Final Project Report (to be submitted by 20th September 2018)

Instructions:

- Document length: maximum 10 pages, excluding this cover page and the last page on project tags.
- We welcome the submission of Annexes (i.e. bachelor or master thesis, references, species lists, maps, drawings, pictures) to further Heidelberg Cement's understanding and future use of your findings, however they will not be reviewed by the Jury, and we kindly ask for these to be sent separately to the National Coordinators.
- Please use the attached template for species data collected during the project and submit with the project report.
- Word/PDF Final Report files must be less than 10 MB.
- If you choose to submit your final report in your local language, you are required to also upload your final report in English if you wish to take part in the international competition.
- To be validated, your file must be uploaded to the Quarry Life Award website before **20th September** 2018 (midnight, Central European Time). To do so, please log in, click on 'My account'/ 'My Final report'.
- In case of questions, please liaise with your national coordinator.
- You should not publish additional private information in your final report (e.g.: address, day of birth, email-address, phone number), just complete the categories we ask for below under "Contestant profile".

The final reports should comprise the following elements:

For research stream projects:

- Abstract (0,5 page)
- Introduction :
  - For projects that are building upon a previous project, write a summary of actions that were already completed in the previous project.
  - Project objectives
- Methods: a detailed description of the methods used during the project is required.
- Results: the results of the project should be outlined and distinguished from the discussion.
- Discussion:
  - Results should be analysed and discussed with reference to region/country taking into account other publications.
  - Outline the added value of the project for science and for the quarry/company.
  - Recommendations and guidance for future project implementation and development on site is requested. Where possible, please mention the ideal timing and estimated costs of implementation.
- Final conclusions: a short summary of results and discussion.

For community stream projects:

- Abstract (0,5 page)

- Introduction
    - For projects that are building upon a previous project, write a summary of actions that were already completed in the previous project.
    - Project objectives
    - A short description of the site and the team members and the targeted audience of the project.
- Actions and activities: a detailed description of planned or implemented actions and outreach activities done to elaborate the project, list of stakeholders involved.
- Discussion:
    - Project teams should discuss the pros and contra and illustrate experiences.
    - Outline the added value of the project for biodiversity, the society and the quarry / company.
- Deliverables: practical implementation and development recommendations of the project are required. Where possible, please mention the ideal timing and estimated costs of implementation.
- Final conclusions: a short summary of the project findings and discussion.

1. Contestant profile

▪ Contestant name:	**Rodolfo Gentili**
▪ Contestant occupation:	Researcher
▪ University / Organisation	University of Milano-Bicocca
▪ Number of people in your team:	**4**

2. Project overview

Title:	**From time to time from quarry to nature**
Contest: (Research/Community)	Research
Quarry name:	Colle Pedrino

Abstract (max 0.5 page)

In calcareous quarries, quarrying can occur in different spatio-temporal phases during a medium-long time span. The restoration of natural conditions on residual slopes performed during subsequent times of the quarry exploitation, may have different success in terms of quality and recovery of soil, vegetation cover and biodiversity. Since the 2000s, SW sectors of the Colle Pedrino quarry have been exploited in different temporal phases. The abandoned slopes were subject to subsequent restoration actions, carried out by specialized companies, using commercial seed mixes on soil substrates deriving from quarry waste material. However, the results of the restoration actions in quarry area, are rarely monitored over time in order to identify the advantages and disadvantages. Therefore, the aim of this project is to evaluate the success of the different restoration actions performed at Colle Pedrino in the recent past, in terms of edaphic environment, vegetation cover and biodiversity, compared with the surrounding natural areas. The materials and techniques used in the various temporal phases of the slope reclamation and restoration were considered. Taking into account soil characters, twenty-four vegetation plots of 3x3 m were set up, using a stratified sampling on seven restored parcels of different ages inside the quarry and one control area outside the quarry. In order to evaluate the similarity/distance between the parcels, the plots were analyzed with classification (cluster analysis) and ordination (principal components analysis, PCA) methods. After a preliminary analisys some fixed factors in mixed linear models were selected among the environmental variables in order to assess the effect and therefore the success of restoration actions at different parcels over time, in terms of total plant cover, grass cover, number of plant species and number of Lepidoptera: distance from natural areas surrounding the quarry, age of restoration, surface stoniness, amount of fine fraction (<10mm) in the soil material, and soil reaction. A specific objective was to assess the suitability of meadows, present in the quarry's surroundings, to be used as hayseed donors in future revegetation actions.
The results showed that the naturality on the abandoned quarry slopes is primarily dependent on their distance from the natural habitat (grassland) surrounding the quarry. Such habitats act as a reservoir of biodiversity for the recolonization of plant species at first, and then of animals (Lepidoptera). In addition, the characteristics of the material used in the slope reclamation play a key role in influencing both the total grass cover and the levels of biodiversity. Our study also showed that the mixes of commercial species used in the restoration are not very resistant to time and are soon replaced by resident species: 4 years after the restoration actions, at the Colle Pedrino quarry, the majority of species are colonizer from adjacent areas. For this reason, the use of the hayseed could improve the restored quarry areas by increasing the natural regeneration of native species and biodiversity. For the quarry of Colle Pedrino, our field survey has shown that hayseed could be recovered in situ, on grasslands owned by Italcementi-Haidelberg and by local farmers and thus promoting the integration of the quarry in the territorial context, increasing the mountain economy.

Introduction

The main objective of the restoration of quarry areas is to convert areas that are no longer productive and degraded from an environmental point of view into new ecosystems that can support natural environments (Gilardelli et al. 2016a). Excavation activities in a site can take place in different spatio-temporal phases, often over a period of time of more than 10-15 years. Consequently, the ecological restoration of the quarry takes place at different times, using significantly different techniques and materials. In particular, in limestone quarries soil development and the recovery of plant and animal diversity are strongly limited by the characteristics of the waste materials used in the slope reclamation. For instance, the presence of a fine matrix may have a strong influence on slope stability and consequently on soil and vegetation development and characteristics (Gentili et al., 2011). However, the final results of the restoration actions in quarry area, are rarely monitored over time in order to identify the advantages and shortcomings. On the other hand, it is well known that in some mining areas the restoration of biodiversity is left to the spontaneous succession, by harnessing the natural attitude of plants to recolonize the environment and then promote pedogenesis (Prach and Pyšek, 2001).

After the 2000s, the SW sectors of the Colle Pedrino quarry (Lombardy, Italy) have been exploited in subsequent phases. The abandoned slopes were then subject to restoration actions, from the top to the bottom of the slope, in distinct phases over the years 2007-2018. The restoration actions in the different years (parcels) were performed by specialized companies, using different techniques (hydroseeding, material) and mix of commercial seeds and planting stock of trees, without taking into account the soil characteristics and dynamics of the areas. The aim of this project is to evaluate the success of restoration actions performed in different parcels over subsequent years, at the Colle Pedrino quarry, compared with the surrounding natural areas. In particular, hypothesizing that the best performances are primarily dependent on the time span (age of recovery), we will assess which abiotic characteristics (edaphic habitat and site features) of the recovered slope will favour a stable vegetation cover, the colonization of the resident plant assemblage and the biodiversity. A specific objective is to evaluate the suitability of the grassland surrounding the quarry, to be used as hayseed donors in future restoration actions.

Methods

Study area and sampling. This project was performed at the limestone quarry of Colle Pedrino (Lombardy, Italy), which is located in the Bergamo Pre-Alps at an average elevation of about 1200 m. The considered quarry slopes have southern aspects. The mean annual rainfall is about 1400 mm (Ceriani and Carelli, 2000). The average mean annual air temperature of the nearby weather station of Palazzago (340 m asl) is about 12.1°C. Soil temperature class (USDA) is reported to be frigid at the more elevate height (Casati, 2000).Thanks to the cartographic material collected at the Italcementi-Heidelberg offices of Calusco (BG) and interviewing the quarry-men working at Colle Pedrino, it was possible to get information on 7 different parcels of the quarry slope restored in different years. In particular, the parcels recovered in the following years (**Fig. 1**) were considered a: 2007 (S1; years from restoration = 11), 2010 (S2; years from restoration: 8), 2012 (S3; years from restoration: 6), 2014 (S4; years from restoration: 4), 2017 (S5; years from restoration: 1) and 2018 (S6; only slope reclamation; years from restoration: 0). In addition, two further parcels/sites were selected: a) a parcel spontaneously revegetated over a period of about 25 years, in order to assess the similarity of the areas actively revegetated compared to those of a spontaneous succession (code: ND); b) a natural area outside the quarry as a control (code: C; age assigned for analysis purposes 100 years).

The distance of each parcel from quarry boundary was calculated and taken into account for the subsequent analyses.

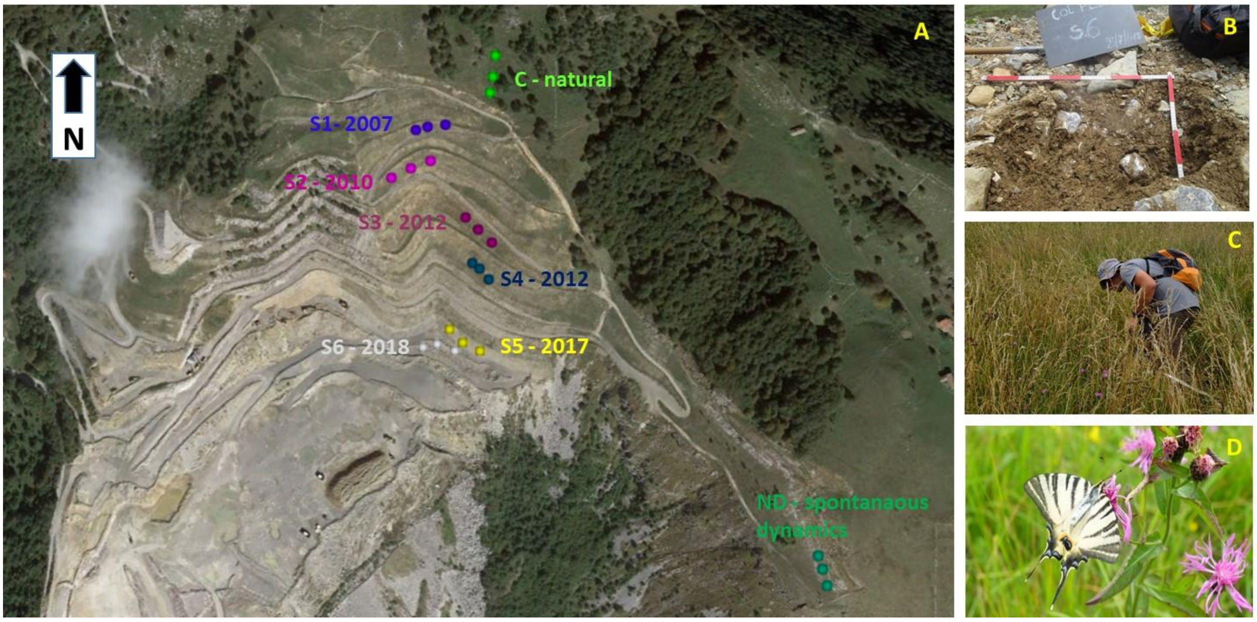

Figure 1: *A) Location of the 3x3 m plots where vegetation and fauna (lepidoptera) data were collected on restoration parcels of different age. The colours indicate the different years of slope reclamation (from S1 to S6) or the control area (C). Soil analyses have been carried out in the same areas. The project took into account: B) Soil characters; C) vegetation and hayseed; D) Lepidoptera.*

Further information was collected on the species' list suggested by Italcementi-Heidelberg to the companies in charge of the restoration action. In particular, based on previous studies the company suggests the use of the following mix: *Bromus erectus*, *Calamagrostis varia*, *Dactylis glomerata*, *Festuca arundinacea*, *F. rubra*, *Lolium perenne*, *Lotus corniculatus*, *Medicago falcata*, *M. sativa*, *Onobrychis viciifolia*, *Poa pratensis*, *Trifolium pratense*. These species have been grouped in a single artificial vegetation plot (MIX, **Fig. 2**) for subsequent comparative analysis.

***Soil characterisation*.** In order to evaluate the role of edaphic and abiotic factors on the different revegetation actions in the restored parcels over time, a soil profile was opened in each parcel/year in correspondence of both within-quarry vegetation plots and outside-quarry control plots. Description was conducted according to national and international manuals (CRA-ABP,2007; USDA 2018). Each horizon from each profile had been chemically and fisically analyzed according to standard national methods. Moreover, coarse fraction of the digged material had been sieved and weighed. All descriptions and results are fully reported in **Supplementary Material 1**).

Plant assemblages and biodiversity. High levels of vegetation cover and plant and animal biodiversity (Lepidoptera) were considered as indicators of environmental quality in the restored parcels. The plant assembleges were investigated in the field both within the different parcels on the quarry slopes, and in the surrounding natural environment within plots of 3x3 m, (3 replicates per year / parcel). The presence and percent cover of each species within the plots were assessed. With regard to Lepidoptera, 4 field trips were carried out, about every 30 days, from May to August within the same plots. The observations were carried out, from about 10h to 15h, ie the hours of maximum activity for these insects; the data collected allowed us to assess the qualitative compositions of the population of Lepidoptera Ropalocera. The biological cycle of butterflies is linked in different ways and in the various stages of their development to different plant species. For this reason butterflies are considered excellent bioindicators, and their presence or absence in a given habitat is indicative of the state of its health. Biodiversity values were measured using the indexes of α- (average number of species present in plots of a parcel), β- (spatial turnover of species between plots of a parcel) and γ-diversity (total number of species in a parcel).

Analysis of local stable meadows for hayseed production. In order to assess the future use of hayseed in the restoration of the Colle Pedrino quarry, the meadows around the extraction sites were analysed, both within the Italcementi-Hedelberg property and in the surrounding areas. The production techniques, using special brushing machines, make it necessary to identify suitable meadow areas (mainly flat and not too steeply sloping lands) that allow mechanical harvesting, and therefore also access to the vehicles. In the following phase, an analysis of the vegetation of meadows was then carried out in order to assess their suitability for seed production, applying the Cerabolini Floristic Quality Index (Cerabolini and Bottinelli, 2015), based on the sum of the individual indices of the species surveyed.

For the first phase, all the areas with a stable meadow within the company's property were analysed, while for the external areas a search for contacts with local farmers was started. The search has allowed to involve the owners of the Agriturismo Coldara of Torre de Busi, which manages a meadow near the Valcava Pass. At the same time, the technical and logistical feasibility was also assessed in order to organise a possible hayseed harvesting for the future. At the end of these selection phases, four grassland areas were found to be suitable, for a total area of about 3.57 ha. For each area, a vegetation survey and a complete floristic list were carried out (**Supplementary Material 2**).

Revegetation with hayseed involves the use of mowing material that includes the reproductive part with the mature seeds (infructescence), using the material on the site to be restored. The hayseed is harvested in species-rich local donor meadows. Previous studies demonstrated that the hayseed can ensure high levels of biodiversity in restoration actions compared to commercial seeds (Gilardelli et al., 2016a).

Data analysis. In order to identify the most successful restoration parcel, at first we investigated those parcels with the highest similarity to the natural grasslands surrounding the quarry. Classification (cluster analysis) and ordination (principal component analysis, PCA) techniques were applied. To evaluate the biodiversity of the different parcels (S1-S6, ND) and of the control (C), biodiversity indices were applied (α-, β- and γ-diversity).

The effects of the restoration actions carried out in subsequent years in the different parcels were evaluated in terms of total vegetation cover (Tot_cover), grass cover only (Grass_cover), number of Lepidoptera (α-Butterfly) and number of plant species (α-Plant) and quantified using linear mixed models. Following preliminary exploratory analyses (not shown) including soil parameters and stational data, 5 fixed nominal factors were considered in the model, resulting the most significant with regards the explained variability: age of restoration (Age), percent surface stoniness (Stoniness), presence of fine fraction in the whole soil <10mm (Fine_particle), pH and distance from natural areas outside the quarry (Grass_dist). The variables were subject to logarithmic transformation to meet the assumption of normality. The parcels (Code) were considered as a random effect factor.

Results

Soil characterisation. The soils described within the quarry area (Table 1), were all formed on anthropogenic materials from quarry activity deposited on the artificial slopes and mechanically compressed before revegetation actions. The landfill material therefore rested directly on the variously fragmented lithological substrate and no traces of the previous soil were found. The soil horizons compared to those of the control area (outside the quarry) was very simplified: (O) Ap (Bw) (C) R with horizons separated by abrupt limits. Soils of older parcels (ND, S1, S2, S3) had a higher complexity with the development of a Bw horizon scarcely differentiated: not or poorly leached showing a more brownish color and a more evident structure than the underlying C horizon, if present above the rock (R horizon). C horizon was mainly made up of coarse fragments of limestone, mechanically fractured before placing the finer material of the deposits. Textural difference between the top and the subsoil seemed to increase with the age of the restored parcels: almost absent in the recent parcels, it is more accentuated in the older ones except for the internal control (parcel ND) which had substantially unchanged values.

The most significant aspect, above all for the root development, was represented by the content of coarse fragments that far exceeded 35% in all horizons, reaching up to more than 75% of the volume in some C horizons. This last, usually, have a matrix supported assembly (S1, S5, S6, ND) in which the voids are filled with fine material, sometimes clast-supported (S3, S4) with voids partially filled and in other cases, even with an open-work organization (S2) with the voids among the fragments not or scarcely filled with fine material (Table 1).

With regard to chemical parameters, these were base saturated soils, generally with a sub-alkaline reaction (pH 7.5-8) which presented an internal trend along the profile with a slight pH increase with depth. The lowest values (6.9-7.5) were found in the superficial horizons that showed a loss of total carbonates, the leaching of which is not only related to the age of restoration but also to a low content of clay (parcels S2, S3). The organic carbon content was obviously very low for the soils of more recent revegetation (parcels S6, S5) with values <0.5% while it tends to increase towards values of 2% with the age of the restored parcels. Exceptions to this are older plots (plots 1 and ND) which showed a lower content between 1.3 and 1.6%. With regard to the content of K^+ and ECC, there was a progressive decrease from the most recently deposited materials (plots S6 and S5) to the older ones. Phosphorus, measured only for superficial horizons, always exhibited very low values, especially in consideration of the possible greater unavailability for plants due to the presence of total carbonates.

Table 1: *Main granulometric, textural, horizon and chemical characteristics of the soils surveyed in the study area. Top: surface horizons (0-20 cm); sub: deep horizons (20-40 cm); Sa= Sand; Si=silt (silt), Cl=clay (clay). C_org = Organic carbon; P_ass= Assimilable phosphorus; ECC = Exchange cation capacity. The complete soil analysis is reported in Supplementary Materials 1*

a)

Parcel	Year	COARSE FRAGMENTS						TEXTURE							
		Surface stoniness	>75 mm	50 mm	20 mm	10 mm	<10 mm	Sa_top	Si_top	Cl_top	Sa_sub	Si_sub	Cl_sub	CLASS top	CLASS sub
		[%]	weight % (whole soil)					weight % (<2mm fraction)							
S1	2007	65	0	24	24	12	41	41.1	38.1	20.8	34.6	33.8	31.6	F	FA
S2	2010	40	0	5	18	15	62	39.0	53.1	7.9	46.7	35.3	18.0	FL	F
S3	2012	30	0	8	15	11	66	37.4	49.0	13.6	36.0	47.1	16.9	F	F
S4	2014	50	40	14	9	4	34	35.6	43.5	20.9	31.5	43.8	24.7	F	F
S5	2017	60	30	12	17	0	41	32.2	38.0	29.8	37.2	35.8	27.0	FA	FA
S6	2018	75	19	11	15	0	54	36.9	38.0	25.1	37.6	37.3	25.1	F	F
ND	2000	60	9	8	17	7	60	49.0	27.4	23.6	46.1	30.5	23.4	FSA	F
C	?	5	0	0	0	0	100	59.5	35.6	4.9	36.8	50.1	13.1	FS	FL

b)

Parcel	Year	HORIZON (depth)			ROOT	pH_H₂O		C_org		P_ass	Ca		K		ECC	
		Mineral		Organic												
		top	sub	/	depth	top	sub	top	sub	top	top	sub	top	sub	top	sub
		cm			cm			g/kg		mg/kg	cmol(+)/kg		cmol(+)/kg		cmol(+)/kg	
S1	2007	16	24	4	40	7.7	7.9	16.3	6.4	2.1	15.9	13.8	0.2	0.2	15.3	12.1
S2	2010	17	24	6	24	6.9	7.8	20.8	5.2	3.4	10.5	9.6	0.2	0.1	11.9	7.4
S3	2012	20	34	0	34	7.5	7.7	20.1	15.4	3.0	13.7	14.9	0.1	0.1	14.2	15.3
S4	2014	10	23	0	23	7.7	7.8	10.6	7.0	10.5	11.6	12.2	0.2	0.2	11.8	12.7
S5	2017	16	35	0	40	7.9	7.9	4.0	4.0	5.7	12.7	11.6	0.4	0.2	7.9	8.8
S6	2018	0	40	0	=	8.0	8.0	4.4	4.4	4.1	11.7	11.7	0.2	0.2	8.4	9.6
ND	2000	17	40	0	37	7.5	7.9	13.7	6.4	4.9	21.8	15.6	0.3	0.2	15.4	14.0
C	?	25	60	2	>60	5.4	5.4	54.3	14.6	10.88	11.4	1.9	0.87	0.15	24.45	12.22

Plant assemblage and biodiversity*.* The classification of the vegetation plots, based on floristic composition and species cover, showed that the plots tend to group on the basis of the year of restored parcels and, as expected, grouping the control plots (**Fig. 2AB**). The most recent plots, S6 (2018) and S5 (2017), the first one surveyed in a parcel still to be restored and the second one in a parcel just recovered, are the ones most separated from the others: a) the S6 plots included only a few colonizing species; b) the S5 plots included only the species used in the commercial mixes. The plots left to spontaneous renaturation (ND), since the end of the 1990s, were the closest (i.e. similar) to the control plots (C; **Fig. 2AB**) surveyed in the natural areas outside the quarry; the ND plots also grouped with the oldest plots inside the quarry (S2 and S1).

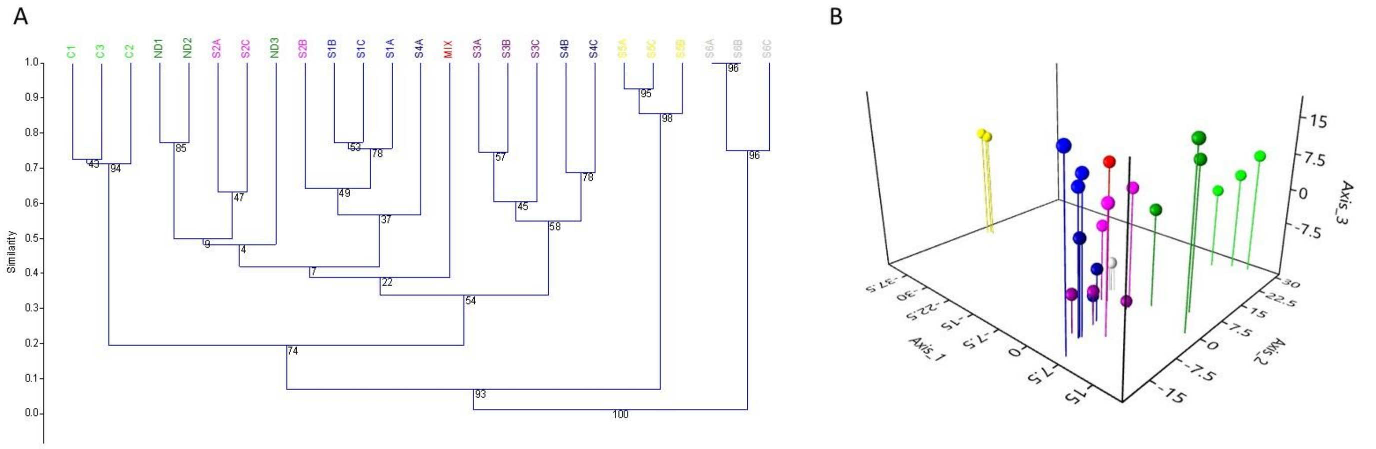

Figure 1: *Cluster analysis with bootstrap values at branches (A) and principal component analysis (PCA; B) of the vegetation plots investigated at the Colle Pedrino quarry. The MIX (red) survey includes the commercial species suggested by the Italcementi-Heidelberg protocols, artificially grouped in a plot. Same color of the objects in cluster analysis and in PCA, corresponds to plots surveyed on the same restored parcel on control areas.*

Biodiversity, in terms of α- and γ-diversity (both for animals and plants) was as expected the highest in the control plots (C) and in the area left to spontaneous succession (ND). Within the quarry, the indices of α- and γ-diversity were the highest in the S3 plots (α=23.6 ±2.3; γ=38), restored in 2012 and secondarily in the S2 plots (α=23.6 ±2.1; γ=36), restored in 2010; these values were therefore higher than those of the S1 plots (α=20.6 ±4.5; γ=29), the oldest within the quarry. For Lepidoptera, α- and γ-diversity increase with the increasing age of the plots (Table 1b).

With regard to β-diversity, the highest values were found in the S3 plots (β= 0.38 ±0.06), for plants and in the S5 plots (β = 0.73 ±0.46), for Lepidoptera (**Fig. 3**).

In the study area, invasive species were numerically scarce in all plots, although the species *Senecio inaequidens* had invasive behaviour over the entire excavated area, colonizing it in a widespread manner.

Table 1: *Mean values of biodiversity indices (± standard deviation) by parcel/year and for controls and presence of invasive alien species. α-diversity = species richness; β-diversity = Witthaker index; γ-diversity = total number of species per parcel.*

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**C**	**ND**
a) Plant								
α-diversity	20.6 (±4.5)	23.6 (±2.1)	23.6 (±2.3)	14 (±5.2)	6.3 (±0.5)	2 (±0)	35 (±2.5)	27 (±2.5)
β-diversity	0.29 (±0.31)	0.32 (±0.31)	0.38 (±0.06)	0..37 (±0.10)	0.16 (±0.08)	0 (±0)	0.30 (±0.10)	0.27 (±0.04)
γ-diversity	29	36	38	23	8	2	52	38
Alien species	1	2	1	1	0	1	0	1
b) Butterfly								
α-diversity	6 (±0)	5 (±1.73)	2 (±1)	2.33 (±0.58)	1 (±1)	1 (±0)	14 (±1)	13 (±1.73)
β-diversity	0.32 (±0.03)	0.39 (±0.01)	0.66 (±0.06)	0.51 (±0.14)	0.73 (±0.46)	0.33 (±0.29)	0.56 (±0.19)	0.45 (±0.12)
γ-diversity	11	8	6	5	2	2	28	27

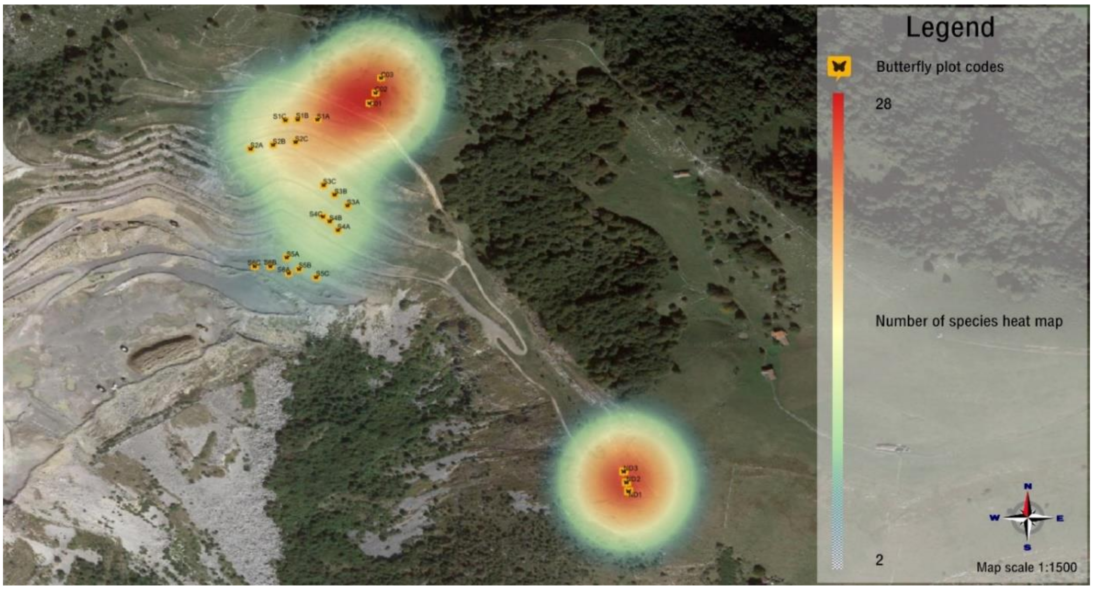

Figure 2: *Concentration map of the number of species in the investigated plots (heat map). From the spatial analysis it is evident that the greatest number of Lepidoptera is greater in areas close to the quarry boundaries and in the control.*

The results of the mixed linear models showed a clear dependence of the restoration success (in terms of vegetation cover/grass cover and biodiversity) on the distance from the natural areas outside the quarry (Grass_dist), which is highly significant in the 4 models considered (**Table 2**). Stoniness was found to have a significant effect on grass cover and plant species richness. The age since restoration (Age) had a significant effect on the number of plant species (**Table 2; Supplementary Material 3).**

Table 2: *Fixed effects for some environmental factors, characterizing slopes subject to restoration, of mixed linear models for total species cover (Tot_cover), grass coverage only (Grass_cover), number of plant species (α-Plant) and number of Lepidoptera (α-Butterfly). The environmental factors considered are: distance from natural areas outside the quarry (Grass_dist), age of restoration (Age), surface stoniness (Stoniness), the presence of a fine fraction <10mm in the soil layer (Fine_particle), and soil pH.*

	DF	Trend	F-value	p-value		DF	Trend	F-value	p-value
a) Total_cover					***c) α-Plant***				
(Intercept)	14	+	45.81041	<0.0001	(Intercept)	14	+	869.9152	<0.0001
Grass_dist	**14**	**-**	**6.54188**	**0.0228**	**Grass_dist**	**14**	**-**	**224.2656**	**<0.0001**
Stoniness	4	-	0.65891	0.4625	**Stoniness**	**4**	**-**	**16.726**	**0.015**
Fine_part	4	-	0.15046	0.7179	Fine_part	4	+	0.1501	0.7181
Age	4	+	0.58401	0.4873	**Age**	**4**	**-**	**9.5972**	**0.0363**
pH	14	+	0.13239	0.7214	pH	14	-	0.0755	0.7875
b) Grass_cover					***d) α-Butterfly***				
(Intercept)	14	+	115.2656	<0.0001	(Intercept)	14	-	54.92069	<0.0001
Grass_dist	**14**	**-**	**40.79741**	**<0.0001**	**Grass_dist**	**14**	**-**	**31.35596**	**<0.0001**
Stoniness	**4**	**-**	**8.95215**	**0.0403**	Stoniness	4	+	0.02042	0.8933
Fine_part	4	-	0.22371	0.6609	Fine_part	4	+	4.68849	0.0963
Age	4	+	0.05727	0.8226	Age	4	+	2.03104	0.2272
pH	14	+	0.38811	0.5433	pH	14	+	2.15968	0.1638

Analysis of local stable meadows for hayseed production. The vegetation reléves on meadows suitable for the production of hayseed accounted for 83 plant species, most of which are typical of dry grasslands and optimal for revegetation activities, such as: *Bromus erectus*, *Arrhenatherum elatius*, *Dactylis glomerata*, *Holcus lanatus*, *Lolium perenne*, *Lotus corniculatus*, *Lolium pratense*, *Trifolium pratense*, *Centaurea nigrescens*, *Achillea millefolium* and *Ranunculus acris*. The average number of species per meadow is 43. In addition, some species of floristic value, such as *Gentiana cruciata*, *Galium rubrum* and *Trollius europaeus,* were found.

The application of the Quality Index, deriving from the sum of the index for each species for each meadow, allowed to assign to all the meadows a positive rating for the collection of hayseed, varying from satisfactory to good (for 3 meadows out of 4; **Table 3**). Therefore, considering the individual species that had a medium-high quality score, the percentage of valuable species for each grassland area was calculated. In this case the data are also encouraging, since all the meadows scored a high presence of valuable grassland species that was equal to or higher than 80%. If from a floristic point of view the meadows are all suitable, it is important to point out that the meadow VCV01 (**Fig. 4**) was a very shrubby and would require a restoration intervention by eliminating the shrub component (mainly *Rosa canina*) in order to proceed with the harvesting of hayseed.

Table 3: *Summary of data referring to the quality of the selected meadows*

Grassland	Properties of Italcement	Area (m^2)	I.Q.	Rating	Presence of species of value for hayseed
VCV 01	SI	4 327	191	satisfactory	80.00%
VCV 02	SI	7 116	203	good	83.33%
VCV 03	NO	10 669	216	good	83.72%
VCV 04	NO	13 647	258	good	87.23%

Taking into account the results obtained, it is possible to foresee the amount of hayseed production. Considering average values in terms of yield of meadows and use of hayseed for revegetation actions, i.e. considering a yield of 50 kg/ha and a sowing at density of 30 g/m2, it is possible to estimate an annual production of about 178 kg of hayseed, useful for restoring an area of 5950 m2. Despite these values have to be considered as indicative due to a series of factors that vary from season to season, they give a useful indication for starting the production and use of local hayseed (**Fig. 4**).

Figure 4: *On the left, the grassland areas identified as suitable for the hayseed harvesting. Example of a possible donor meadow on the right (VCV03)*

Discussion

The results of the present work carried out at the Colle Pedrino quarry (BG, Italy) show that the restoration of natural conditions in the quarry slopes subject to revegetation is primarily dependent on the recolonization potential of plant and animal (Lepidoptera) species (distance from quarry surrounding), which grow in the natural areas surrounding the quarry. On the other hand, the characteristics of the landfill material (soil and stoniness) used for slope reclamation, plays a key role in influencing both the plant cover (grasses) and the levels of biodiversity. For example, in our study the highest levels of plant biodiversity within the quarry area (excluding the parcel subject to a spontaneous revegetation for more than 20 years) are found in the parcel S3 showing best pedologic characteristics, not in the most ancient parcels more close to natural areas (S1 and S2) . In particular, in the parcel S3 an higher content of fine particles (less stoniness) and less surface erosion, determined improved horizon development and leaching processes than in the oldest areas (S1 and S2; as one would expect). This lead to less alkaline soil reactions. Therefore, these results seem to diverge from the expected assumption that the better restoration conditions were primarily controlled by the restoration age.

With regard to vegetation/grass cover and biodiversity, our results are, as a general rule, in agreement with previous observations (Prach and Řehounková, 2006; Trnková et al., 2010) who found that the characteristics of the site, the surrounding vegetation and the character of the surrounding landscape (land cover) influence the spontaneous succession of vegetation within the quarries. Similarly to our results, they also found that graminoid species are the most successful in the first years of succession (4-10 years). Several studies on the successions in limestone quarries support this trend (Kather et al. 2003; Gilardelli et al. 2016b). It should be also noticed that in the Colle Pedrino quarry, after just two decades after abandonment, the parcels left to spontaneous recolonization (ND) has highest levels of similarity compared with the control area outside the quarry. Equally, the richness of Lepidoptera is quite low in very recent plots and high in the ancient ones, in agreement with the results of Frouz et al. (2008) that pointed out that fauna does not colonizes the neo-formation areas without vegetation. However, in our work, the age factor of the restored parcel was only significant, for the number of plant species that colonize the quarry over time, not for what concerns the vegetation (grass) cover. For such a reason, it is evident that the effects due to plant succession are counterbalanced by those of soil characters (stoniness).

The soil stoniness is a factor rather dependent on the extraction technique of the calcareous material, the production process of waste and the characteristics of such waste in terms of grain size. Previous studies have shown that this factor is one of the main environmental filters that limits the establishment of plant species and explains the high levels of ecological variance of plant communities living in quarry areas (Gilardelli et al. 2015). On the other hand, it should be pointed out that the excessive presence of fine material could cause slope instability and increased risk of surface erosion (Gentili et al. 2011). Therefore, it would be necessary to find the right balance between the grain size composition of the landfill material used in the slope reclamation, which favours the use of fine material while preserving the stability of the slope. In this direction, specific studies at the site level would be necessary.

Our study also showed that the mixtures of commercial species used at the Colle Pedrino quarry have not been very resistant to time and have been soon replaced by local species: 4 years after restoration action, the majority of the occurring species are colonist from neighbouring areas. Despite commercial mixes prepare the ground for the establishment of local species, a direct use of local species could favour a more rapid recovery of natural conditions. In fact, the recent study by Gilardelli et al. (2016a) showed how native plant materials such as hayseed can improve the quarry areas to be restore both by quickly increasing natural regeneration and biodiversity levels similar to those present in natural sites around the quarry and by contrasting the colonization of alien species.

Implication for quarry restoration. Our study suggests several management actions to increase the added value of the restoration actions of the Italcementi-Heidelberg's limestone quarries and in particular the quarry of Colle Pedrino, located in a highly natural context.

a) The weighted use of the seed amount to be used during sowing/hydroseeding operations, on the basis of the distance of the slope from the areas outside the quarry should be considered; therefore, revegetating the areas towards the boundary of quarry using less material (seeds or hayseed) could led to a cost reduction for the company. Indeed, according to our results spontaneous restoration has achieved high levels of naturalness over two decades (observed in the ND parcels of Colle Pedrino). In any case, the slope of the areas to be revegetated and the presence of invasive exotic species have to be considered.

b) Site-specific studies to evaluate the grain size of the landfill material to be used in the modelling of slopes, in order to favour both spontaneous recolonization and safeguard the stability of the slope are recommended. This could led to a higher stability of slopes with lower level of surface erosion and a higher success of revegetation actions.

c) This study encourages, at least in some parcels of the quarry slope to be recovered, the use of hayseed in order to improve and accelerate the natural dynamics by increasing biodiversity within the revegetated areas; this also may contrast alien species colonization and the use of non-native genotypes. For the quarry of Colle

Pedrino, as demonstrated by our investigation, the hayseed could be collected in situ, on grasslands owned by Italcementi-Haidelberg and by local farmers and thus promoting the integration of the quarry in the territorial context, increasing the mountain economy. The production and use of local hayseed for the year 2019, would allow to test the technical potentials of this material; the subsequent monitoring during 2020 could be useful to verify the positive effects (vegetation cover and biodiversity) following the creation of vegetation well-matched with the local ecological context.

Conclusions

Our study highlighted that the naturality (vegetation cover and biodiversity) on the abandoned quarry slopes is primarily dependent on their distance from the natural habitat (grassland) surrounding the quarry and then on the characteristics of the material used in the slope reclamation (stoniness). In addition, results also showed that the mixtures of commercial species used at the Colle Pedrino quarry have not been very resistant to time and have been soon replaced by local species. Therefore, this study encourages, at least in some parcels of slope to be recovered, the use of hayseed in order to improve and accelerate the natural dynamics by increasing biodiversity. At Colle Pedrino, the hayseed could be collected in situ, on grasslands owned by Italcementi-Haidelberg and by local farmers and thus promoting the integration of the quarry in the territorial context, increasing the mountain economy. Finally, a special meeting to illustrate the main results of the project will be agreed in the near future with the technical staff of Italcementi-Heidelberg who work in the quarries of the region

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