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Quarry rehabilitation: a case study

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Abstract

Quarrying activities such as limestone extraction entail significant visual impacts and degradation problems as a result of soil depletion and deep alteration to the original topography. These areas are at high risk of erosion due to removal of vegetation and the lack of available soil on steep slopes. In addition, the common method of quarry exploitation in platforms increases drainage and the physical and chemical erosion of the substrate, hindering natural germination and establishment of young plants, and thus delaying recolonisation.

In the past, quarries were simply abandoned after extraction. However, natural colonisation of disused limestone quarries is slow. The time scales involved in the creation of new communities are not considered acceptable for reclamation or restoration.

A reclamation project was conducted in a limestone quarry within the Serra da Arrábida Natural Park (Portugal), one example of well-preserved Mediterranean vegetation in Europe. We compared the revegetation of 5 abandoned platforms sequentially revegetated over the last 15 years, at 3 year intervals. The successive revegetation of each platform resulted in distinct plant communities, differing in age and cover. This allowed the evaluation of establishment and growth of introduced species as well as the succession of spontaneous species and stabilisation of natural vegetation. The evolution of soil characteristics was also evaluated as well as the contribution of different species to soil formation on the platforms. The results obtained allowed us to recommend strategies and to establish criteria for evaluation of the success of the revegetation in these degraded areas.

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Introduction

Quarrying and open-cast mining entail significant visual impacts and degradation problems as a result of soil depletion and deep alteration in the original topography of the area. Quarrying is an important industry, and as the demands for limestone increase, quarrying has become concentrated in several deep quarries in karst areas which have enormous effects on the landscapes. It has had dramatic impacts on karst landscapes, as many quarries are located in areas of high scenic value and are of considerable scientific interest as Natural Parks or Reserves [1,2]. This kind of exploitation leads to a process called rock desertification, producing denuded areas that are extremely difficult to rehabilitate.

In the past quarry sites were simply abandoned after exploitation. However, natural colonisation of disused limestone is very slow, and takes decades or even hundred of years to reach a new woodland community with an acceptable cover. It is not considered acceptable as a reclamation or restoration strategy. Since the starting material is skeletal, revegetation is limited by the slower processes of primary succession rather than the more rapid processes of secondary succession. This succession is dependent on two distinctive aspects: colonisation and development of the ecosystem [3]. The factors responsible for this slow recovery in limestone quarries are: (i) low input or retention of propagules; (ii) climatic and edaphic limitations on establishment and survival; and (iii) biotic checks, including disturbance, grazing, invertebrate attack and competition [4].

Nowadays environmental legislation obliges the industry to revegetate the mined lands in order to accelerate the recovery of these denuded areas and to favour their reintegration in the natural landscape. For this reason it is urgent to implement revegetation programs to rehabilitate these areas.

The revegetation of the quarry platforms can rapidly create attractive shrublands and decrease the landscape visual impact. It can also circumvent establishment problems and enable more favourable conditions for seed retention, germination and seedling survival of herbaceous and shrub indigenous species, accelerating the natural succession. However the limitations faced by the species that might migrate are enormous due to the extreme edaphic and climatic conditions which limit the ecesis of these propagules. It appeared that, when suitable adapted species are introduced, appropriate niches for their establishment could be developed.

The use of chronosequences for analysing primary succession serve as substitutes for observations of vegetation change over time at a single site. This approach is based on the assumption that spatial variation among sites of known ages will accurately reflect temporal changes.

Over the past 15 years, container-grown plants were introduced by a mining industry (SECIL) to recover the quarry floor, after exploitation. The establishment of these container-grown plants was compared in 5 quarry platforms revegetated at 3 years intervals.

The main purpose of this work was to obtain biological and ecological information about mediterranean species able to colonise these degraded areas through the evaluation of plant cover and composition in revegetated quarries. To

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fulfil this objective we developed studies: (i) to compare the establishment of plants on different platforms with different age, (ii) to assess the importance of introduction fast-growth species (*Pinus* spp.) in these communities, (iii) to assess the importance of these plantings for migration and establishment of other indigenous species and (iv) to assess the benefits of artificial revegetation *vs* natural successional processes in the rehabilitation of abandoned limestone quarries.

Two quarries abandoned around 15-23 years ago - one revegetated, the other with natural regeneration were compared in order to assess benefits of artificial revegetation *vs* natural successional processes in the rehabilitation of abandoned limestone quarries. This approach was based on studies of biodiversity and cover in both quarries and their surrounding vegetation.

Sites description

The sites were located in the Serra da Arrábida Natural Park in south-west Portugal, a small chain of limestone outcrops with maximum elevation of 500 m, with a quite steep topography. Nearly half the area has slopes between 50 and 70%. The climate is mediterranean sub-humid, with average yearly temperature of 16,4 °C. Average total precipitation is 650 mm. (Further details can be found in Catarino *et al.* [5]).

The area has a long tradition of limestone quarrying. This study was performed in one of the largest limestone quarries of this region (SECIL, Outão, 38° 29' 46" N, 8° 57' 00" W, with elevation from 120 m to 340 m, and a total area of 482,7 ha, 4 % of the Natural Park area (Fig. 1, site A). About 86 ha are used for quarrying limestone, which is processed in an cement factory located at the bottom of the quarry.

The limestone is extracted in platforms 20 m high and 20 m wide with near vertical slopes. A coversoil layer, with high clay and stone content, and about 1 m depth, derived from the marl quarry spoil, was added to the bare rock in each platform. Immediately after extraction, revegetation with two-year old plants, was undertaken by SECIL, from 1983 to 1995, leading to defined plant communities of different ages (3 year intervals) and covers (Fig. 2).

This progressive revegetation of platforms allows valid simultaneously observation of a series of sites of different ages.

Nursery plants were planted in holes of about 50 cm depth, filled with organic soil. The indigenous mediterranean sclerophyllous species used for revegetation were: *Arbutus unedo, Ceratonia siliqua, Juniperus phoenicea, Myrtus communis, Olea europaea, Phillyrea angustifolia, Phillyrea latifolia, Pistacia lentiscus, Quercus coccifera, Quercus faginea, Retama monosperma* and *Spartium junceum*. *Pinus* species (*P. halepensis* and *P. pinea*) though not abundant at this site, were introduced as fast-growing species.

One quarry, abandoned in 1975, and its surrounding vegetation were also studied, in Jaspe (38° 27' 34" N; 9° 0' 20" W, elevation 270 m), in a mixed sclerophyll scrub, 30 years old, on a south facing slope (site B, Fig. 1).

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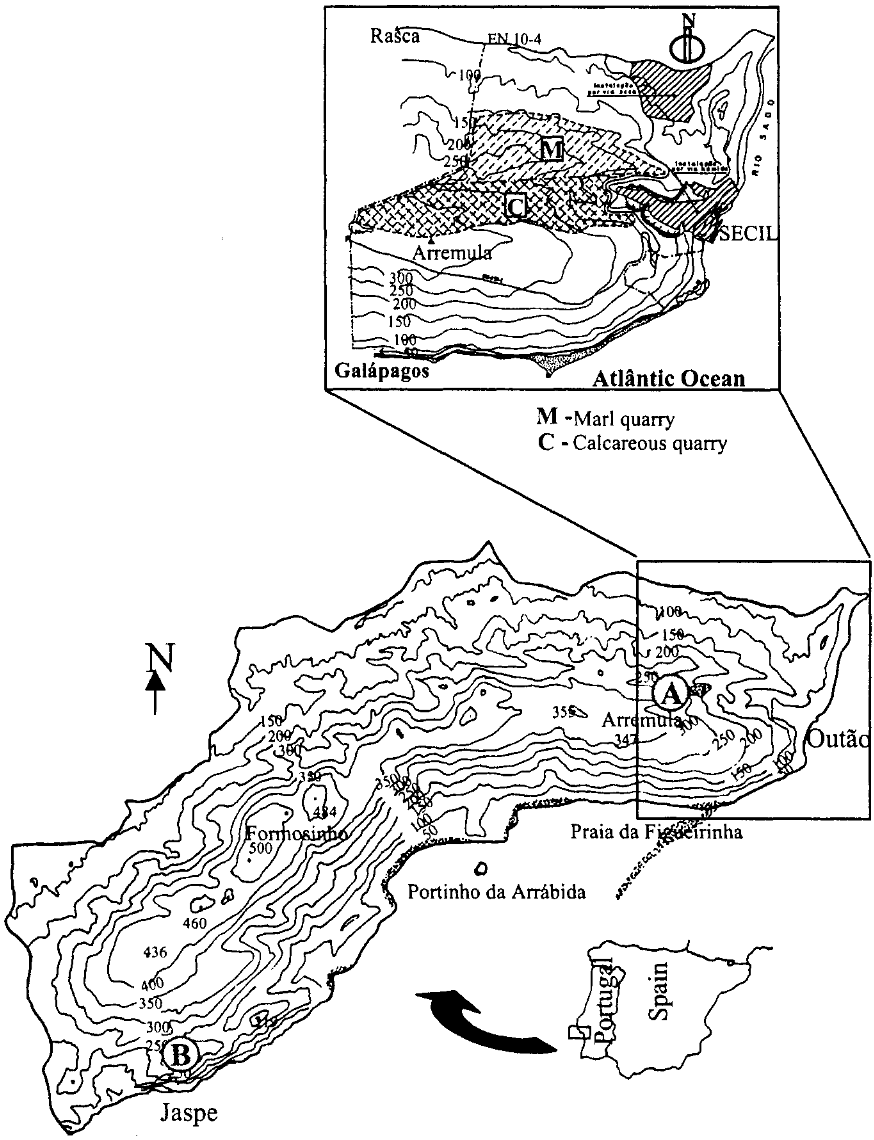

Figure 1: Location of the study sites in south-west Portugal. A – Revegetated quarry at Outão, B – Quarry at Jaspe disused since 1975.

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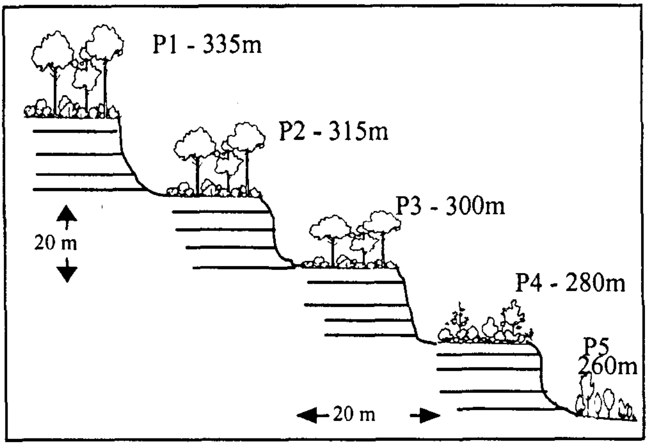

Figure 2: Schematic representation of vegetation recovery in the quarry platforms in Outão (Serra da Arrábida). Revegetation was initiated from the top downwards in 1983, 1986, 1989, 1992 and 1995 in platforms P1 - P5, respectively.

The plant communities surrounding the study sites consist of evergreen sclerophyllous and drought-semi deciduous shrubs. Detailed descriptions of the vegetation of this region are available in Catarino *et al.* [5] and Santos [6].

Methods

In this work we examined the revegetation of 5 different platforms of quarries which has been abandoned 15 years ago and revegetated sequentially, at three years intervals: P1 – 15, P2 – 12, P3 – 9, P4 – 6, P5 – 3 years old. The studies were performed during 1998. These studies were also performed in the surrounding natural vegetation – Maquis, and in the coversoil used during the revegetation process – Marl.

Soil characteristics

Topsoil samples (0-10 cm) were obtained in platforms 1, 2 and 5, in the surrounding natural shrubland and also in the marl used during the revegetation process. The soils from different platforms were obtained below 5 plants of *Pinus* species and 5 plants of *C. siliqua*. To study the effect of different plants in the soil formation, soil samples were collected below *Pinus* spp. *O. europaea, C. siliqua, J. phoenicea* and *Cistus* spp. in platform 3 and 12 years old. The main physical and chemical characteristics were analysed. Physical analyses included: coarse sand>2mm, fine sand, clay and silt. Chemical analysis undertaken were:

pH, soil organic matter (OM), total nitrogen (N), P, K, Ca, Mg. Exchangeable Ca, Mg, K, Na and the effective cation exchange capacity (CEC) were also estimated.

Fungal biomass and fauna was also evaluated two years later (2000), in two platforms of the quarry (P1 – 17 years old and P6 – 2 years old) and in the surrounding natural shrubland. For fungal analysis, three cores (3.5 cm diameter and 15 cm deep) were taken around five plants of *C. siliqua*, 20 cm from the plant. The fungal biomass was evaluated by the ergosterol extraction, performed as described by Miller *et al.* [7] with spectrophotometrically quantification at 282 nm according to Arthington-Skaggs *et al.* [8]. The fungal biomass was roughly estimated using a conversion factor of 5 mg ergosterol per g of fungal biomass [9]. For fauna analysis, at each site 4 quadrats (50 x 50 cm) were selected at random beneath the vegetation. After careful removal of the leaf layer from each quadrat, three samples of the organic horizon, designated by humus horizon, were taken. Fauna were extracted by means of Berlese-Tullgren funnels after seven, fourteen and thirty days, sorted under a binocular microscope and identified to order level. The results are expressed as number of individuals per site.

Soil chemical data were analysed statistically by one-way ANOVA followed by Tukey-test .

Vegetation sampling

The establishment and growth of nursery plants and the natural recruitment of herbaceous and shrub species were studied in the 5 revegetated platforms during spring and summer 1998. The vegetation was sampled within forty 3x3m plots, positioned along a belt transept parallel to the quarry wall. The percentage of bare soil, number of individuals, canopy shrub cover (m^2) and height of adult shrubs were recorded in all plots. The presence of all herbaceous species was also recorded. Species diversity was measured according to Whittaker [10] [11]. Each revegetated platform was compared to natural vegetation using the Sörensen similarity coefficient [12].

One quarry, abandoned 23 years ago, and its surrounding vegetation, located at Jaspe (site B) were also studied and compared with the oldest artificially revegetated platforms, 15 years old (P1 at Outão - A) (Fig.1). The two quarry sites (A, B) and surrounding areas (A', B') were sampled by 10 random quadrats (3x3m) according to Braun-Blanquet. TWINSPAN was carried out on the vascular plant species data to identify patterns within the vegetation communities across the sites. The Shannon-Weaver diversity index and the evenness index was evaluated according to Kent & Cocker [12].

Differences between platforms in shrub density, cover and height were tested by one-way ANOVA followed by Tukey-test.

Results

The physical and chemical characteristics of soils from different platforms and surrounding maquis are summarised in Table 1.

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Physical analysis demonstrated a higher proportion of clay and silt than sand in the maquis soils, which is characteristic of red mediterranean soils. On the other hand, the platform soils contained a higher proportion of larger particles corresponding to sandy loam soils. These soils resulted from the mixture of clay with sandy materials and organic soil during the revegetation trials. N, K, and Mg concentrations (Table 1), exchangeable Ca, Mg, K, Na and the cation exchange capacity (CEC) (data not shown) were lower than in maquis soils. No significant differences between the platforms were observed

Table 1. Physical and chemical soil characteristics at the study sites

Source	Marl	P5	P2	P1	Maquis
Age		3 Years	12 Years	15 Years	> 50 Years
Coarse sand (%)	-	20.28±11.32	-	29.18±15.53	10.44±3.17
Fine sand (%)	-	29.82±3.53	-	23.94±2.96	18.44±3.65
Silt (%)	-	32.40±9.71	-	27.36±9.69	38.42±5.16
Clay (%)	-	17.50±4.79	-	19.52±7.69	32.70±4.98
O.M. (%)	0.54±0.08c	0.55 ±0.13c	1.68±0.71b	1.43±0.41b	7.97±0.72a
PH	8.68±0.08d	8.42±0.15c	8.38±0.10c	8.22±0.11b	7.94±0.09a
Total N ($mg.Kg^{-1}$)	0.22±0.1b	0.40±0.13b	0.51±0.29b	0.60±0.14b	4.26±2.00a
Available P_2O_5 ($mg.Kg^{-1}$)	0.0±0.0	17.5±27.1a	56.3±117.0a	78.3±90.4a	6.2±13.9a
Available K_2O ($mg.Kg^{-1}$)	123±18bc	134±47bc	177±40c	126±26b	351±80a
Mg ($mg.Kg^{-1}$)	217±97a	266±46a	130±45b	202±66b	630±712a
Ca ($mg.Kg^{-1}$)	3103±579bc	4502±117a	2935±493b	4358±206a	4614±1989a

Values followed by different letters are statistically different ($p < 0.05$, one-way ANOVA followed by Tukey-test)

Organic matter (O.M.) was higher on older revegetated platforms (P1 and P2) than in recently revegetated ones. However the differences from maquis vegetation were still very high. pH values decreased with the soil evolution and the older platforms were close to the maquis soil (Fig. 3).

The relative contribution of the different plant species to the soil was similar, even 12 years after revegetation (data not shown).

The fungal biomass increased over time after revegetation. On the most recent revegetated platform, P6, the plants showed a low level of fungal biomass. However, the levels were higher on P1 site, revegetated 17 years ago. The levels obtained in the maquis were higher than those of the quarry sites (Fig. 4).

In terms of soil fauna, a total of 3403 individuals, distributed by 23 taxa were identified. Maquis vegetation supported the highest variety of orders but a similar abundance of individuals was observed on the 17-years old platform. On 2-years old platforms the orders richness and individuals abundance were lower, and only 9 different orders were identified (data not shown). The major orders of

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soil fauna, acarina, collembola and isopoda, were more abundant on the 17-years old platform and in maquis than in younger platform. Isopoda were less abundant in natural ecosystems than on 17-years old platforms (Fig.4).

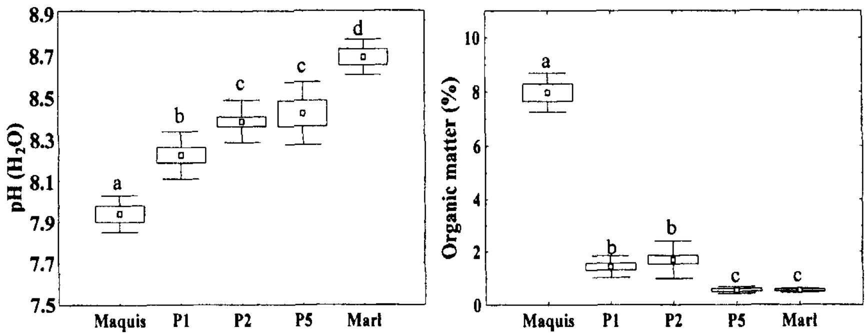

Figure 3: Comparison of organic matter and pH of revegetated platforms with the natural vegetation (Maquis) and the original substrate used on the revegetation process (Marl). Values with different letters are statistically different ($p < 0.05$, one-way ANOVA followed by Tukey-test).

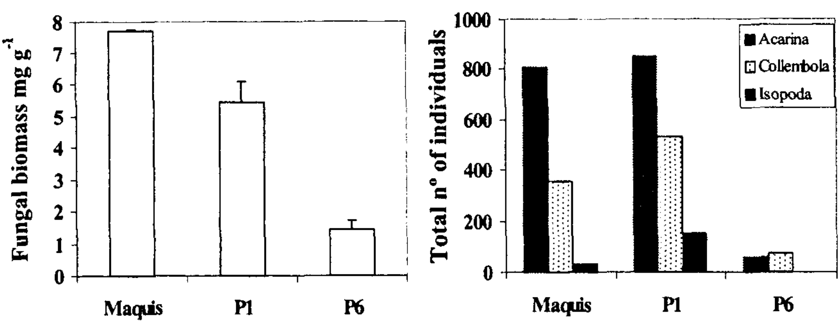

Figure 4: Fungal biomass and total number of individuals of the most important fauna orders in each platform and in natural vegetation (Maquis). P1 – 17 years old, P6 – 2 years old.

Analysis of vegetation indicated that the use of mediterranean sclerophylls for revegetation resulted in low mortality and rapid plant growth and establishment. Density studies allowed evaluation of the number of introduced species and the number of woody and herbaceous species which had migrated from the surrounding areas and colonise the different platforms.

The density of introduced sclerophyllous species was similar on all platforms, while *Pinus* species and *J. phoenicea* were introduced in higher

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densities on the more recent platforms (P3 and P4) (Tukey test, $p<0.01$) (Fig. 5A). *P. latifolia, Q. coccifera, P.lentiscus* and *Q. faginea* were used at low densities. Relatively to the woody species which had migrated and established in the area, *Cistus* species appeared on all the platforms, and *Cistus salvifolius* presented a higher density (0.2 plants m^{-2}), similar to that of *Pinus* species and twice that of the introduced sclerophyllous species (Fig. 5B).

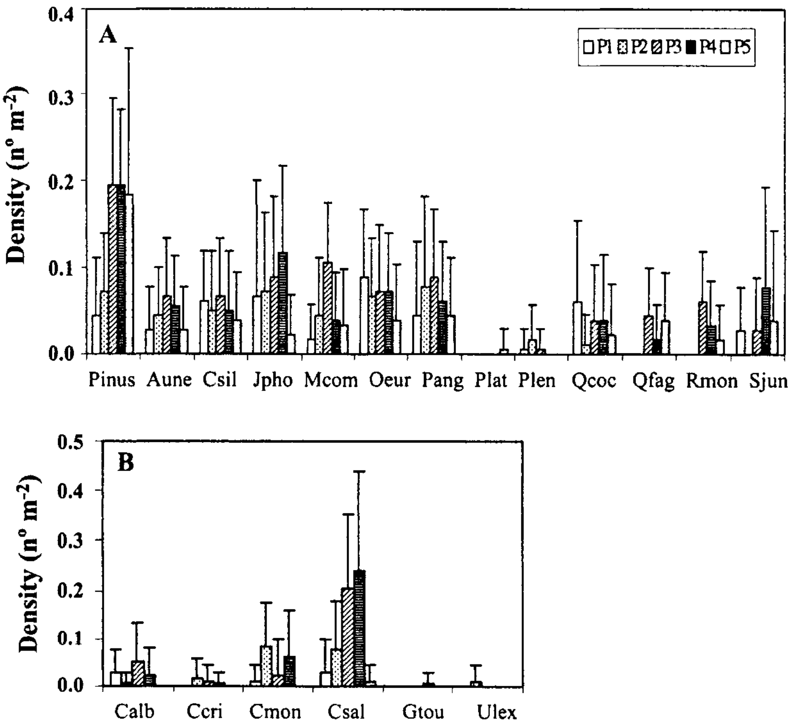

Figure 5: A - Density (n° of plants m^{-2}) of the main species introduced during the revegetation of platforms. Species: Pinus – *P. halepensis* + *P. pinea,* Aune – *A. unedo,* Csil – *C. siliqua,* Jpho – *J. phoenicea,* Mcom – *M. communis,* Oeur – *O. europaea,* Pang – *P. angustifolia,* Plat – *P. latifolia,* P.len – *P. lentiscus,* Qcoc – *Q. coccifera,* Qfag – *Q. faginea,* Rmon – *R. monosperma,* Sunj – *S. junceum.* P1, P2, P3, P4, P5 – platforms 15, 12, 9, 6, 3 years old respectively. B - Density of the indigenous species colonising the platforms. Species: Calc – *Cistus albidus*, Ccri – *C. crispus*, Cmon – *C. monspeliensis*, Csal – *C. salvifolius*, Gtour – *Genista tournefortii*, *Ulex* sp..

Pinus species, although introduced with a density similar to that of the sclerophyllous species (around 0.05 plants m^{-2}) on the first two platforms (P1 and P2) (Fig.5) showed higher height and cover values (Fig. 6). *Pinus* spp. made up a higher fraction of the cover in older platforms, with significant differences between the younger platforms (P4 and P5) and the oldest ones (P1, P2 and P3) (Tukey-test, $p<0.001$). The height of *Pinus* spp. was significantly different between platforms (Tukey-test, $p<0.001$), with a maximum height around 3,6 m. The other species were also higher and made up a higher fraction of cover in older platforms, but without significant differences.

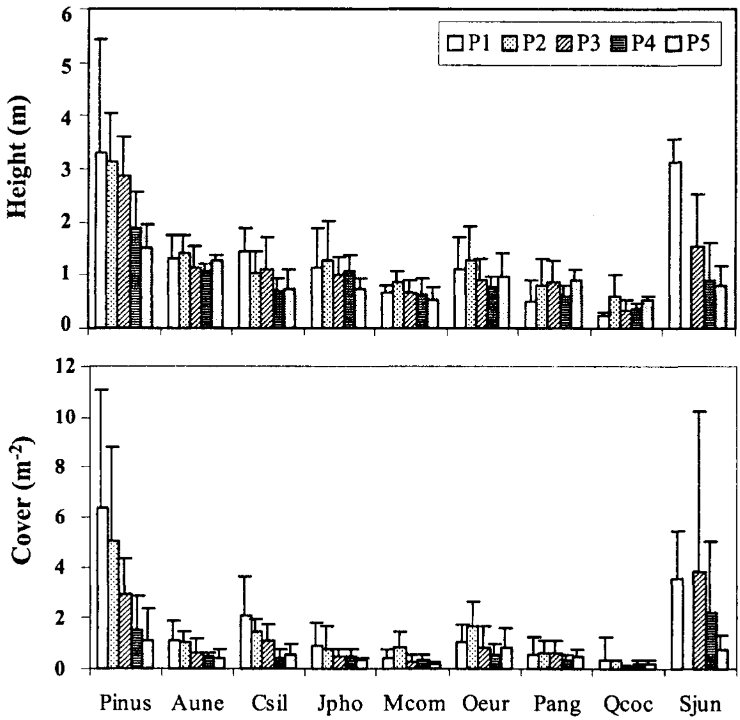

Figure 6: Height and cover of the main species introduced during the revegetation of different platforms. See Figure 5 for species and platforms legends.

Pinus species represent 40-60% of the total plant cover, while the sclerophyllous species attained a maximum of 10% (*C. siliqua* and *O .europaea*) and lower for the other species. The sclerophyllous species maintained low cover values during the first 9-12 years and only in the oldest platforms (P1) was observed an increase. The percentage cover of the legume species, *Spartium junceum* was also higher than that of the sclerophyllous species (18%). Though *Cistus* species, were present at higher densities, they made up a small part of cover, around 7% (data not shown).

The Whitaker diversity index was higher in platforms P3 and P4 (Table 2). The diversity and the total number of species was lower in the oldest platforms, probably due to increased competition.

Table 2. Whitaker diversity index and the Sörensen similarity coefficient between revegetated platforms and the surrounding natural vegetation

Platforms	Age years	Diversity index	Total nº species	Similarity coefficient
P1	15	35.64	36	0.45
P2	12	31.88	54	0.34
P3	9	54.44	69	0.29
P4	6	40.27	61	0.31
P5	3	27.85	62	0.18
Maquis	> 50	21.11	43	—

The Sörensen similarity coefficient, which indicates the similarity between the platforms and the natural vegetation, increased with the platforms' age, and showed a very low value in the recently revegetated platform. These results reveal the time effects on the species migration from the surrounding areas. When this index is evaluated only with the woody species the value increases, showing that the herbaceous species are the responsible for the main differences between sites.

A total of 150 plant taxa were found on revegetated platforms, 16 of these had been introduced as part of the reclamation process, while an additional 109 herbaceous species also became established. The remaining 25 species were indigenous woody taxa which typically invade and occupy disturbed sites most of them occurred in indigenous plant communities in the locality (e.g. *Cistus* spp. *Ulex* spp.).

The artificially revegetated quarry at Outão presented a higher number of species, total plant cover and diversity than the naturally regenerated quarry at Jaspe (Table 3).

The evenness index was higher in the natural vegetation, showing that species were more even distributed there than in the quarry sites.

TWINSPAN analysis (Fig. 7) showed a clear division, at level 1, between the revegetated quarry (A) and the other sites (B - regenerated disused quarry, A', B' - natural vegetation sites).

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Table 3. Total plant cover, mean plant height, Shanon–Weaver diversity index (H') and evenness index (J) in quarry sites.

Site	Type	Cover (%)	Height (m)	N° species	(H')	(J)
A - Outão	revegetated	54	1,1	29	2.52	0.523
A' - Outão	Maquis	80	2,1	26	2.52	0.772
B - Jaspe	regenerated	40	<0.5	19	1.58	0.537
B' - Jaspe	Maquis	95	1,7	35	2.32	0.653

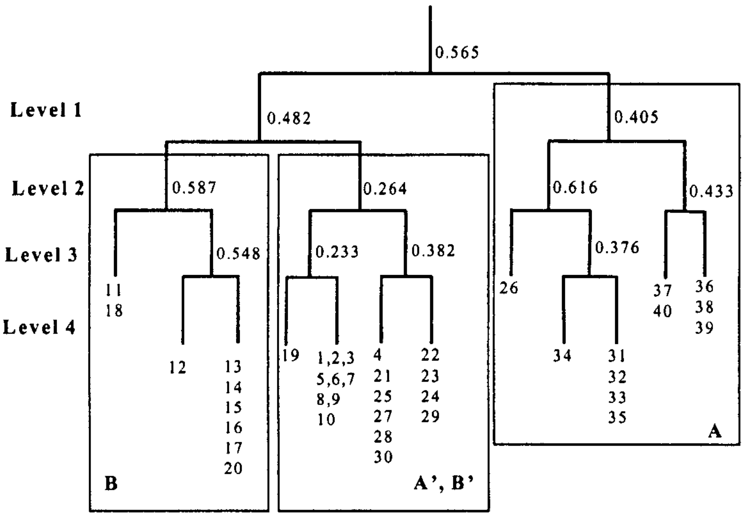

Figure 7: TWINSPAN hierarchy of sites based on vegetation. A – revegetated quarry sites (Outão), A' – natural vegetation surrounding Outão quarry (Maquis), B – naturally regenerated disused quarry (Jaspe), B' – natural vegetation surrounding Jaspe quarry (Maquis). Quadrats 1-10 - Jaspe natural vegetation, quadrats 11-20 - Jaspe regenerated quarry, quadrats 21-30 - Outão natural vegetation, quadrats 31-40 - Outão revegetated quarry.

At level 2, quadrats from the natural sites at Jaspe and Outão (A', B') were separated from quadrats at the Jaspe quarry (B) except quadrat 19 which stayed with the natural vegetation quadrats due to the high cover of *Pistacia lentiscus.*

At the Outão artificial revegetated quarry (A), the quadrats were separated in two main groups, due to a higher number of herbaceous species in quadrats 36-40.

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Discussion

Reclamation of degraded quarry areas is a difficult task, since rock extraction results in a complete removal of vegetation and loss of soil. The results of this study suggest that artificial revegetation favours a quicker establishment of species leading to a lower landscape visual impact. This also minimises soil erosion and promotes microclimatic conditions favourable for colonisation by other species

Since the initial materials of quarry sites are skeletal and lack the physical, chemical and biological characteristics of normal soils, the most critical processes are related to soil development [13]. The addition of a coversoil layer as a first step to provide an environment which allows recolonisation and establishment of new plant communities seemed to play a very important role in soil evolution.

The changes in the physical and chemical soil characteristics were slow (Table 1). The most obvious changes during these years were in pH and organic matter (Fig. 3). In spite of the evolution observed in these parameters, they are still far from those in maquis soils. Even the fungal communities were not fully re-established after 17 years (Fig. 4). In contrast, the soil fauna showed a rapid recovery. Their were of greater importance on older platforms similar to natural maquis, probably because they feed indifferently on decaying leaves, wood, fungal hyphae and faeces of other animals. The major groups found in this study, the saprophagous mites (Acarina) and the springtails (Collembola), play a major role in producing a crumblike structure in surface layers.

The biotic factors studied – fungal biomass and soil fauna – are responsible for the breakdown of litter, cellulose and pectic substances. They presented a more rapid evolution than soil abiotic characteristics which were probably responsible for the incorporation and consequently increase of organic matter in the older platforms (Fig. 3). The other soil characteristics such as total N are mainly dependent on bacterial community activities which are in turn dependent on soil pH. Although a slight increase of N was observed (Table 1), the high pH still present would not permit high nitrification rates and a consequently larger retention of N in the soil. Nevertheless, the presence of such important biotic components in older platforms give indication of the considerable evolution needed for complete recovery of soil characteristics.

Revegetation also contributes to minimise soil erosion and runoff [14], and to promote microclimatic conditions favourable to colonisation by other species.

The use of sclerophyllous mediterranean plants irrigated in the first year resulted in low mortality and successful establishment. Native species have the advantage of being highly adapted to the local edaphic and climatic conditions, which are characterised by strong seasonality and can withstand years of extreme climatic events.

Pinus spp. established itself more successfully than the other species, displaying higher growth and occupying more cover than the sclerophylls (Fig.6). Growth rates in pine trees were also exceptionally low when compared with other ecosystems. It is clear that the species used are tolerant to low nutrient and water conditions, but the growth rate is very low. The sclerophyllous species, present from the beginning but belonging to the later successional stages, only begin to grow more rapidly when the soil had evolued in terms of organic matter and pH. The species used for revegetation seemed to be able to increase the total vegetation cover and diversity. However, the greater cover occupied by pine species indicates a high competition for space and light at later successional stages.

The diversity in these platforms decreased probably due to high competition for light and nutrients (Table 2). However, if rapid re-greening of the area is the primary goal, then fast growing species (e.g. *P. halepensis*) could be used in the first stage of revegetation.

The occurrence of a larger proportion of indigenous species on reclaimed sites suggests that floristic diversification is occurring as a result of natural processes. This could be largely attributed to the invasion of plants from the surrounding vegetation via seed dispersal and establishment. Their establishment may have been favoured by the microclimatic conditions created by the trees and shrubs planted. The development of a dense canopy facilitates [15] the establishment of longer lived stress-tolerators (sensu Grime [16]), such as *P. lentiscus, P. angustifolia* and *R. alaternus*, which showed numerous seedlings in the older platforms (data not shown).

The revegetated platforms were floristically diverse and highly variable in composition, due to the proximity of natural vegetation and the introduction of lime and soil from other regions. It is possible that some of the ruderal species were introduced during the manipulation process of revegetation and took advantage of the conditions within the reclaimed area.

The TWINSPAN analysis suggests that the vegetation of the artificially revegetated quarry clearly diverges from the natural vegetation and the naturally regenerated quarry, mainly due to the exclusive presence of *S. junceum, C. siliqua, P. halepensis* and *P. pinea* (Fig.7). Also native species, such as some bulbous species (e.g. *Paeonia broteroi, Scilla* sp, *Arisarum vulgare*) which are tolerant of soils with moderate nutrient levels and humidity, but probably not of soils with extreme conditions, did not colonise the quarry site. The vegetation of the naturally regenerated quarry is more similar to that of the natural surrounding vegetation than the vegetation of the abandoned quarry. However, we found significantly more bare ground, fewer herbaceous plant species, less vegetation cover and lower diversity on the disused and naturally regenerated quarries than on the revegetated ones.

Nevertheless, if we consider total vegetation cover and diversity as targets for ecological rehabilitation of limestone quarries, the species used in revegetation seem to be able to contribute positively for the rehabilitaion of these areas.

The results of this study suggest that artificial revegetation with different functional groups (fast-growth *vs* slow growth species) favours a quicker establishment of species leading to a lower landscape visual impact. Also the direct planting of trees on quarry floors as reported by Ursic *et al.* [17] could help to accelerate the succession on quarry walls. These plantings shade the walls and facilitate the recruitment of stress tolerators found later in the natural successional sequence.

This study showed that, sites should not be left unattended after revegetation. The ecosystems must be monitored, to determine whether development is proceeding well or if aftercare management is required. Even minor aftercare could alleviate the major constraints on revegetation and significantly accelerate development. From these results, it seems very important to reduce the inter-specific competition between species by selective thinning of pine trees and thus accelerate the successional stages.

On the other hand, time is a very important factor in soil formation and since the success of rehabilitation is dependent on soil quality, it will be important to improve initial soil conditions through various types of amendments.

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