 ± 0.01	0.73 ± 0.02	0.73 ± 0.02
RU2	0.22 ± 0.03	0.34 ± 0.01	0.67 ± 0.03	0.76 ± 0.03
RU3	0.35 ± 0.07	0.51 ± 0.02	0.80 ± 0.04	0.91 ± 0.04

Seedling height also varied according to species and RUs (Figure 20). At the end of the monitoring period, the 80 % of introduced species exceeded the height of the tree-shelter (0.6 m) and the 25% of the species were above 1 m. The tallest species found in RU1 and RU2 were *Colutea arborescens* and *Rhamnus alaternus* whose average heights were 1.6 m and 0.9 m, respectively. While in the RU3 *Sorbus domestica* and *Lonicera etrusca* were the tallest ones with 1.4 and 1.1 m, respectively. Although some introduced seedlings were slow-growing species, as *Juniperus oxycedrus* and both *Juniperus phoenicea* and *Quercus faginea, they* reached values around 0.7 m on average in RU3.

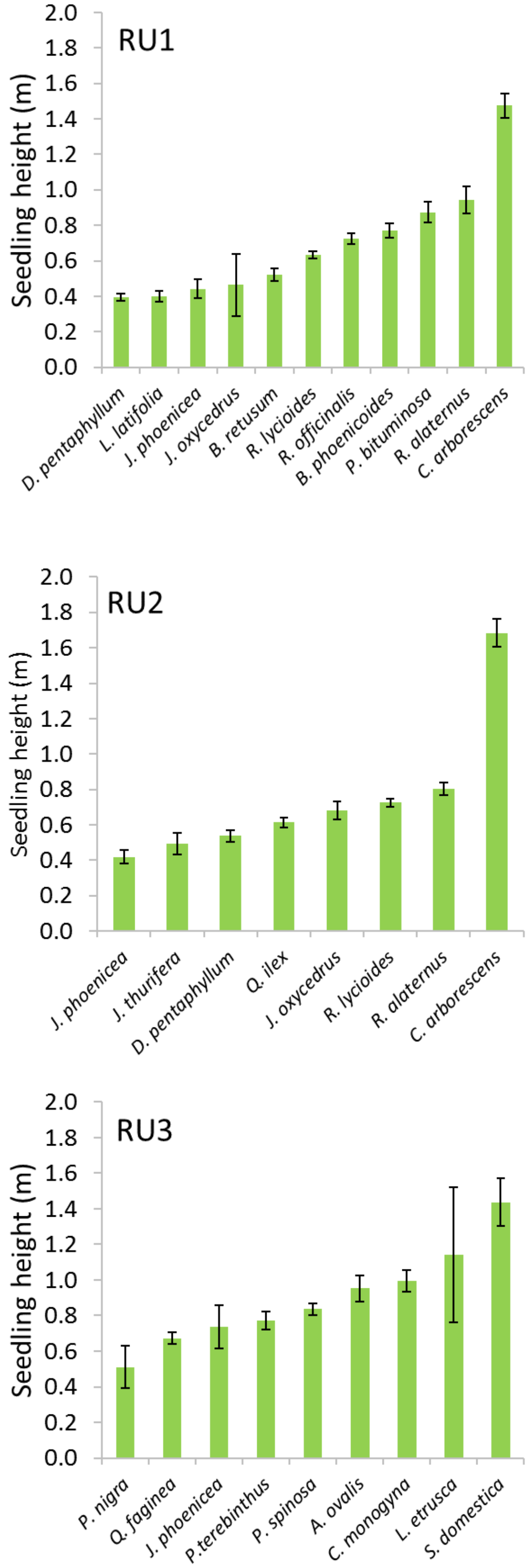
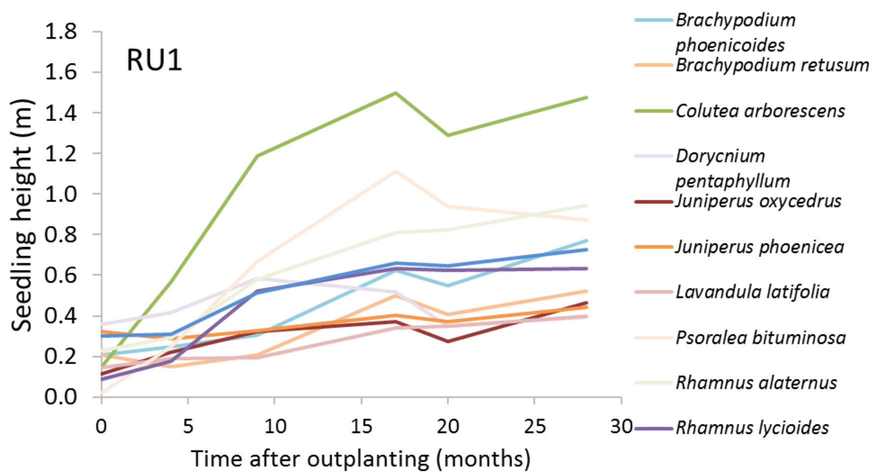
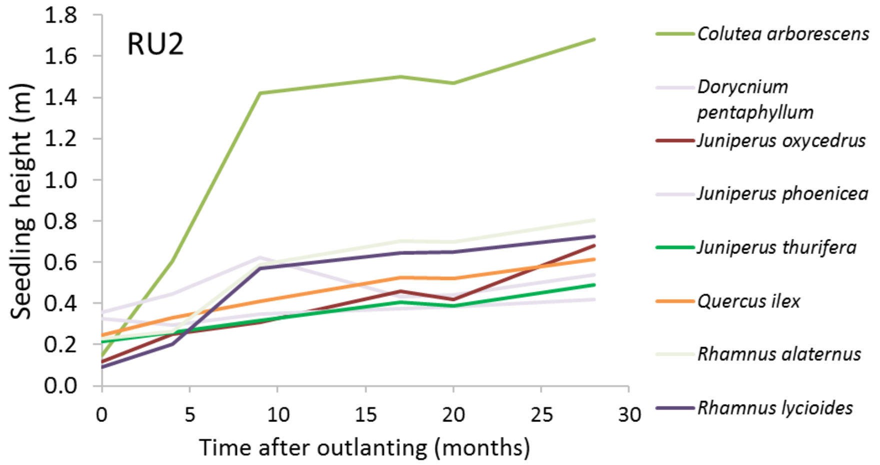


Figure 20. Seedling height values (mean ± SE) according to species, at the end of the monitoring period (June -21) for each Restoration Unit: RU1 (top), RU2 (medium) and RU3 (bottom).

Growth rates in height across time for the whole monitoring period (2019-2021) depended on the introduced species and on the RUs (Figure 21). Despite the post-planting stress and the dry conditions occurred during the first summer season, some species such as *Colutea arborescens*, *Psoralea bituminosa*, *Rosmarinus officinalis*, *Lonicera etrusca* or *Rhamnus* sp. grew notably in height. Most of the species experienced the greater change in height after the second growing season (17 months after planting, spring 2020). Then, seedling height generally stabilized without registering abrupt changes. We observed, nevertheless, a certain decrease in height that could be linked to the desiccation of plant apical parts, as is the case of species such as *Colutea arborescens*, *Lavanda latifolia* and *Psoralea bituminosa* in the RU1 or *Sorbus domestica* and *Lonicera etrusca* in the RU3. *Dorycnium pentaphyllum* also decreased in total height due to the lie down effect after the treeshelter removal. *Pinus nigra* was the species with the lowest annual growth increment, possibly due to the low initial seedling size from the nursery (~7cm height). On the other side, there were fast-growing species such as *Colutea arborescens* and *Sorbus domestica* which grew more than the rest of the species (Table 9).





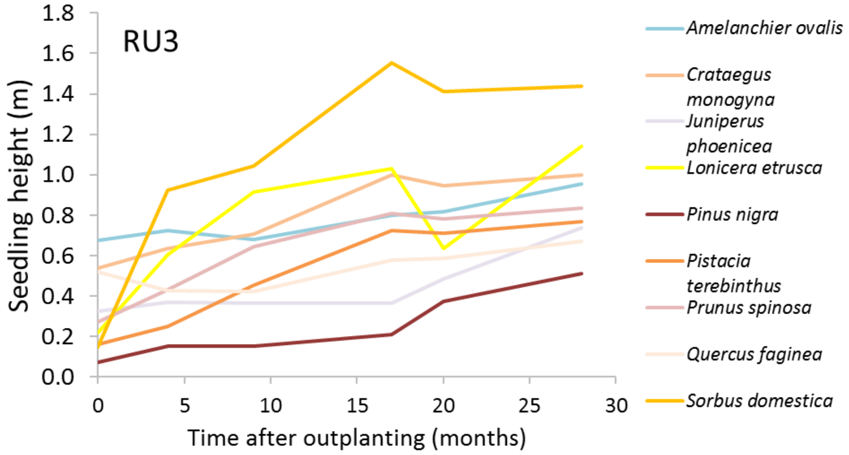


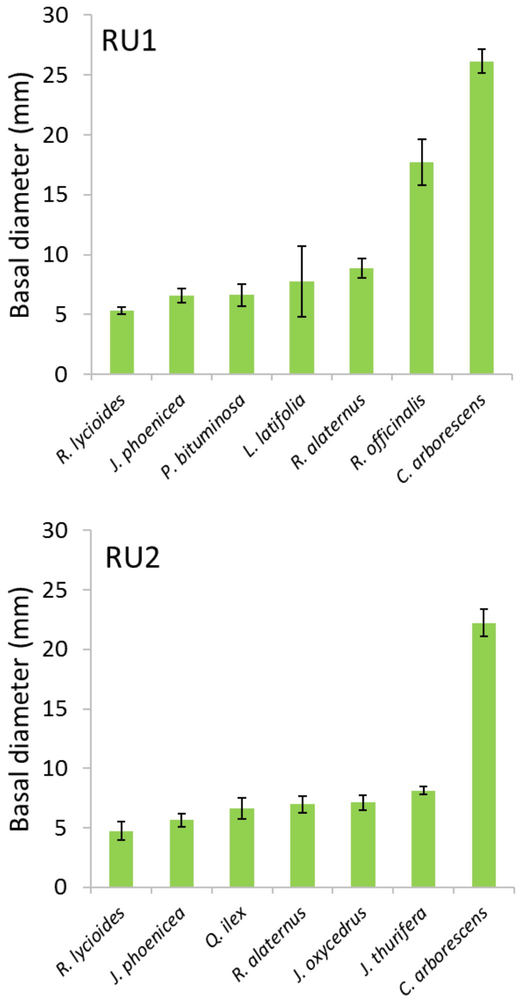
Figure 21. Average seedling height across time, according to species. Period covers from nursery to the end of monitoring period (June-21) for each Restoration Unit: RU1 (upper plot), RU2 (medium plot) and RU3 (bottom plot).

Table 9. Seedling annual height growth (mean ± SE) depending on the species and Restoration Unit. Values are calculated as the difference between height values at the end of the monitoring period (28 months, spring 2021) and the initial height, in spring 2019 (4 months after planting, spring 2019). Data is expressed as height increment over time (meters/year).

Restoration unit	Species	Seedling height increment (m/yr)
RU1	*Dorycnium pentaphyllum*	0.03 ± 0.01
	Juniperus phoenicea	0.07 ± 0.02
	Juniperus oxycedrus	0.08 ± 0.08
	Lavandula latifolia	0.09 ± 0.02
	Brachypodium retusum	0.16 ± 0.02
	Rosmarinus officinalis	0.20 ± 0.02
	Rhamnus lycioides	0.21 ± 0.21
	Brachypodium phoenicoides	0.25 ± 0.25
	Psoralea bituminosa	0.27 ± 0.27
	Rhamnus alaternus	0.32 ± 0.32
	Colutea arborescens	0.40 ± 0.40
RU2	*Dorycnium pentaphyllum*	0.05 ± 0.01
	Juniperus phoenicea	0.07 ± 0.01
	Juniperus thurifera	0.10 ± 0.03
	Juniperus oxycedrus	0.12 ± 0.04
	Quercus ilex	0.14 ± 0.02
	Rhamnus lycioides	0.22 ± 0.02
	Rhamnus alaternus	0.23 ± 0.02
	Colutea arborescens	0.38 ± 0.05
RU3	*Pinus nigra*	0.02 ± 0.01
	Amelanchier ovalis	0.08 ± 0.04
	Quercus faginea	0.08 ± 0.01
	Juniperus phoenicea	0.11 ± 0.06
	Lonicera etrusca	0.12 ± 0.08
	Crataegus monogyna	0.14 ± 0.04
	Prunus spinosa	0.14 ± 0.03
	Sorbus domestica	0.16 ± 0.04
	Pistacia terebinthus	0.21 ± 0.04

4.4.1.2 Basal diameter

Regarding changes in basal diameter, the mean basal diameter values for the three RUs ranged from 7 mm to 10 mm at the end of the sampling period. There was a significant increase in this parameter for all the introduced species (Figure 22). *Rosmarinus officinalis* and *Colutea arborescens* showed the largest basal diameters in the RU1 and RU2, together with *Sorbus domestica* and *Prunus spinosa* in RU3. The rest of basal diameter values ranged between 5 and 10 mm.



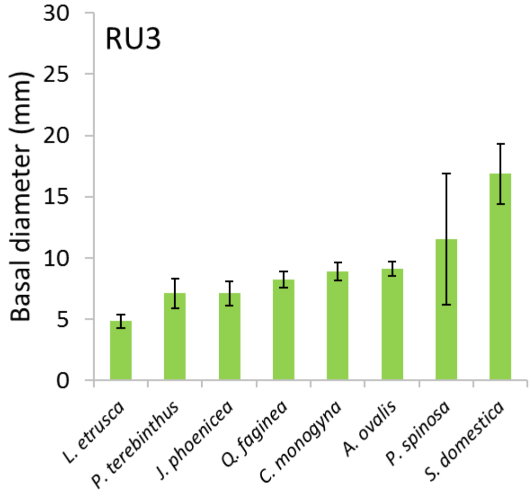
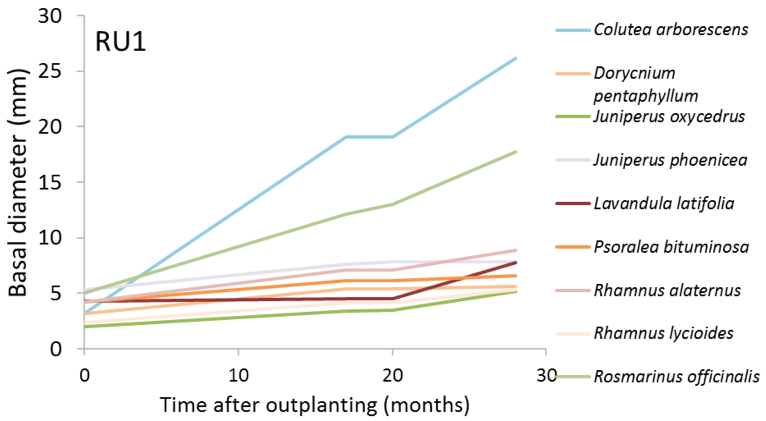


Figure 22. Basal diameter values (mean ± SE) according to species, at the end of the monitoring period (June-21). Values are organized for each Restoration Unit, RU1 (upper plot), RU2 (medium plot) and RU3 (bottom plot).

Most species introduced in the RUs showed gradual changes in basal diameter across time (Figure 23). The species that grew the most during the monitoring period, were *Colutea arborescens* (23 mm), *Rosmarinus officinalis* (13 mm) and *Sorbus domestica* (9 mm). Exceptionally, some species such as *Colutea arborescens* (RU1 and RU2), *Rosmarinus officinalis* (RU1), *Rhamnus alaternus* (RU1 and RU2) and *Prunus spinosa* (RU3) showed a greater increase in basal diameter after spring 2020.



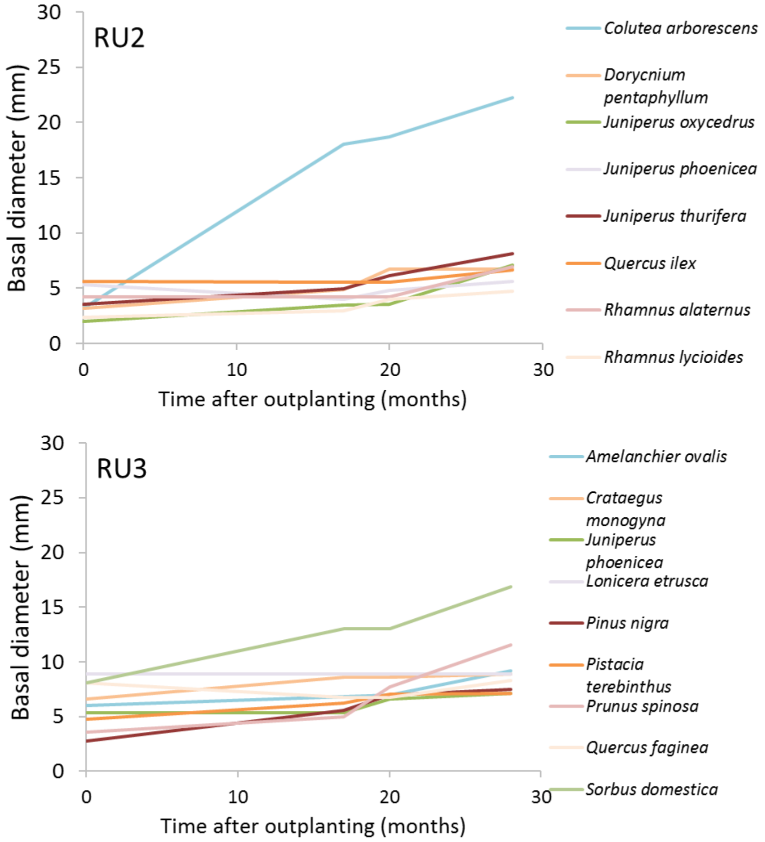
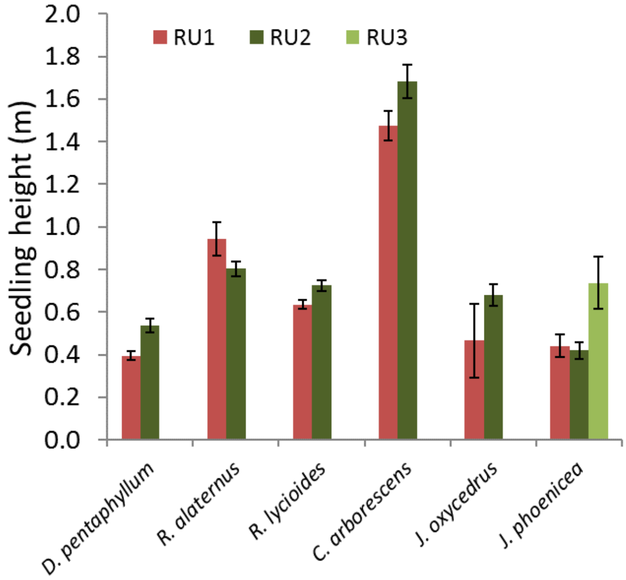


Figure 23. Average basal diameter across time, according to species. Period covers from nursery to the end of monitoring period (June-21) for each Restoration Unit: RU1 (upper plot), RU2 (medium plot) and RU3 (bottom plot).

4.4.1.3 Analysis of common species in different Restoration Units

Overall, the changes in sizes of both total heights and basal diameters were similar between common species introduced in the different RUs. Regarding height, we found a tendency to a higher total seedling height in the RU2 (Figure 24, left). Contrarily, for basal diameter, we found a trend to larger basal diameter in the seedlings introduced in the RU1 than in the ones in RU2, especially for *Colutea arborescens* (Figure 27, right). These results are related to the different plant growth strategies and the short period of monitoring that did not allow the species develop their growth habits completely.



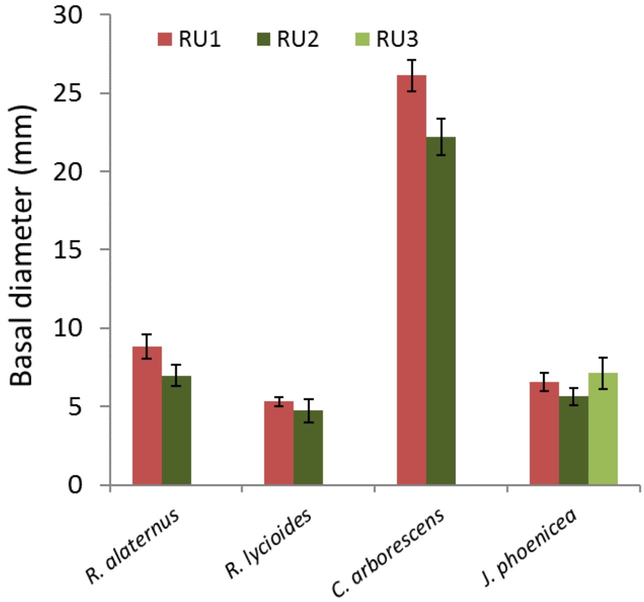
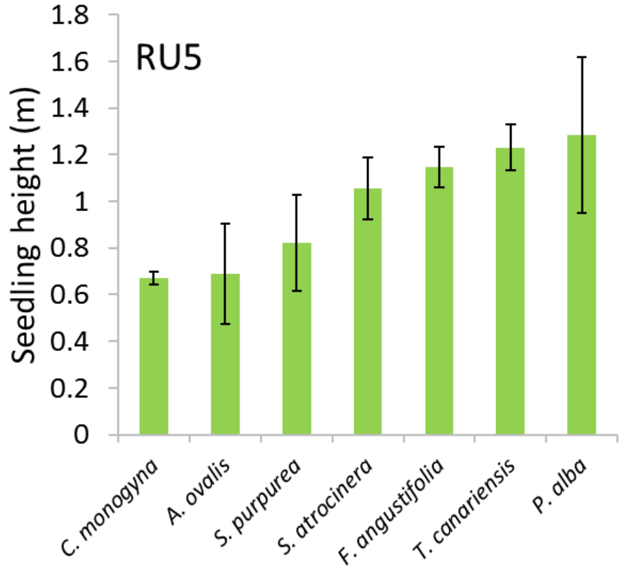


Figure 24. Seedling height (upper) and basal diameter (lower) (mean ± SE), at the end of the monitoring period (June-21), for common species in each Restoration Unit (RU1, RU2, RU3).

4.4.2 Permanent Pond area (RU5)

The average height values and average basal diameter for the seedlings in this RU were 0.96 m and 11 mm, respectively (Fig 26). *Populus alba* and *Tamarix canariensis* reached the maximum sizes in height and basal diameter (1.2 m and 14.5 mm, respectively).



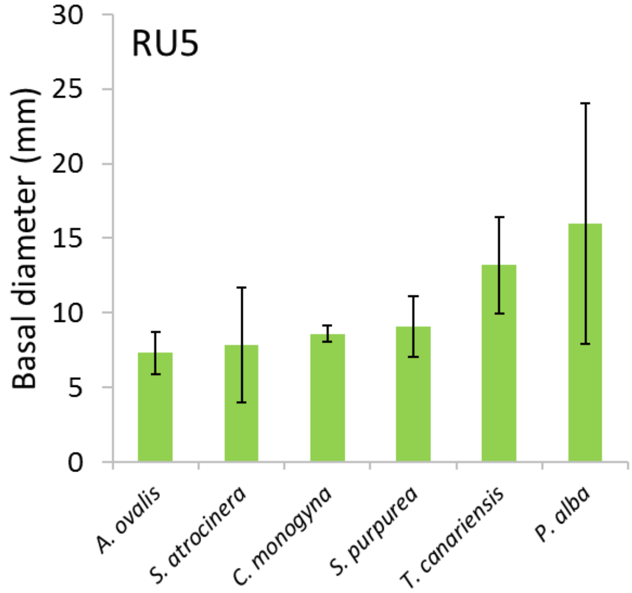


Figure 25. Seedling height (upper) and basal diameter (lower) (mean ± SE) at the end of the monitoring period (June-21), according to species in the Permanent Pond area (RU5).

4.5 Phenological observations: reproductive effort

On year after planting, we observed flowers and fruits in some species such as *Dorycnium pentaphyllum*, *Colutea arborescens*, *Brachypodium* sp. and *Rosmarinus officinalis* (Table 10, Figure 26). For the second year, we also observed flowers and fruits in *Rhamnus alaternus* and *Amelanchier ovalis* and natural recruitment of *Colutea arborescens* (Figure 27). These signs of reproductive efforts can have important implications for ecosystem dynamics and wildlife interactions, and are good indicators of the proper seedling establishment in the restored area and good ecological conditions for seed germination and new seedling establishment. Flowering and fructification have been rarely reported at this early stage of restoration. To our knowledge, only fructification for *Rosmarinus officinalis* was observed one year after planting, while other introduced species did no fructified until five years after planting (Jorba et al., 2013).

Table 10. Phenological observations for several introduced species over the whole restored area.

Species	Flowers	Fruits
Dorycnium pentaphyllum	X	X
Colutea arborescens	X	X
Brachypodium retusum	X	
Brachypodium phoenicoides	X	
Rhamnus alaternus	X	X
Amelanchier ovalis	X	

Figure 26. Detailed images of both phenological states in *Dorycnium pentaphyllum:* Flowers (left) and fruits (right). Dates corresponded to March-20 and July-20, respectively.

Figure 27. Detailed images for phenological observations, flower of *Rosmarinus officinalis* (left) and fruits for *Rhamnus alaternus* (right). Date corresponds to May-21.

4.6 Supplementary sampling (Autumn 2021)

After the monitoring period, we evaluated survival and growth along the whole restored area in an extraordinary field-sampling in December 2021. In general, the global survival for all the introduced seedlings, and the survival rates according to species, showed the same tendency as the one found in Spring 2021 (Table 11). However, some individuals of *Colutea arborescens*, *Quercus ilex*, *Juniperus phoenicea* and *Juniperus thurifera* in the RU2, died during the 2021 summer period. Then, the survival rates were reduced in an 8% at this date. In addition, in the Permanent Pond area the mortality of some individuals of *Pinus nigra*, *Tamarix canariensis* and *Rhamnus alaternus* also reduced the survival rates in a 4%.

Table 11. Survival results of the extraordinary field sampling after monitoring period (December 2021). Data correspond with survival (%) measured for each introduced species and Restoration Units (RU1, RU2 and RU3).

Restoration Unit	Survival (%)	Restoration Unit	Survival (%)
RU1	**73**	**RU5**	**34**

Brachypodium retusum	55	*Salix purpurea*	6
Rhamnus alaternus	57	*Pinus nigra*	10
Juniperus oxycedrus	67	*Crataegus monogyna*	37
Lavandula latifolia	78	*Amelanchier ovalis*	39
Psoralea bituminosa	78	*Tamarix canariensis*	45
Colutea arborescens	79	*Populus alba*	47
Rhamnus lycioides	80	*Fraxinus angustifolia*	60
Juniperus phoenicea	88	*Rhamnus alaternus*	70
Rosmarinus officinalis	88	*Dorycnium pentaphyllum*	83
Dorycnium pentaphyllum	93		
Brachypodium phoenicoides	100		
RU2	**71**	**RU7**	**88**
Rhamnus alaternus	61	*Brachypodium phoenicoides*	94
Colutea arborescens	65	*Dorycnium pentaphyllum*	82
Rhamnus lycioides	68		
Quercus ilex	76		
Juniperus oxycedrus	79		
Juniperus phoenicea	79		
Juniperus thurifera	86		
Dorycnium pentaphyllum	91		
RU3	**70**		
Pinus nigra	11		
Juniperus phoenicea	60		
Sorbus domestica	71		
Amelanchier ovalis	73		
Prunus spinosa	74		
Lonicera etrusca	75		
Quercus faginea	81		
Pistacia terebinthus	86		
Crataegus monogyna	100		

We also evaluated seedling height, basal diameter and canopy projection. The average sizes in each RU did not vary from the last sizes evaluated at the end of monitoring period (July 2021; Table 12). Thus, the species did not show any relevant change in seedling height or basal diameter along the summer-autumn 2021. Regarding canopy projection, we found a notably development in some species introduced in the RU1 such as *Dorycnium pentaphyllum*, *Rosmarinus officinalis*, *Psoralea bituminosa* and *Brachypodium* sp.

Table 12. Results of an extraordinary field-sampling in December 2021. Values (mean ± SE) for seedling height, basal diameter and canopy projection according to species and Restoration Unit (RU1, RU2 and RU3).

	Seedling height (m)	Basal diameter (mm)	Canopy (cm^2)
RU1	0.69 ± 0.02	10.41 ± 0.92	26.67 ± 2.42
Brachypodium phoenicoides	0.75 ± 0.05		32.89 ± 3.89
Brachypodium retusum	0.52 ± 0.03		10.31 ± 1.75

Colutea arborescens	1.42 ± 0.04	23.24 ± 1.33	
Dorycnium pentaphyllum	0.39 ± 0.02		38.01 ± 5.55
Juniperus oxycedrus	0.45 ± 0.17	3.48 ± 1.88	
Juniperus phoenicea	0.47 ± 0.04	5.27 ± 0.73	
Lavandula latifolia	0.26 ± 0.01		4.16 ± 0.43
Psoralea bituminosa	0.81 ± 0.06		26.86 ± 10.68
Rhamnus alaternus	0.89 ± 0.06	8.77 ± 0.55	
Rhamnus lycioides	0.63 ± 0.02	4.35 ± 0.29	
Rosmarinus officinalis	0.76 ± 0.04		40.08 ± 5.65
RU2	0.78 ± 0.06	9.44 ± 1.08	42.11 ± 8.88
Colutea arborescens	1.56 ± 0.10	19.97 ± 2.81	
Dorycnium pentaphyllum	0.51 ± 0.03		42.11 ± 8.88
Juniperus oxycedrus	0.72 ± 0.04	6.92 ± 1.37	
Juniperus phoenicea	0.46 ± 0.03	6.25 ± 0.82	
Juniperus thurifera	0.51 ± 0.06	7.81 ± 0.72	
Quercus ilex	0.80 ± 0.23	7.89 ± 0.75	
Rhamnus alaternus	0.76 ± 0.04	10.18 ± 3.13	
Rhamnus lycioides	0.71 ± 0.03	4.28 ± 0.52	
RU3	0.91 ± 0.07	9.30 ± 0.61	
Amelanchier ovalis	0.90 ± 0.05	9.23 ± 0.52	
Crataegus monogyna	0.92 ± 0.06	9.37 ± 0.71	
Juniperus phoenicea	0.55 ± 0.08	6.77 ± 0.64	
Lonicera etrusca	1.03 ± 0.24	3.62 ± 0.01	
Pinus nigra	0.67 ± 0.21	5.63 ± 0.01	
Pistacia terebinthus	0.70 ± 0.03	9.06 ± 1.45	
Prunus spinosa	0.80 ± 0.03	7.10 ± 2.25	
Quercus faginea	0.83 ± 0.23	8.90 ± 0.70	
Sorbus domestica	1.38 ± 0.12	15.58 ± 2.52	

5. Analysis of Results

Regarding survival, we should highlight that the monitored period corresponds with the first stages after plantation. Globally, the survival results can be considered overall positive with high survival rates. Comparing with other results found in the literature (Table 13), from plantations also conducted under Mediterranean conditions, we might conclude that the survival rates obtained in the TECMINE project about 75% on average after 2.5 years are very good.

Table 13. Average survival rates (%) for some common species reforested under Mediterranean conditions in the Valencia region, evaluated at 6 and 36 months after outplanting. The data showed are from: Vallejo, 1996

Species	6 month	36 months
Juniperus phoenicea	93	48
Juniperus oxycedrus	99	89
Pistacia lentiscus	100	91
Rhamnus alaternus	100	90
Rhamnus lycioides	99	90
Pinus halepensis.	92	73
Erica multiflora	93	40
Pinus pinea	96	47
Quercus ilex	82	52
Ceratonia siliqua	77	16
Chamaerops humilis	93	72
Coronillla juncea	92	88

Previous works regarding several common species such as *Quercus ilex* or *Juniperus phoenicea* reported lower survival rates on average, whereas others (i.e. *Rhamnus alaternus and Rh. lycioides)* showed similar results three years after planting (Vilagrosa et al., 1997). Exceptionally, the RU3 experienced a second decrease in survival rates after the second summer, probably because species such as *Quercus faginea*, *Sorbus domestica*, *Crataegus monogyna* and *Pistacia terebinthus* are low drought tolerant species. During this period of early establishment, water availability is crucial (Squire et al., 1987; Haase & Rose, 1993).

It is well known this initial period is critical for seedling establishment (Vilagrosa et al., 1997; Vilagrosa et al., 2003). The data showed a slight decline during the first nine months after planting, and later the mortality stabilized for all RUs. A suitable seedling implantation at this moment could guarantee the long-term restoration success (Margolis 1990; MAPA, 1994). Therefore, the first summer season after planting is usually the main chance of mortality, since the rooting system is not yet sufficiently developed to obtain the available water at deeper soil layers (Padilla et al., 2007, Chirino et al., 2008). In this regard, the post-planting conditions in the TECMINE project in terms of precipitation can be considered normal to dry, especially during June and July 2019, with a total precipitation of 9mm, comparing with the historical range for the same months (30-50mm). In this sense, irrigation application during Spring-early summer 2019 was completely justified to ensure a good seedling implantation. The irrigation supplied after the planting works was key for guaranteeing high survival rates during the first summer (about 80%). Several works have previously reported the benefits of irrigating during the first following months after planting (Jorba and Vallejo 2008, Luna et al 2016). In addition, the implementation of techniques to improve abiotic conditions such as the creation of microcathments in the planting holes in the RU2 and RU3 redirecting surface water flows towards the seedling, resulted in higher soil moisture values in these RUs than in standard reforestations (Valdecantos et al., 2014). In this sense, other studies conducted under dry conditions also showed enhanced survival rates in areas where the micro-catchment were applied for mining restoration (García-Ávalos et al., 2018). Finally, the organic amendment added into the planting holes resulted in slow-release fertilizer that also have favored high survival rates as well as the good development of the introduced plants (Moreno-Peñaranda et al., 2000; Fuentes et al., 2010).

In general, the increments in height and basal diameter registered at each field-sampling also showed a suitable establishment and growth of the introduced species. Regarding growth, we found important differences according to species and RU. Differentiated growth rates reveal the nature of each species. Thus, we found fast-growing species such as *Colutea arborescens*, *Rosmarinus officinalis* or *Rhamnus* sp. and other slow-growing such as *Juniperus* sp. and Quercus sp. However, despite the intrinsic response of each species, in general, those slow-growing species responded very positively, increasing their sizes in heights and diameters within the monitoring period.

On the other hand, since each RU shows specific physiographic conditions, the differences in plant size between individuals within the same RU can also be conditioned by the variation in these microsite conditions. Thus, the species introduced in the RU1 and RU3 showed greater differences in changes in size than the species introduced in the RU2 where the slope and aspect conditions were more homogeneous. In previous works conducted under similar climatic conditions, species of the same functional groups such as *Pistacia* sp., *Rhamnus* sp. or *Quercus* sp. showed similar sizes or even below (Kribeche et al., 2012). In the analysis of both growth variables, it is important to notice that, in general, the species that grew more in height also did so in diameter, showing good allometric relationships, which ensures a proportional seedling architecture and a proper development. Surprisingly, the species that showed the highest growth rates did not coincide with maximum survival rates, such the case of *Colutea arborescens* or *Sorbus domestica*. This may be linked to the strategy of the mainly generative species, whose good development allow them to have a good seed bank to perpetuate themselves. This strategy, contrasts with other as shrub species, for instance, whose development tends to cover the ground, as the case of *Rosmarinus officinalis*, that presented a proper development in diameter and high survival rates. Other studies obtained similar results in terms of differences in development and survival for *Pinus* sp. and other shrubs (Molina-Villamar et al., 2016).

6. Concluding remarks and main recommendations.

1) Make an accurate initial identification of the different Functional Restoration Units of the landscape, according to their physiographic conditions, prior to the restoration design. Characteristics such as slope and aspect will condition the decision-making on the substrate stabilization techniques, reforestation at the planting hole level, planting densities, as well as species selection. Both the characterization of the restoring area and the consequent restoration design are crucial to enhance success in terms of survival and seedling growth.

2) A careful species selection will facilitate high survival and growth rates independently of the abiotic conditions, even in the most unfavorable sites. In this regard, choosing suitable ecosystem references will be crucial to select proper native species naturally present in the surrounding of the restoring area. Moreover, if the species selection is conducted considering the characteristics of each defined Restoration Unit, the early seedling establishment success will be maximized. In addition, local seed provenance together with pre-planting seedling acclimatization to the abiotic conditions through suitable plant nursery protocols will promote higher survival and growth rates, regardless of climatic constrains.

3) Assessing plant quality at the end of the nursery period will allow the identification of low-quality plant stocks and it will prevent high mortality rates and low plant growth in the plantation.

4) The application of low-cost restoration field techniques such as micro-catchments, instead of more expensive irrigation systems, will produce a positive effect on seedling establishment and growth, reducing the costs and the waste of water in climates with important water limitations.

5) Regarding amelioration of abiotic conditions, adding organic amendments and irrigation at critical periods during the early stages after planting, will enhance the probability of seedling survival. Moreover, the installation of protective meshes and treeshelters, or hydrogels in specific conditions, will alleviate plants from high radiation, desiccation and herbivory.

6) All the factors mentioned above will contribute to ecosystem recovery and signs of reproductive efforts, such as flowering, seed germination and establishment of new seedlings, are indications that functional recovery is working.

7) Finally, it is important to emphasize the importance of supervised and follow-up at each step of the plant restoration process. Additionally, setting up a monitoring program will be essential for evaluating the success of plantation and detect critical stages which may compromise seedling success, and establish corrective measures if required.

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