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APPLICATION OF RESTORATION ECOLOGY PRINCIPLES TO THE PRACTICE OF LIMESTONE QUARRY REHABILITATION IN LEBANON

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ABSTRACT

Restoration ecology is an emerging science dealing with applied ecology and aiming at "helping nature to recreate itself". This comprehensive paper presents the findings and main results related to the analysis of natural vegetation dynamics on abandoned limestone quarries in Mediterranean environment. It aims to answer three basic questions: where, when and how should intervention by ecological restoration be achieved in abandoned limestone quarries.

Results show that quarries are heterogeneous ecosystems and interventional strategies should be planned according to the different landforms observed. Quarry faces potentially host a particular saxicolous flora often composed of rare and endemic species, intervention is not recommended, unless required by urban planning issues. Intervention on platforms can be very expensive (substratum fracturing) and involves heavy engineering works. Restoration on quarry embankments aims at orienting and accelerating natural regeneration processes in order to shortcut the first stages naturally dominated by annuals and ruderal species. 27 species suitable for revegetation purposes have been identified for the different bioclimatic levels in Lebanon. They respond to two major criteria: availability in the natural surroundings (indigenous species) and adaptability to local conditions (pioneer adapted species). In conclusion, this paper suggests future openings for a development field integrating economical opportunities on solid scientific bases.

Keywords: restoration ecology, limestone quarries, rehabilitation strategies, plant adaptability, species availability, Mediterranean degraded ecosystems, Lebanon

Nomenclature Mouterde (1966)

INTRODUCTION

Restoration ecology is an emerging science that deals with several aspects of applied ecology situated at the interface between ecosystems concepts, plant biology and landscape engineering. The concept of restoration ecology is dated back to 1935 (Jordan *et*

al., 1987), but only in the late 80's was it definitely defined as "an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability" (SER, 2002). The ecological trajectory of an ecosystem describes the developmental path of an ecosystem through time. It concerns as well the spontaneous trajectory in cases of natural regeneration, as well as any oriented pathway initiated by human intervention aiming to orient and accelerate natural processes. In principle, there are three possibilities to consider the restoration of a disturbed site (1) rely completely on spontaneous processes; (2) exclusively adopt technical measures and (3) combine (1) and (2) by directing natural/spontaneous succession (Prach, 2003).

Mediterranean ecosystems are defined by hydrological and temperature conditions that will determine the landscape organization (Quézel & Médail, 2003). On the ecological level, this will result in having (1) plant species adapted to drought as well as to winter sudden temperature drops, (2) accelerated erosion processes and (3) fragmentation of ecosystems and plant populations. Spontaneous regeneration, following ecosystem degradation can be seriously slowed down or completely hindered in such environmental constraints.

Over the past decades, Lebanon has witnessed anarchic exploitation of hilly ecosystems for quarrying purposes resulting in one quarry/ 15km² (Dar Handassah, 1996). Quarrying operations induce ecosystem disturbance and profound modifications on the substratum and the topographical profile of a site. On such heavily disturbed areas, spontaneous colonization is slow (Whisenant *et al.*, 1995) and the natural vegetation succession is often inefficient to ensure proper protection against erosion (Bradshaw, 1993; 1997). Restoring disturbed ecosystems is often the result of land planning requirements; nevertheless, the intervention strategy should be inspired on the observation and analysis of the natural trajectory of the ecosystem (Bradshaw, 1987; Jochimsen, 2001). The success of such an operation is highly dependent on the choice of species to be used for revegetation purposes (Martin *et al.*, 2002; Khater *et al.*, 2003). The selection of such species should respond to three major principles: Biotic integrity (neighboring or local species), competitiveness (competitive perennial species in local conditions) and availability (presence in the market of viable seeds) (Martin *et al.*, 2002; Khater, 2004).

This paper is based on the main results of an analysis of spontaneous vegetation dynamics on abandoned limestone quarries in Lebanon (Khater, 2004; Khater *et al.*, 2003) and attempts to answer the following question: *where and when is an intervention by ecological restoration really justified?*

Therefore, this paper presents a methodology for practical interventions in ecological restoration on limestone quarry sites in Mediterranean environments.

STUDY AREA

The study area extends on the western part of Mount Lebanon on three vegetation levels defined along an altitudinal gradient of 500 m: the thermo, meso and supra Mediterranean (MOA, 1996). The rain fall regime concentrates from November to March and defines three bioclimatic levels on the study area (subhumid, humid and perhumid). The substratum is mainly composed of hard limestone particularly suitable for quarrying activities (Shaban *et al.*, 1999).

MATERIALS AND METHODS

Mechanical excavations related to quarrying operations lead to the formation of three physiographical elements on a quarry site: cliffs, platforms and embankments. Cliffs or quarry faces are vertical headwalls resulting from the extraction of rocky materials for gravel and/ or stone production. Platforms are horizontal landforms initiated by the quarrymen in order to facilitate truck mobility and transport of the material extracted. Embankments result from the erosion of neighboring slopes and/or reject material deposited. Substrata are mostly sterile and infertile lacking organic matter, microbial and faunal activity and seed bank (Fig.1).



Figure 1. Three physiographical elements are present on a quarry site: the cliffs, the platforms and the embankments.

Surveyed plots (116) were selected in representative quarries (26) in each of the different bioclimatic levels on each of the three physiographical elements within the quarry (cliffs, platforms and embankments) but also in the neighboring ecosystems defined here as the reference ecosystem (SER, 2002). On each site, an area of 75m² was inventoried by compiling a floristic list (290 species) and described 39 environmental parameters (phyto ecological releves). The surface cover was recorded for each species according to the Braun-Blanquet (1932) scale (0 to 5). Resulting data comprising 116 plots out of 26 quarries, enclosing 290 species and 39 environmental parameters were analyzed by multivariate correspondent analysis (Khater, 2004).

RESULTS AND DISCUSSION

In Mediterranean ecosystems, quarrying disturbance induce profound modifications on the landscape and stressful abiotic conditions on plant communities. It is thus difficult to estimate the speed of spontaneous vegetation recolonization. A dataset extending over 40 years shows that natural regeneration occurs at a very slow pace, up to 25- 40 years in hard limestone quarries in Lebanon (Khater, 2004). Vegetation dynamics relies on species that are both available in the natural surroundings and adapted to local environmental (topography and soil) constraints. Since natural dynamics is specific upon the different topographic units within a quarry and spontaneous succession differs on embankments, on quarry faces and on platforms, it is necessary to adapt the restoration intervention accordingly.

Restoration on quarry faces

Natural cliffs naturally host a particular and diverse saxicolous and rupicolous flora (Boulet, 1996), especially in hilly Mediterranean landscapes (Coumoul & Mineau, 2002). Vertical quarry faces can be topographically compared to natural cliffs. Our surveys as well as those of Cullen *et al.* (1998) revealed comparable floristic composition between them. Natural surroundings cliffs could therefore be considered as reference ecosystems for quarry faces.

These surveys revealed the presence on quarry cliffs of rupicolous species, such as *Centaurea speciosa*, *Galium canum*, *Putoria calabrica*, *Asperula libanotica*, *Tracheliopsis tubulosa* and *Onosma frutescens* many of which are endemic to the Mediterranean region. Scientific literature lacks suitable references highlighting the ecological value of abandoned quarries, but Arnal (1993) and Vela (2002) confirmed the presence in quarries of particular plant species, some of them being exclusive to this type of ecosystems and some rare and/or protected species spotted in abandoned quarries have been reported beyond their natural distribution area.

A restoration scheme on quarry faces should respect their potentialities to naturally host endemic and/ or very interesting species. It is therefore recommended to avoid systematic intervention on quarry faces. Intervention should be restricted to urban surroundings when land use management is required.

Restoration on platforms

On quarries platforms, field visits revealed that species only occupied the rock fractures (Fig 1). Vegetation succession is very slow and seems unable to ensure sustainable effective spontaneous colonization. Intervention on such sites might be deemed necessary. Le Duc (1985) suggested rock fracturing with or without soil amendment as an appropriate but very costly method. Platforms could also be allocated as picnic areas, parking or even landfill sites depending on the quarry location. Consequently, reallocating quarry platforms will require implementation of important security measures and "visitor centers" if site planning implies regular public visits. In those cases, quarry platforms management rather falls under site engineering vocabulary than under restoration ecology principles.

Restoration on embankments

In Mediterranean region natural vegetation succession on quarry embankments is initiated and dominated by annual species as well as “all purpose” or cosmopolitan species.

Such *taxa* invest in reproduction and dissemination strategies, through short and rapid cycles of soil occupation monitored by germination, rapid vegetative spring growth and seed production and death of mother plant in late summer. Therefore, during the rainy autumns in Mediterranean ecosystems, the annual vegetation fails to ensure sufficient soil cover and important erosions result on barren substrata. Spontaneous establishment of perennial vegetation composed of hemicryptophytes, chamaephytes and phanerophytes capable of ensuring lasting soil occupation and surficial stabilization by root development will only occur 5 to 6 years after site abandonment. Table 1 presents the dominant species recorded on quarry embankments in comparison to those in reference ecosystems in the different rainfall ranges/ bioclimatic levels.

These results (Khater *et al.*, 2003) have shown that intervention on quarry embankments would not only enhance vegetation cover composition but will also reduce erosion by providing long lasting plant rooting, ensure a better stabilization of substrata and promote visual integration within the landscape.



Figure 2. Hydroseeding technique particularly adapted to revegetate steep slopes and hard access areas.

TABLE 1

Dominant/ Major Species Recorded on Quarry Embankments and in Reference Ecosystems in the Different Range Fall Ranges

	Major species on quarry embankments	Major species on both quarry embankments and reference ecosystems	Major species in reference ecosystems
700- 1000 mm Sub humid	<i>Inula viscosa</i> <i>Avena Sterilis</i> <i>Verbascum sinuatum</i> <i>Lotus corniculatus</i> <i>Geranium distachyum</i>	<i>Sarcopoterium spinosum</i> <i>Callycotome villosa</i> <i>Phagnalon rupestre</i> <i>Micromeria nervosa</i> <i>Ainsowrthia cordata</i>	<i>Rubia tenuifolia</i> <i>Urospermum picroides</i> <i>Helichrysum sanguineum</i> <i>Trifolium stellatum</i> <i>Anagallis arvensis</i> <i>Stachys distans</i> <i>Teucrium pollium</i>
1000- 1200 mm Humid	<i>Inula viscosa</i> <i>Oryzopsis miliaceae</i> <i>Geranium distachyum</i>	<i>Salvia triloba</i> <i>Ptilostemon chamaepeuce</i> <i>Stachys distans</i> <i>Origanum syriacum</i> <i>Callycotome villosa</i>	<i>Rubia tenuifolia</i> <i>Cistus creticus</i> <i>Smilax aspera</i> <i>Pinus pinea</i> <i>Quercus calliprinos</i> <i>Pistacia palaestina</i>
1200- 1500 mm Per humid	<i>Inula viscosa</i> <i>Dactylis glomerata</i> <i>Ainsworthia cordata</i>	<i>Origanum syriacum</i> <i>Rhamnus punctata</i> <i>Sarcopoterium spinosum</i> <i>Melica uniflora</i> <i>Salvia triloba</i> <i>Anthemis creticum</i> <i>Helichrysum sanguineum</i> <i>Verbascum sinuatum</i>	<i>Rubia tenuifolia</i> <i>Stachys distans</i>

An adapted restoration strategy on quarry embankments should orient the natural processes towards an earlier establishment of perennial *taxa* in order to shortcut the annuals phase and ensure a rapid self sustained vegetation succession and ecosystem development. Previous researches (Coumoul & Mineau, 2002; Martin *et al.*, 2002; Brofas & Karestos, 2002) have proven that revegetation by hydroseeding is one of the best suited methods for high steep and hard access sites such as quarries and highway embankments and allowed to shortcut the natural succession processes by gaining 5 to 10 years on natural processes (Coumoul & Mineau, 2002). The method consists on spraying a seed assortment mixed with straw mulch and water, by means of a pump and a hose directly to the depleted area to be restored (Fig 2).

Intervention should be inspired on the natural trajectory of the ecosystem i.e from plant communities observed in situ (Bradshaw, 1997; Khater, 2004). Then it appears the question on the choice of best suited species to be used for such purposes.

Choosing species for revegetation purposes

Success of revegetation operations depend on the choice of species used in the seed mixture, with respect to the principles of biological integrity, local competitiveness and seed availability and adaptability (Pywell *et al.*, 2002; Khater *et al.*, 2003; Pywell *et al.*, 2003). Therefore this choice is mainly articulated on three main axes: ecological needs, agro-ecological constraints (biology of the species) and economical feasibility.

Seed mixture should be composed of:

1) Species naturally present in the direct surroundings of the degraded site (principle of availability), and species that naturally develop in comparable sites (principle of adaptability); adding such species in the seed mixture helps reinforcing the chances of their establishment and further on-site colonization

2) Species absent from the direct surroundings of the site but whose ability to colonize comparable environments is indicated by their presence in similar degraded sites (principle of adaptability but non availability).

Seed mixture for revegetation on quarry embankments should include broad spectrum species that have the ability to colonize various types of ecosystems, described as "all purpose" species or « generalistic species » *sensu* Pywell *et al.* (2003). Those species will ensure rapid vegetation development. The integration of hemicryptophytes and chamaephytes will ensure long lasting cover. This later category should include some specialized saxicolous, rock adapted species. Choosing small sized seeds that are able to penetrate in the gaps of the stony substrata, will enhance the chances of species colonization.

In reference to species auto ecology, Table 2 displays for three ranges of rainfall, suggested generalistic herbaceous species and specialized chamaephytes, to be used in revegetation intervention on embankments (limestone quarries, side roads, degraded mountain slopes) in Lebanon.

TABLE 2

Suggested *Taxa* for Revegetation of Quarry Embankments in Lebanon in the Different Bioclimatic Level

Rainfall range	« Generalistic » herbaceous	« Specialized » chamaephytes
700-1000 mm Sub humid bioclimatic level	<i>Bromus madritensis</i> <i>Dactylis glomerata</i> <i>Hymenocarpus circinatus</i> <i>Hyparrhenia hirta</i> <i>Blackstonia perfoliata</i> <i>Melica uniflora</i>	<i>Teucrium pollium</i> <i>Putoria calabrica</i> <i>Salvia triloba</i> <i>Ononis reclinata</i> <i>Ptilostemom chamaepeuce</i> <i>Phagnalon rupestre</i>
1000- 1200 mm Humid bioclimatic level	<i>Ainsworthia cordata</i> <i>Dactylis glomerata</i> <i>Hymenocarpus circinatus</i> <i>Andropogon distachyus</i> <i>Dactylis glomerata</i> <i>Urospermum picroides</i> <i>Oryzopsis holciformis</i> <i>Andropogon distachyus</i>	<i>Salvia triloba</i> <i>Origanum syriacum</i> <i>Putoria calabrica</i> <i>Ptilostemom chamaepeuce</i> <i>Phagnalon rupestre</i> <i>Stachys distans</i> <i>Satureja thymbra</i>
1200- 1500 mm Per humid bioclimatic level	<i>Sterigmotemom sulphureum</i> <i>Euphorbia thamnoides</i> <i>Oryzopsis holciformis</i> <i>Lotus corniculatus</i> <i>Poterium verrucosum</i> <i>Ainsworthia cordata</i> <i>Hymenocarpus circinatus</i> <i>Andropogon distachyus</i> <i>Hyparrhenia hirta</i> <i>Dactylis glomerata</i>	<i>Ptilostemom chamaepeuce</i> <i>Teucrium pollium</i> <i>Phagnalon rupestre</i> <i>Calycotome villosa</i> <i>Stachys distans</i> <i>Salvia triloba</i>

Once those scientific requirements in relation with the choice of adapted species to be used are met, we are faced with two alternatives in order to make those seeds available for revegetation operations. One could either use directly harvested seeds from natural populations or harvested seeds can be used to cultivate mother plants themselves becoming a source of seeds. In this latter option, it is important to develop adequate know how in terms of agricultural domestication of such wild species for their production. Those techniques have been mastered in Southern France to develop into an active economical branch especially devoted to the production of "wild cultivated species", mainly used in restoring side road and railways embankments (Martin *et al.*, 2002).

CONCLUSION

Restoration of degraded sites implies enabling spontaneous mechanism to occur in shorter periods of time by making available adapted species by revegetation. Quarries represent extreme cases of degradation characterized by complete removal of vegetation cover and profound landform modifications. Conclusions drawn of such ecosystems are therefore applicable to other types of degraded sites such as side road embankments, mountain slopes. It is also possible to rely on the findings presented in this paper in a landscaping perspective introducing alternatives towards water economy in urbanized areas by promoting the use of indigenous adapted species for landscaping purposes.

Going beyond scientific results, strategic orientation for Lebanon would be to develop economical opportunities in the restoration field as it was the case 15 years ago in Southern France. Relying on governmental and academic institutions for collecting, domesticating, producing wild species would orient further commercial activities for their promotion and use. This first step represents leading potentials for new economical openings combining landscape integrity and local community involvement.

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