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RESTORING LIMESTONE QUARRIES: HAYSEED, COMMERCIAL SEED MIXTURE OR SPONTANEOUS SUCCESSION?

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Abstract: The main goal of quarry restoration is to convert degraded, unproductive areas into new, self-sustaining ecosystems that develop into highly natural environments. With the aim to individuate the best practices for restoring limestone quarries, we investigated the short-term effects on vegetation features and economic advantages of three restoration approaches. These approaches included tree and shrub planting, no herb layer, or a commercial seed mixture or hayseed. The different approaches were tested in a limestone quarry within the Botticino extractive basin (N-Italy). A donor grassland area of hayseed and a quarry area that had undergone spontaneous revegetation over a decade were used as control areas. We surveyed the vegetation plots to investigate the structure and the productivity of the herbaceous layers; collecting data on plant species cover, the mean plant height, the tree and shrubs mortality and biomass enabled us to perform gradient analysis. The main differences between the sites were due to biotic factors; specifically, vegetation cover was affected quite differently by the different restoration approaches. Restoration with commercial seed mixture resulted primarily in dense stands of *Lolium perenne* that caused an increase in shrub and tree mortality. Cost-benefit analyses showed that despite hayseed being the most expensive approach in terms of cost and time, it ensured higher species diversity, vegetation structure and greening. Our results highlighted that autochthonous plant materials can improve excavation-area restoration by both contrasting the colonisation of non-native species and increasing natural regeneration and biodiversity levels.

Keywords: hayseed; commercial seed mixture; hydroseeding; transplantation; cost-benefit analysis

INTRODUCTION

Over the last thirty years, great efforts have been made all over the world to rehabilitate stone quarries including improving environmental conditions, removing impacts and damages on ecosystems, by ensuring the reuse of the degraded areas and increasing sustainable development (Neri & Sánchez, 2010; Abakumov *et al.*, 2011; Porqueddu *et al*., 2013).

Where a naturalistic endpoint is desired, spontaneous succession is often incapable of recovering the ecosystem and its natural self-regulatory processes. Abiotic limits, such as water and nutrient deficiency, soil erosion and water contamination and the risk of landslides typically give rise to this failure. In addition, the critical distance from valuable natural areas and human-induced disturbance due to quarry activities together discourage the natural vegetation succession (Duan *et al.*, 2008; Gentili *et al*., 2011; Ballesteros *et al.*, 2012). Other environments are affected by similar problems (high erosion rates, poor soils and the need of vegetation recovery: minespoils (Martín-Moreno *et al*., 2013), badlands areas (Cerdà, 1999), roads and railways embankments (Cerdà, 2007) and agriculture lands (Li *et al*., 2013). In such cases, technical measures are required to increase the speed of the regeneration process and the earlier development of site-specific and self-sustaining plant communities and ecosystems (e.g., Khater & Arnaud, 2007; Prach & Hobbs, 2008).

The ecological recreation of valuable semi-natural habitats from highly disturbed ecosystems is not a simple process, and quarry restoration is an even greater challenge because the starting area is generally bare and comprises a low-fertile substrate (Tischew & Kirmer, 2007). Thus, the identification of optimal approaches is fundamental to plan a successful restoration and involves detailed quantitative case studies, field experiments and comparative studies over wide geographical areas (Yundt & Lowe, 2002; Prach, 2003). Modelling the spontaneous successional dynamics will enable restorations for specific ecosystems that will be based on precise, successional phases and on the level of environmental complexity (e.g., Prach *et al.*, 2001; Tischew & Kirmer, 2007). Following the identification of a target ecosystem and a successional phase, quarry restoration can commence using key steps, such as landform modelling, substrate preparation, plant species selection, revegetation *sensu stricto* (i.e., plant translocation) and post-plantation interventions (e.g., Warman, 1988; Bernini *et al.*, 2003).

With respect to revegetation, which begins on bare substrates, different approaches have been developed including the use of diasporas-rich plant clipping material, the dumping of overburden with seed bank and vegetative propagules, mulch seeding, and shrub and tree planting (e.g., Muzzi & Rossi, 2003; Tischew & Kirmer, 2007). In particular, hayseeding involves mowing plant stalks carrying mature seed heads (i.e., infructescences) in species-rich meadows and scattering the product over the site to be restored (Cottam, 1987). Hydroseeding is a useful sowing technique that could significantly increase biodiversity and plant cover within a few years after its application (Martínez-Ruiz *et al.*, 2007; Prats *et al.*, 2013). It is typically performed using commercial seed mixtures. With respect to the tree and shrub layers, seeding generally do not regenerate rapidly from seeds or may be subjected to other factors such as climatic conditions or the germination process (Bullard *et al*., 1992; Madsen & Löf, 2005). Transplantation requires more intensive efforts but fresh plant clippings may accelerate the development of vegetation (Kirmer & Mahn, 2001).

Although many studies have reported on a single restoration method, only a few experimental studies have thus far tested the efficacy of different restoration approaches, in particular, hayseed. We hypothesised that different restoration approaches would result in different biodiversity levels and ecological functions. Thus, the principal aim of this study was to report on short-term results on the effectiveness of three different restoration techniques that were based on the transplantation of trees and shrubs and the use of hydroseeding for the herb layer. These three different conditions were no herb layer, a commercial seed mixture and hayseed. To identify the optimal approach we investigated the test areas at different levels: 1) ecological suitability (compared with natural conditions); 2) short-term monitoring of tree/shrub mortality and biomass productivity; 3) comparative economic advantages (cost-benefit analysis).

MATERIALS AND METHODS

Study area and experimental site

The experimental site was located on the "Botticino extractive basin" (Brescia, Lombardy, Italy), which is the second biggest Italian extractive basin after the Carrara quarries and it is famous worldwide for the extraction of the limestone, commercially known as "Botticino marble". The vegetation in the hills around the extractive basin is dominated by *Quercus pubescens* and *Ostrya carpinifolia* woodlands and by natural/semi-natural arid grassland with high biodiversity (*Festuco–Brometalia* community; Gilardelli *et al.*, 2013).

We selected an area of about 600 m^2 (ATE 13; Municipality of Nuvolento; coordinates: N 1606633, E 5044874; altitude: 394 m a.s.l.; aspect: 225°), that was previously remodeled (June 2011) so that the final abandonment profile was made by three terraces of about 200 m^2 almost horizontal (slope between 2-5°) and connected by two small areas with slope of 45° and 32°, respectively (Figure 1). An homogeneous topsoil with an average thickness of 50 cm was created by use of waste material deriving from quarry activities (i.e. a mixture of soil removed during the quarry opening and limestone debris deriving from extraction) of a working quarry close to the experimental site (quarry "Marmi Spinetti S.r.l."; ATE 13), according to the Provincial Quarry Plan. Thus, topographic and environmental conditions of the three adjacent terraces were the same.

We characterised the soil according to the parameters of the Italian legislation (regional law "D.G.R. 21.12.2000, n. VI/120"; Supplementary Material S1). During the site preparation (October 3rd 2011), we removed superficial stones >50 cm in diameter. Topsoil displayed a "clayey" texture and had a skeleton of heterogeneous limestone fragments. The soil received no further treatments to ameliorate its characteristics. Thus, we reduced both, the risk of contamination of groundwater resources in the karst area and the cost of the restoration actions. Shrubs and trees and the sowing of the herb layer was carried out October 4th 2011.

Experimental design

We tested three different approaches on three terraces:

1. *No herb layer*. This approach comprised the manual planting of young individuals (1-2 years) of shrub and tree species randomly distributed over the same surface (about 180 m^2) on the three terraces; we did not sow any herb layer

and we evaluated only spontaneous vegetation recovery. We had previously determined the species composition and the optimal density of trees and shrubs based on a semi-quantitative procedure (see Supplementary material S2). Such procedure took the limiting environmental site characteristics and the type and density of woodlands growing on the areas surrounding quarries into account. The species composition and number of woody plants that were manually transplanted in each of the three terraces are reported in Table 1.

2. *A commercial seed mixture*. The approach comprised the hydroseeding of a commercial seed mixture followed by the manual planting of shrubs and trees as in no herb site. To reproduce a widely used restoration technique, we used a commercial seed mixture made by *Poaceae* (*Festuca rubra*, *Lolium perenne*, *Poa pratensis*, etc.) and *Fabaceae* (*Lotus corniculatus* and *Trifolium hybridum*) that is suited to a wide range of environmental conditions (see Supplementary material S3, for the complete species list). We added 40 g/m^2 of the seed mixture to the mixture for “potentiated hydroseeding”, which is usually used in adverse site conditions (Full Service, 2008; see Supplementary Material S4).

3. *Hayseed*. This comprised the hydroseeding of hayseed (Poschlod & WallisDeVries, 2002) to establish a calcareous grassland followed by manual planting of shrubs and trees as in no herb site. We selected as a donor grassland an annually mowed semiarid grassland (belonging to *Festuco-Brometalia*; see Supplementary Material S5) located in a clearing of a woodland dominated by *Quercus pubescens* that was close to the experimental site (Municipality of Serle; coordinates: 1606045 – 5046163; altitude: 438 m a.s.l.; mean aspect: 147°; mean slope: 15°). We collected 8.2 kg of hayseed during May 2011 using a brush

harvester. Once dried, it was characterised from a floristic point of view (i.e. the list of species from seeds) and for seed density. Following the preparation of the experimental site, we spread the hayseed manually on terrace C at a density of 36.28 g/m^2 (i.e., approximately 50% of the optimal calculated sowing density; see Supplementary Material S5). Thus, we sowed the mixture using "potentiated hydroseeding" as in the commercial seed site.

Post-plantation interventions

We watered the soil on the day of transplantation. Subsequently, "help irrigations" took place in the following year based on rainfall distribution (see Supplementary Material S6 for rainfall dates). In order to favour plant establishment, the frequency of irrigations was high in the post-plantation phase (Gilman, 2002): October 10th, 13th and 17th 2011. During prolonged periods without rainfall in dry periods (i.e. summer) further irrigations took place: June 28th 2012. Each treatment received the same amount of water over the course of the experiment: 5 l m^2 on each terrace.

Reference sites

To test the suitability of the three tested restoration techniques, we selected two areas as reference sites: the donor grassland where the hayseed was collected and an abandoned area with an homogeneous topsoil (thickness of about 50 cm) very similar to those of the experimental site, and subjected to spontaneous revegetation from about 9 years (natural revegetation site): mean slope 10°, aspect 222.5°, soil cover 27.5% and surface stoniness 32.5%.

Data collection and analysis

We collected data based on the protocol recommended by the regional administrative authority for monitoring the success of restoration interventions in natural areas (Regione Lombardia, 2011), with some modifications. Specifically, we surveyed 3 vegetation plots of 3 x 3 m in each experimental site and reference area randomly distributed, but avoiding the edges of the terraces. To detect differences that were linked to environmental heterogeneity, we recorded or estimated abiotic factors in June 2012 when vegetation productivity shows the highest levels, such as: a) elevation (m a.s.l.; recorded by GPS), b) aspect (°; recorded by clinometer), c) slope (°; recorded by clinometer), d) stoniness (%; visually estimated by the first author), e) rockiness (%; visually estimated by the first author) and f) maximum stone dimension (cm; measured by ruler). In addition, we collected biotic factors by estimating visually the following parameters (%): g) tree cover, h) shrub cover, i) herb cover and l) moss-layer cover. We also recorded species richness. We estimated plant species cover based on the Braun-Blanquet scale (Braun-Blanquet, 1928) as modified by Pignatti (1953). With the aim of estimating competition, we measured the mean plant height of the herbaceous and the low shrub layers using a ruler. Inside each plot, we also identified four subplots of 20 x 20 cm randomly distributed. These subplots were used to assess the effectiveness of the different restoration techniques by collecting or estimating a) the number of individuals or stems (i.e., species diversity), b) cover (%), c) maximum height (as an indicator of competition), and d) the presence of flowers and fruits (as an indicator of self-propagation) for each species.

To estimate biomass production of the herbaceous layer, we sampled each terrace of the experimental site in July 2012 (3 plots of 1 x 1 m in each terrace). We cut plants at one cm above the ground and oven dried them for almost one week at 60°C. We then weighed the biomass. We also counted the number of live or dead individuals (i.e., mortality) of the planted trees and shrubs in each experimental site.

To explore the existence of significant differences in survival rates of woody plants between treatments we used contingency table and chi-square analysis. During analysis we retained high frequency species (*Quercus pubescens*, *Cotinus coggyria*, *Fraxinus ornus* and *Ostrya carpinifolia*) and grouped the other species with low frequency (less than 5%)

We investigated ecological gradients dependent on the different restoration approaches and plant species patterns in the 3 x 3-m plots with respect to biotic and abiotic factors using Canonical Correspondence Analysis (CCA), which was performed by the CANOCO software.

We calculated and estimated the cost and benefit of the three different restoration approaches of limestone quarries based on three types of indicators: a) economic: including costs for site preparation, herb layer characterization, hydroseeding, and irrigation; to calculate costs, we summed up all the expenses for materials used and for rental of equipment; we then calculated the mean cost per square metre; b) time: considering the time period for restoration actions, monitoring, to have a landscape benefit, to reach the complete site recovery; c) ecosystemic: considering biodiversity and types of species involved in the restoration.

All parameters listed in the cost benefit analysis are self-explanatory with the exception of the “naturalistic value” that refers to the origin of the plant material: high = autochthonous plant material; medium = autochthonous/allocthonous material; low = allocthonous material. The use of this last parameter is in accordance with Yokomizo *et* *al*. (2012) that highlighted cost benefit analysis for the introduction of non native species.

RESULTS

Ecological trends

With respect to abiotic factors, we recorded differences between sites for slope, soil cover, maximum stone dimension and stoniness (Figure 2a). With regard to biotic factors (Figure 2b), we recorded the highest height of the herbaceous layer in the commercial seed site (100 cm), the second highest in the hayseed (93.3 cm) and the lowest height in the no herb site (16.3 cm). The greatest species richness (Figure 2c) was found in the donor grassland (28 species) followed by the natural revegetation site (20 species) and hayseed site (16 species). The lowest value was recorded in the commercial seed site (10 species). No herb site showed the lowest vegetation cover and the lowest herb layer cover (15% and 10%, respectively). With the exception of the natural revegetation site, all sites showed very high vegetation and herb cover of over 80% (see Supplementary Material S7). We recorded the highest maximum stone dimension in the natural revegetation site (46 cm) whereas no stoniness was observed in the donor grassland and the experimental site showed similar values (23 cm in the hayseed site, 19.3 cm in the no herb site, 18.7 cm in the commercial seed site).

The CCA analysis plotted species distribution and experimental/references sites according to biotic factors of vegetation structure and abiotic factors (Figure 3; Table 2). The CCA resulted in medium eigenvalues and high cumulative percent variances for the species data (73.8 for the first three axes). The four eigenvalues were canonical, corresponding to axes that were constrained by the environmental variables. Among the abiotic factors maximum stone dimension was significant (LambdaA = 0.26; F = 3.29; p = 0.020). Among biotic factors, the following ones were significant: herb layer (LambdaA = 0.49; F = 0.17; p = 0.001), species richness (LambdaA = 0.38; F = 3.40; p = 0.013), and moss layer (LambdaA = 0.21; F = 2.14; p = 0.048). As expected, plots surveyed in the same site (experimental or reference) grouped together or along the same trend. Hayseed site and donor grassland plotted towards an increase of species richness (16 and 20 species, respectively); main species reference were *Anthyllis vulneraria*, *Dactylis glomerata*, *Medicago lupulina*, *Sanguisorba minor* and *Trifolium pretense* (Figure 4). Commercial seed site plotted along a decrease of species richness (6 species; Figure 4); main reference species were *Festuca rubra* and *Lolium perenne*. *Lolium perenne* showed the highest cover in commercial seed site, reaching also 100% of the total (Figure 4). No herb site plotted toward a strong decrease of herb layer; main reference species were *Setaria viridis* and *Senecio inaequidens*, two ruderal invasive non-native species in Italy. Natural revegetation site plotted toward an increasing of maximum stone size and moss layer and toward a decreasing of herb layer; main reference species were *Arenaria serpyllifolia*, *Lotus corniculatus*, and ruderal and/or invasive non-native species such as: *Daucus carota*, *Picris hieracioides*, *Setaria viridis* and *Senecio inaequidens*. The detailed analysis of species mainly contributing to the percent cover and abundance on the subplots is shown in Figure 4.

Short term monitoring of the restoration approaches

We recorded the highest number of dead trees and shrubs on commercial seed site (74.49% in mean) for all the planted species; in particular, *Corylus avellana*, *Quercus pubescens* and *Ostrya carpinifolia* showed mortality over 80% in commercial seed site (Figure 5). No herb site showed the lowest mortality, that was lower than 20% for most species (4.08% in mean). We recorded intermediate values of mortality on hayseed site (18.37% in mean). Contingency table analysis found that different restoration approaches have a significant influence on tree survival (Chi-square = 39.17 df = 8, $p < 0.0001$).

The biomass production was higher in commercial seed site (355.23 g; at about the same mean plant height of the herbaceous layer for commercial seed site and hayseed site: 100 cm and 93.33, respectively). We recorded lower values in hayseed site (190.19 g) and no herb site (30.70 g).

Cost-benefit analysis

Hayseed site showed the highest cost (Table 3), while no herb site was the less expensive technique. Main differences among techniques were due to the collection and characterization of the hayseed, both regarding cost and time required. However, both hayseed and commercial seed sites showed an immediate green effect and an expected lower term for restoration. Qualitative ecosystem indicators such as number of species (biodiversity), and the number and cover of non-native species showed that hayseed site was the most advantageous in term of naturalistic value, similar to the natural or semi-natural surrounding areas.

DISCUSSION

An evaluation of success can only be conducted after several years because future vegetation dynamics are not always easy to predict due to, among other reasons, the varying influence of the surrounding vegetation over time and the possible deterioration of commercial species, that only become obvious many years after seeding (SER, 2004; Zhang *et al.*, 2006; Martínez-Ruiz *et al.*, 2007; Tischew & Kirmer, 2007; Prach & Hobbs, 2008). However, preliminary short-term considerations, when compared with reference sites, are very useful when monitoring the restoration and in the determination of whether post-transplantation treatments are required (Hobbs & Norton, 1996; Hobbs & Harris, 2001; Mendez & Maier, 2008).

With the exception of the semi-natural reference donor grassland, the abiotic conditions in each site were similar. In particular, the soil in each experimental area was homogeneous and only the abiotic factor "maximum stone dimension" was statistically significant between areas. However, this finding was incidental because it is very difficult to completely normalise this factor during site preparation. Consequently, and as hypothesised, biotic factors influenced by the three different techniques directly affected the species composition and thereby the vegetative structure, such as herb layer percent cover and the number of species. Thus, differences in vegetation features between the experimental sites primarily depended upon the restoration approach used. Vegetation parameters are very useful to characterise the state of the restoration: for example, vegetation structure provides information on the habitat characteristics, ecosystem productivity and vegetation succession, whereas species composition and diversity are indicators of the susceptibility to invasions and ecosystem resilience (Ruiz-Jaén & Aide, 2005).

Our experiment showed that, in general but in particular in the commercial seed site, the use of an artificial herbaceous layer that was too dense resulted in competition with the transplanted shrubs and trees and caused high mortality of the latter, especially the light-demanding species, such as *Quercus pubescens*. Our findings are consistent with those of Davis *et al*. (1998) and Gakis *et al*. (2004). The competition between herbaceous plants and tree seedlings for water and light especially in the early stages of their establishment, represents a limiting factor for tree survival and growth. It is likely that this trend is also due to micro-climatic site conditions where higher temperatures and humidity are noted in the dense herbaceous layers (Zhang & Chu, 2011; Mantilla-Contreras *et al*., 2012). For this reason the simultaneous application of tree planting and high density seeding approaches seems few compatible. To overcome this issue different strategies could be adopted: a) tree and shrub planting could be carried out in different times than herbaceous layer, so that they are more developed when the herb layer is individuals sown; b) to transplant older and more resistant tree and shrub individuals at least 5 years old; c) no planting of trees and shrubs; and, d) the sowing density of the herbaceous layer could be modified, i.e. significantly reduced.

In particular, both no planting of trees and shrubs, or applications of significantly less seeds when trees or shrubs are planted (point c and d), might provide significant savings from an economical point of view, yet still satisfactory results from an ecological point of view. In any case, simultaneous application of tree planting and high density seeding approaches should be optimised and better modelled. Based on previous technical studies (Bernini *et al.*, 2003), 20-30 g/m^2 is an optimal sowing density for hydroseeding to ensure a rapid establishment of vegetation, to control erosion, to rebuild soil, to maintain biodiversity and ecosystem functions, to provide wildlife habitats and to improve the aesthetic appeal of the quarry (Burton *et al.*, 2006). This sowing density was lower than we used for the commercial seed site but higher than the hayseed site, which comprises vegetative parts other than seeds in the last.

Nevertheless, we found that species density and, indirectly, the "immediate green effect" and the minimisation of short-term erosion, should not be considered as an indicator of the success of the restoration, by itself. The creation of an overly monotonous, dense and compact herb layer dominated by a few competitive grasses, as in the case of commercial seed site, could divert or arrest the succession over the long-term because of the unsuitable specific composition (Prach, 2003). Indeed, artificially introduced species could compete with the valuable autochthonous colonising species from the quarry surroundings, thereby resulting in very low levels of biodiversity in the long-term and impeding the recovery of a valuable target ecosystem (Bernini *et al.*, 2003; Hodačová & Prach, 2003; Moreno-de las Heras *et al.*, 2008; Ballesteros et al., 2012). Moreover, commercial seed site was dominated by artificially selected genotypes of foreign origin that could be a potential threat, i.e., genetic pollution, for the local flora. In contrast, no herb and natural revegetation sites showed high frequencies of ruderal and invasive non-native species.

The height and the cover of the herbaceous layers were very similar between the hayseed and commercial seed sites and were higher when compared with no herb and natural revegetation sites, as also demonstrated by the high, fast biomass production with values dependent on the sowing density. The rapid establishment of a continuous herb layer in the hayseed site may depend upon the sowing technique, i.e., the "potentiated hydroseeding". Indeed, the mulch is an insulates heat, absorbs and retains water, reduces soil evaporation and plant transpiration and represents a "buffer layer" on the beating action of the meteoric water (Cook *et al.*, 2011). Moreover, it favours the infiltration of water drops in the soil, reduces the superficial water runoff, protects soil and the seedbed from wind and water erosion, thereby creating an ideal microclimate for seed germination (Kirmer & Mahn, 2001; Muzzi & Rossi, 2003). Data from the literature indicate that in addition to sowing technique, the time of sowing and post-plantation irrigation could be critical for successful restoration (Glenn *et al.*, 2001; Brofas & Karetsos, 2002). We selected to transplant in autumn, which is typically recommended in areas where summers are characterised by soil-water deficiency and precipitation is low and erratic. Indeed, high precipitation at the beginning of spring and autumn, supported by artificial irrigation for at least 3-6 months after the restoration could be fundamental for plant establishment and for maintaining suitable temperature above ground (Muzzi & Rossi, 2003; Mendez & Maier, 2008).

Cost-benefit analyses showed that despite the fact that the hayseed site involved the most expensive approach with respect to cost and time, it resulted in a higher species richness, vegetative structure and green effect. Thus, the expected time to recovery of a valuable ecosystem was lower than the other techniques. With respect to ecosystem indicators, native species typically evolve survival mechanisms suited to local conditions, are resistant or resilient to fluctuations and/or sudden changes in environmental conditions, thus a plurispecific autochthonous mixture harvested on quarry natural surroundings, e.g., the hayseed, is recommended to facilitate the colonisation by a self-sustaining valuable plant community, provide a more diversified soil layer, maintain local species diversity and minimise human efforts over the medium-long term (Chosa & Shetron, 1976; Khater *et al.*, 2003; Mendez & Maier, 2008). Previous authors have emphasised that native species richness is positively correlated with both soil microbial and invertebrate communities (Wheater & Cullen, 1997; Zhang & Chu, 2011). Moreover, the deliberate introduction of native plant species could overcome the lack of suitable local plants capable of colonising the quarry site and could supply food for wildlife thereby avoiding the massive colonisation of ruderal or non-native species (Chosa & Shetron, 1976). In contrast, in the case of Botticino quarries, spontaneous succession such as no herb and natural revegetation sites, should be avoided for the establishment of the herbaceous layer. At approximately a decade after abandonment, the natural revegetation reference site showed a very scattered vegetative cover (Angiolini *et al*., 2005) and a high frequency of ruderal/non-native species such as *Senecio inaequidens* and *Setaria viridis*. Thus, the use of autochthonous hayseed resulted in the most favourable restoration of the limestone quarry of the Botticino extractive basin.

CONCLUSION

The use of a commercial seed mixture created a monotonous and compact herb layer that competed with the shrub and tree layers; in contrast, the mere planting of shrub and tree species was the most economical technique but discouraged biodiversity. Although the use of hayseed resulted in the highest cost in both economic price and time, it ensured the highest biodiversity, vegetative structure and green effect.

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TABLES

Table 1. Species and number of plants planted in each terrace

No. of plants	Species
35	*Quercus pubescens*
15	*Cotinus coggygria*, *Fraxinus ornus*, *Ostrya carpinifolia*
5	*Sorbus torminalis*
3	*Corylus avellana*, *Prunus mahaleb*
1	*Acer campestre*, *Celtis australis*, *Cornus sanguinea*, *Crataegus monogyna*, *Cytisus scoparius*, *Rosa canina*, *Ulmus minor*

Table 2. (a) Eingenvalues of the CCA and **(b)** Significance of the environmental variables

(a)

Axes	1	2	3	4	Total inertia
Eigenvalues	0.626	0.461	0.363	0.126	1.966
Species-environment correlations	0.996	0.984	0.997	0.968	
Cumulative % variance of species data	31.9	55.3	73.8	80.2	
Cumulative % variance of species-environment relation	33.4	58.0	77.3	84.1	
Sum of all eigenvalues					1.966
Sum of all canonical eigenvalues					1.876

(b)

	Marginal Effects	Conditional Effects		
Variable	Lambda1	LambdaA	P	F
Herb layer_cover	0.49	0.49	0.001	3.69
Species richness	0.39	0.38	0.013	3.40
Maximum stone dimension	0.13	0.26	0.02	3.29
Moss layer cover	0.33	0.21	0.048	2.14
Stoniness	0.45	0.06	0.474	0.97
Soil cover	0.42	0.09	0.277	1.25
Slope	0.31	0.12	0.116	1.68
Mortality	0.25	0.08	0.454	1.27
Aspect	0.22	0.07	1.000	0.00
Shrub layer	0.21	0.07	0.473	0.99
Rockiness	0.15	0.06	0.523	0.84
Diameter at the base of the stem	0.10	0.08	0.334	1.16

Table 3. Cost-benefit analysis of the tested approaches; economic costs are expressed as net price/m^2 and are based on our practices; *calculated on 100 m^2

Economic indicator	Cost - benefit	Hayseed	Commercial seed	No herb
Direct cost	Mechanical ground preparation	€ 1.67	€ 1.67	€ 1.67
	Tree and shrubs plantation			
	Cost of plant material	€ 0.59	€ 0.59	€ 0.59
	Plantation	€ 0.50	€ 0.50	€ 0.50
	Herb layer			
	Collection and characterization of the hayseed	€ 2.50	-	-
	Cost of commercial seed mixture	-	€ 0.20	-
	Hydroseeding	€ 1.20	€ 1.20	-
	Irrigation for the first year	€ 1.77	€ 1.77	€ 1.77
	Total cost	€ 8.22	€ 5.92	€ 4.52
Time	Monitoring	almost 5 years	almost 5 years	almost 5 years
	Time required for restoration actions	~ 30-45 days	~ 5-10 days	~ 5 days
	"Green effect" on landscape	immediate	immediate	medium/long term
	Expected time for recovery	short/medium	medium	Long
Ecosystemic	Naturalistic value	High	Low	Medium
	No. of herbaceous species*	6	4	5
	No. of herbaceous non-native species or commercial varieties*	2	3	2
	Invasion rate by non-native species	Low	Very low	High

FIGURES

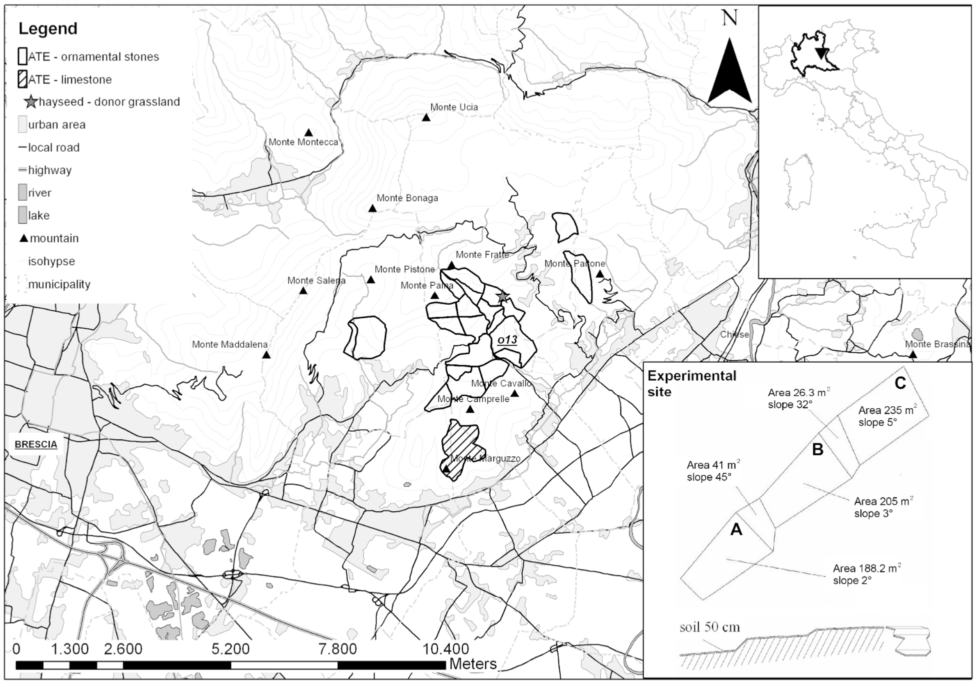
Figure 1. Study area and experimental site (data from: Geoportale della Regione Lombardia, http://www.cartografia.regione.lombardia.it/geoportale/ and Geoportale della Provincia di Brescia, http://sit.provincia.brescia.it/PTCP). Experimental site is located in the "Ambito Territoriale Estrattivo" ATE 13 (indicated wit o13) that is an area where the extractive activity is allowed. In the right boxes the geographical location (upper box) and the geometry of experimental terraces (lower) are shown.

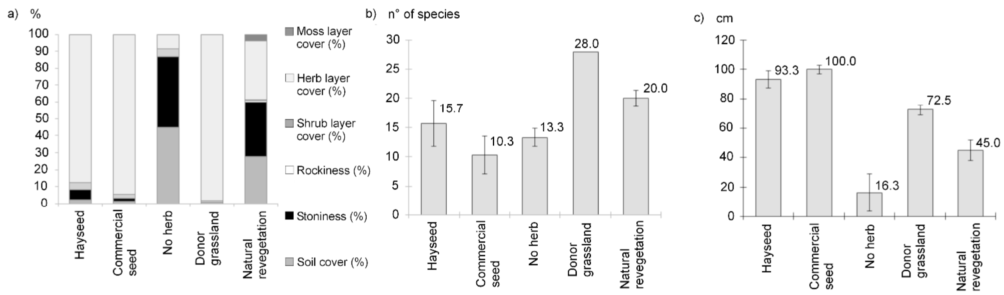
Figure 2. **a)** Relative percent cover (mean) of the abiotic and biotic factors recorded within plots; **b)** mean species richness (No) and **c)** mean height of the herbaceous layer (cm)

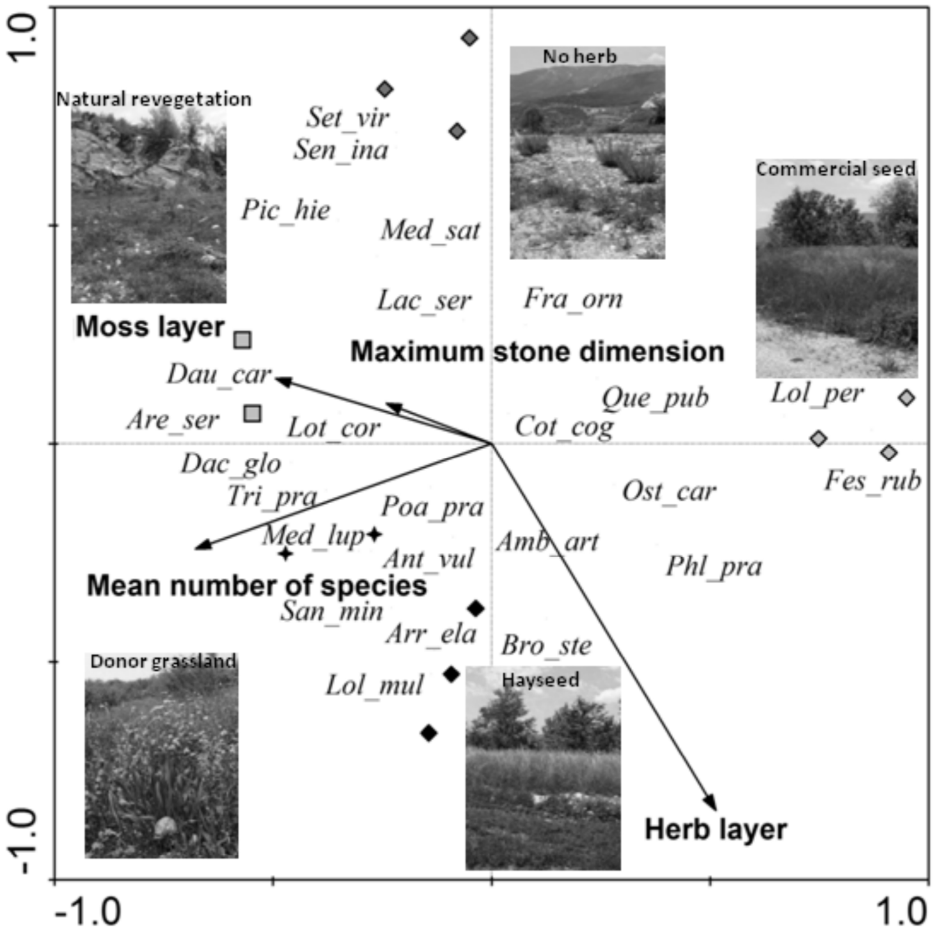
Figure 3. CCA according to biotic and abiotic factors.

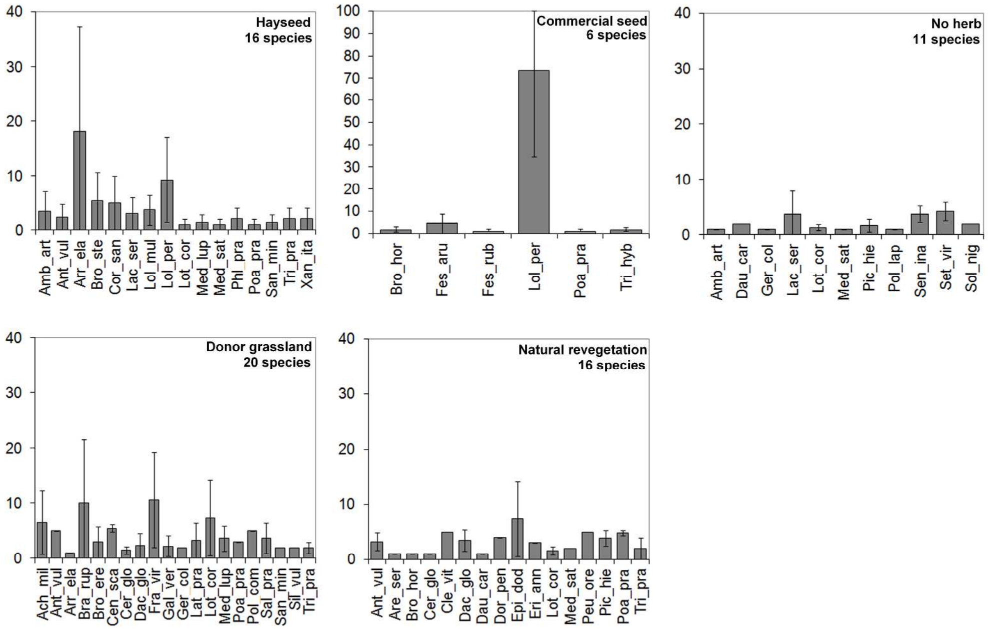
Figure 4. Means of plants species cover (%) on the subplot (20x20 cm). Error bar represents standard deviation.

Figure 5. a) Survival of tree and shrub species (%) on the experimental site recorded on the whole terraces. Contingency table statistics (Chi-square) revealed significant differences among the three restoration approaches ($p < 0.0001$). Legend: black: hayseed site; gray: no herb site; pale gray: commercial seed site; **b)** amount of standing biomass during the most productive season (g) and mean plant height of the herbaceous layer (cm) recorded on plots of 1 x 1 m


Legend
ATE - ornamental stones
ATE - limestone
hayseed - donor grassland
urban area
local road
highway
river
lake
mountain
isohypse
municipality
N
Monte Ucia
Monte Montecca
Monte Bonaga
Monte Fratta
Monte Pistone
Monte Salena
Monte Palla
Monte Pallone
Monte Maddalena
o13
Monte Cavallo
Monte Camprelle
Monte Marguzzo
BRESCIA
Chiese
Monte Brassina
Experimental site
Area 26.3 m2 slope 32°
Area 235 m2 slope 5°
Area 41 m2 slope 45°
Area 205 m2 slope 3°
Area 188.2 m2 slope 2°
A
B
C
soil 50 cm
0 1.300 2.600 5.200 7.800 10.400
Meters


a) %
Moss layer cover (%)
Herb layer cover (%)
Shrub layer cover (%)
Rockiness (%)
Stoniness (%)
Soil cover (%)
Hayseed
Commercial seed
No herb
Donor grassland
Natural revegetation
b) n° of species
15.7
10.3
13.3
28.0
20.0
c) cm
93.3
100.0
16.3
72.5
45.0


1.0
-1.0
-1.0
1.0
Natural revegetation
No herb
Commercial seed
Donor grassland
Hayseed
Moss layer
Maximum stone dimension
Mean number of species
Herb layer
Set_vir
Sen_ina
Pic_hie
Med_sat
Lac_ser
Fra_orn
Dau_car
Are_ser
Lot_cor
Cot_cog
Que_pub
Lol_per
Fes_rub
Dac_glo
Tri_pra
Poa_pra
Med_lup
Ant_vul
Amb_art
Ost_car
Phl_pra
San_min
Arr_ela
Bro_ste
Lol_mul



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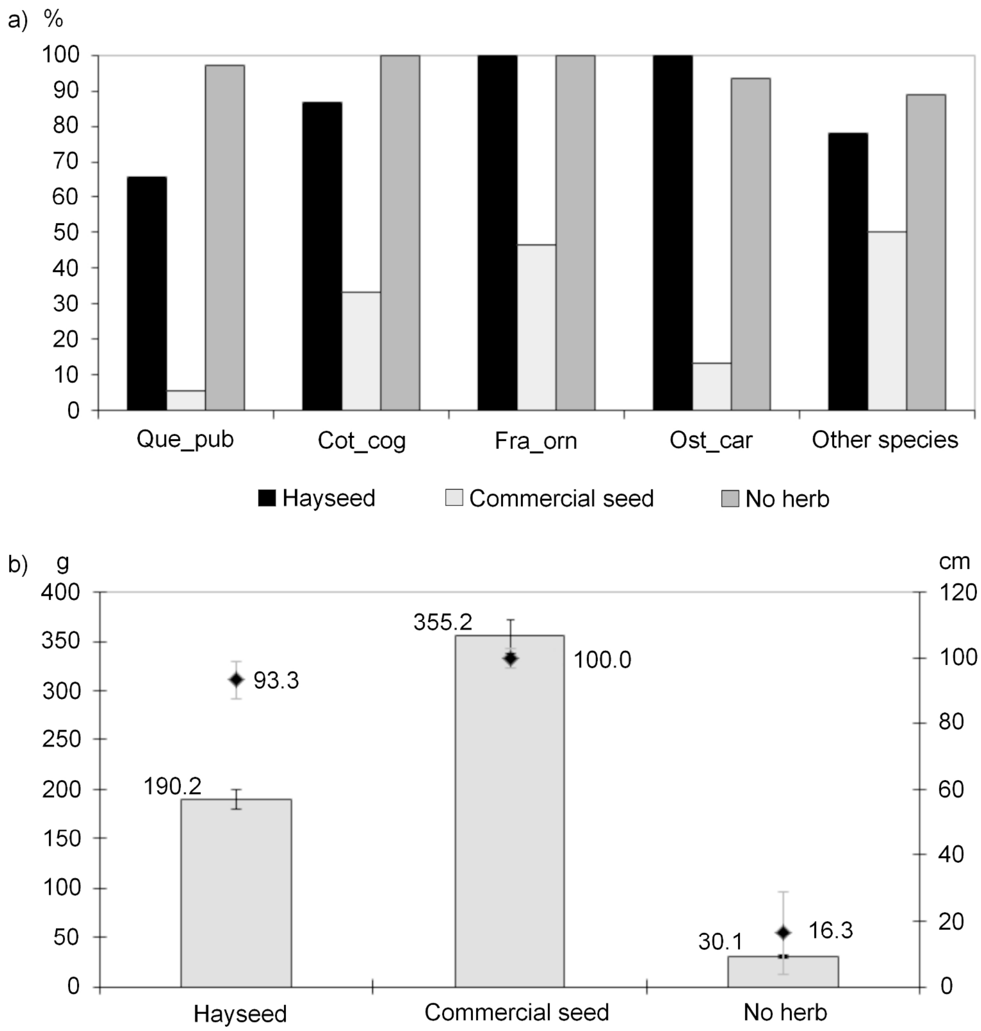
a) %
100
90
80
70
60
50
40
30
20
10
0
Que_pub
Cot_cog
Fra_orn
Ost_car
Other species
Hayseed
Commercial seed
No herb
b) g
cm
400
350
300
250
200
150
100
50
0
120
100
80
60
40
20
0
355.2
100.0
93.3
190.2
30.1
16.3
Hayseed
Commercial seed
No herb