Vegetation dynamics and restoration trials in limestone quarries: the Botticino case study (Brescia, Italy)

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To all the quarrymen and their families.

A tutti i cavatori e le loro famiglie.

Abstract

Background. All over the world, the naturalistic restoration of abandoned quarry areas represents a real challenge because of the very adverse initial site conditions for plant species colonization. In order to identify the best restoration practices, the present thesis considered, as a case study, the "Botticino extractive basin" (Lombardy, Italy), that is today the second greatest Italian extractive basin and it is famous worldwide for the limestone extraction. In particular, the thesis proposes a multidisciplinary approach based on the study of the local vegetation dynamics, laboratory tests, plant selection for restoration and field experiments to test different restoration techniques.

Methods. Spontaneous vegetation dynamics over the whole extractive basin was studied by an ecological approach through 108 plots, that were carried out on surfaces whose "disused time" from quarry abandonment was known; data were analysed by cluster analysis and Canonical Correspondence Analysis (CCA) and compared to the available data on grassland and woodlands related to the study area. We identified successional phases according to the trend of the most common species whose cover significantly increases or decreases with time. To assess the influence of geomorphological heterogeneity on vegetation succession, we studied morphology and ecology of plant species growing on the following three main geomorphological quarry surfaces: artificial cliffs, dump deposits and quarry platforms; data were subjected to statistical analysis (contingency tables) and CCA.

Since any restoration project should ensure the soil stabilisation of quarry dump deposits, the contribution of herbaceous root systems to limit superficial movements was studied by calculating the root cohesion of three herbaceous species with different types of root systems (*Anthyllis vulneraria*, *Bromus erectus* and *Stachys recta*). To this aim, we made 421 tensile strength tests by the Stable Micro System TA Hd Plus apparatus and we collected root traits by means of image analysis and the software Winrhizo.

In the view of field experiments regarding quarry restoration projects, we carried out some preliminary tests and analysis, such as: a) germination tests on some common species characterizing the local vegetation succession; b) planning the structure and the species composition of the tree layer by using natural woodlands as reference model; c) collection and characterization of the hayseed coming from a "donor grassland" close to the Botticino extractive basin.

We performed field experiments in an apposite site of about 600 m^2 (consisting in three terraces almost horizontal) selected on a fully exploited quarry inside the Botticino extractive basin. Topsoil showed a clayey texture and some physical (e.g. limited soil depth, high stoniness) and chemical (very alkaline pH, low availability of nutrients) limitations. We tested three different restoration methods: 1) terrace A: hydroseeding of hayseed and plantation of shrub and trees; 2) terrace B: traditional hydroseeding of a commercial seeds mixture and plantation of shrub and trees; 3) terrace C: only plantation of shrub and trees without herb layer. In the tree layer of the three terraces, 98 individuals per terrace were planted (main species: *Quercus pubescens*, *Fraxinus ornus*, *Cotinus coggygria*, *Ostrya carpinifolia*). One year after the experiment, we collected vegetation data by means of 3 x 3

m plots in which we measured some species traits, e.g. species cover, mean plant height of the herbaceous layers, number of dead individuals; in addition we collected further species traits for each species in four subplot (20 x 20 cm): e.g. number of individuals, cover, maximum plant height. Data were subjected to CCA and compared to reference sites, i.e. the "donor grassland" and a quarry area spontaneously revegetated.

Main results. Sinchronic analysis of vegetation allowed to identify 10 plant communities and to assigned them to 5 successional phases: a) pioneer phase (0-2 years from abandonment), b) early phase (3-10 years), c) intermediate phase (11-22 years), d) later phase (23-44 years) and e) advanced phase (>44 years).

B. erectus showed the highest value of root cohesion thanks to the high volume of the root system and to the high root tensile strength. Moreover, the selection of herbaceous species should also take into account that root tensile strength strongly decreased with root diameter according to a potential curve and that, as for root volume, it is species-specific.

As regards restoration trials, terrace C showed the lowest vegetation cover (15%), plant height and biomass production (16.33 g/m^2). Terrace B showed the highest herbaceous plant height (100 cm) and biomass production (355.23 g/m^2), although determined only by 6 species (with a clear dominance of *Lolium perenne*). On the other hand, terrace A showed similar plant height (93.3 cm), but lower biomass production (190.19 g/m^2) and a much higher number of species (16), anyway lower than those on the donor grassland (28). As concerns the number of dead tree and shrub in the experimental site, for each single species we recorded the greatest number of dead plants on the terrace B (74.49%), while 18.37% of plants died on terrace A, and only 4.08% on terrace C.

Discussion and Conclusion. The succession in the quarry area was partially similar to a primary one and was affected by environmental factors (e.g. stoniness, slope) immediately after the pioneer phase, so that different types of vegetation community grew on different morphological surfaces at the same time. In particular, dump deposits resulted similar to platforms for ecological features and dominant species traits, while artificial cliffs differed significantly, being mostly affected by rockiness and slope. Considering the time needed for the spontaneous vegetation succession and the cost of restoration interventions, human efforts are recommended on dump deposits and platforms. Results also highlighted that the use of species belonging to the *Poaceae* family (or/and with a fasciculated root system) are recommended for their attitude to stabilize superficial soil layers.The planting of shrub and tree followed by the sowing of hayseed could be a suitable method to ensure a successful restoration. In this way the death of shrub and trees due to the plant competition with the herb layer is avoided and suitable biodiversity levels are ensured.

The present thesis provides a procedure for the restoration of calcareous quarries that can be applied on large scale, directing human efforts to reduce the economic costs for restoration.

Contents

1 Introduction

1.1 The global need of restoration

All over the world, man is the primary cause of ecosystem changes and land degradation, intentionally or not, many human activities affect the environment and the ecosystems, producing relevant impacts, according to disturbance, stress intensity, duration and scale (Hobbs & Norton 1996; Velázquez et al. 2003). Thus, "*the problem now is to know how to dominate the mastery of nature and not nature itself*" (Michel Serres). Many efforts have been made and are required in order to protect living and abiotic resources: e.g. by nature conservation and habitat management policies. Nevertheless, such strategies are not sufficient or applicable if resources have been already damaged irreversibly, or even lost: in such cases, the priority is to reestablish suitable environmental conditions and turn the degraded areas into a new land-use, with protective, productive, aesthetical and/or naturalistic value (e.g. McDonnell & Williams 2000; Del Tredici 2010). The answer to such a need is the "Ecological Restoration", that is an integral part of the conservation biology and land management (Hobbs & Harris 2001). In fact, it can be defined as "an intentional activity that assists, by initiating or accelerating towards the local historical trajectory, the recovery of an ecosystem which has been degraded, damaged, transformed or entirely destroyed by human activities, with respect to its health, integrity (including a critical range of variability in biodiversity, ecological processes and structures, regional and historical context and sustainable cultural practices) and sustainability" (SER 2004). In this context, also the public support is fundamental (van Diggelen et al. 2001).

Restoration approach. The successful reestablishment of a proper self-sustaining vegetation and of a functional community in a degraded context requires a careful and systematic planning and monitoring, especially in complex landscapes (SER 2004). For this reason, a detailed site-specific study is always necessary (van Diggelen et al. 2001) in order to identify the initial environmental conditions such as climate, nutrient availability, physical and chemical soil characteristics, possible pollutant contamination. Further knowledge are required regarding community organization (structure and functions) and responses to disturbance and manipulations (e.g. functional success, durability, system vigor, resilience), historical and cultural background, actual constraints and opportunities and the socio-economic needs (Bradshaw 1984; Young et al. 2005). In particular, a deep knowledge of the causes of the degradation will allow to remove the degrading factors (and not to merely control the negative consequences), that, in some simple situations, could ensure a successful restoration without further interventions (Hobbs & Norton 1996; Hobbs & Harris 2001).

Once the initial situation is defined, a big question comes out: what should be restored? "*Restoration s.s.*" tries to recreate the lost ecosystem that was present before the disturbance, by establishing former functions and characteristic species, communities and structures (Fig. 1.1). Nevertheless, such an approach is possible only in some restricted conditions at a local scale, because of limitations at higher levels, in relation to high costs, land-use conflicts and long distances effects (van Diggelen et al. 2001). Moreover, ecosystems are dynamic realities, so that the exactly recreation of past static compositional or structural features, even if known and desirable, is simply impossible because of irreversible changes, especially on very degraded sites (Hobbs & Harris 2001). Thus, in almost all the cases, only the "*rehabilitation*", i.e. the reintroduction of only some ecosystem functions according to the desired level of structural and functional replication, is possible (van Diggelen et al. 2001). In such a case, the original ecosystem can be used as a model and the spontaneous vegetation dynamics (considered as a continuous replacing of species and community towards a more and more complex ecosystem for structure, diversity and functions) can guide the rehabilitation process (Bradshaw 1984). A third possibility, according to ecological potentials, biotic interactions, abiotic limits, social and stakeholders' needs, is the "*replacement*" of the degraded ecosystem with an another one, even much different from the original one (Hobbs & Harris 2001).

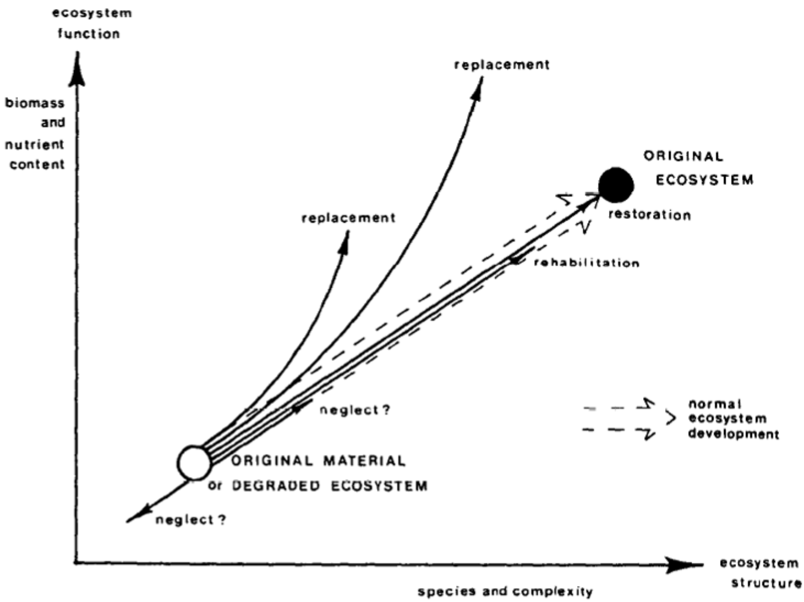

Fig. 1.1 The process of ecosystem development (from: Bradshaw 1984)

Independently by the method, a restoration can be considered successful when the new ecosystem is self-sustaining (no further manipulations are required in order to ensure its health and integrity), functional and comparable to a reference one for species assemblages, structure and functions, besides being integrated and interactive with the surrounding landscape; potential threats should also be reduced as much as possible (e.g. Hobbs & Norton 1996; Zhang et al. 2006).

1.2 Application fields

Being recognized as an academic field only from 1980s, the approach of the Ecological Restoration has been widely applied, directly or not, wherever human activities have caused some form of environmental degradation: e.g. for erosion control, grassing and reforestation, habitat and range improvement (Young et al. 2005), environmental engineering (McVicar et al. 2007), soil treatment or replacement (Bradshaw 1984; Forbes & Jefferies 1999). Thus, the application fields of such a science are numerous. For example, Ecological Restoration is required in order to improve agricultural landscape (e.g. Tsuyuzaki et al. 1994; Lencová & Prach 2011) or to restore damaged or even deleted (semi)natural woodlands, grasslands, heathlands (e.g. Hofmann et al. 1983; Knut et al. 2010) and wetlands such as polluted bogs, eutrophic lakes, river basins and costal environment (e.g. Yetka & Galatowitsch 1999; Matthews & Spyreas 2010). Ecological Restoration has also a key role in contrasting the spread of exotic and invasive plant species (e.g. Kauffman et al. 1995; Bay & Sher 2008) and the natural desertification, especially where it is worsened by human activities (e.g. Wallace & Romney 1980; Marqués et al. 2005). In any case, the biggest efforts are required to restore productive areas that have been drastically disturbed or lost because of urbanization and industrialization processes. An example is the restoration of polluted soils by heavy metals because of mineral extraction (Arienzo et al. 2004), presence of urban and/or industrial areas (e.g. Sopper 1989; Zhang et al. 2006) or dumping of industrial wastes (e.g. Wong & Ho 1994; Wehr et al. 2006). Other application fields are road construction (e.g. Tyser et al. 1998; Tormo et al. 2007), ski track construction (Ruth-Balaganskaya & Myllynen-Malinen 2000; Regione Lombardia 2011) and wars (Zhuang 1997). Particular attention is required for the restoration of quarry areas (e.g. Pamukçu & Simsir 2006; Tischew & Kirmer 2007), as topsoil and vegetation have been completely removed, buried or altered both chemically and structurally (Claassen & Hogan 2002).

1.3 The restoration of quarry areas

A quarry can be defined as *a place, typical a large, deep pit, from which stone or other materials are or have been extracted* (Oxford Dictionary). Generally, quarry activity is a complex process made by almost four different phases: a) exploration and prospecting, b) site preparation and construction, c) quarrying (s.s.) and production, d) rehabilitation or abandonment. The first three phases are typical of the "working quarries", while the last usually take place on "disused quarries", but also wherever the exploitable ore body is locally exhausted. Stated that each quarry is unique in time and space because of the heterogeneity in extraction techniques, technologies and natural environmental conditions, stone quarries have the aspect of amphitheatres with many large steps opened on the top or on the slopes of mountains and hills. The within-quarry geomorphological heterogeneity is high both at small scale (e.g. bulk ripples, tips, hollows and ponds; Tischew & Kirmer 2007) and at large scale (e.g. Gimblett et al. 1987; Carò & Im 2012), where three main geomorphological surfaces can be identified: artificial cliffs, embankments (or dump deposits) and platforms (Fig. 1.2).

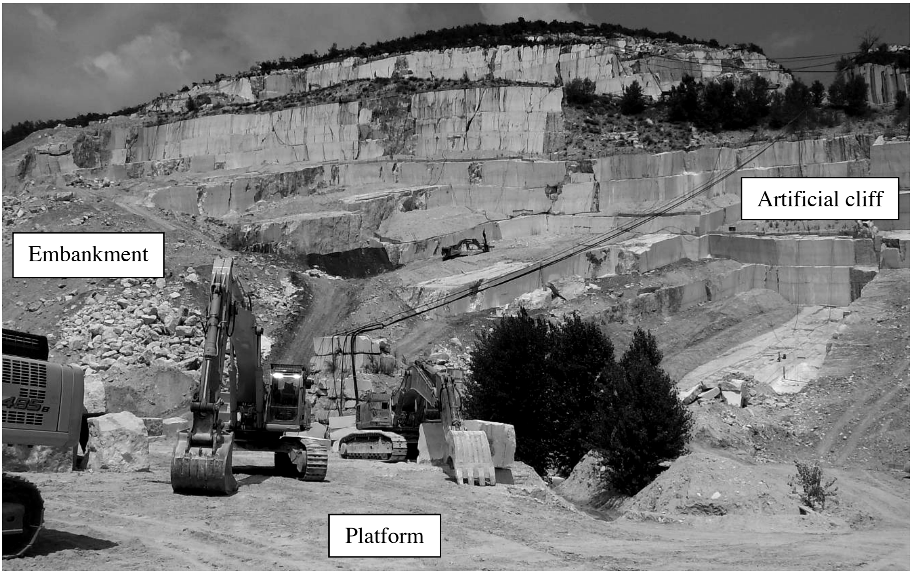

Fig. 1.2 Main geomorphological surfaces on quarries: artificial cliffs, embankments and platforms; Quarry "Coop. Operai Cavatori del Botticino" (ATE[1] 3/2), Botticino (Lombardy, Italy)

Plant succession in quarry areas. Once the exploitable ore body has been locally exhausted (even temporary), artificial cliffs, platforms and dump deposits are almost bare. If no human interventions are made, vegetation dynamics follow the course of a succession similar to a primary natural or semi-natural one, as described by many authors (e.g. Wali 1999; Frouz et al. 2008). The deep knowledge of such vegetation dynamics is the basic support for the restoration practices, including the selection of the most suitable plant species and technique.

In the pioneer phase, which could lasts about two years after quarry abandonment (Martínez-Ruiz & Fernández-Santos 2005), abiotic filters are the most limiting factors (Shu et al. 2005): substrate and soil characteristics (e.g. moisture and nutrient availability) play a crucial role in species selection (e.g. Kather et al. 2003; Tropek et al. 2010). Most areas remain bare or with some vegetation patches made by few dominant species (Cullen et al. 1998), i.e.: light-requiring fast-growing annual and ruderal herbs (R-strategist) with a very effective anemochorous dispersal (e.g. Wali 1999; Zhang & Chu 2011). The contribution by surrounding vegetation is very low (Brofas & Varelides 2000). However, high levels of

[1] "Ambito Territoriale Estrattivo": area where quarry activity is allowed by the Provincial law in Italy

plant and animal diversity can be found (Martínez-Ruiz et al. 2001) because of the high environmental (spatial and geomorphological) heterogeneity and the absence of spatial limitations (e.g. Brändle et al. 2000; Tischew & Kirmer 2007).
Once the annual flora is well established and abiotic conditions are better (Tischew & Kirmer 2007), many different and more exigent species colonize the area, increasing inter-species competition and the selective role of biotic filters (Duan et al. 2008). Colonizing species, that are usually perennial (or eventually biennial) herbs and sometimes shrubs, become more and more dominant (Kather et al. 2003; Novák & Prach 2003), affecting the latest successional phases (Martínez-Ruiz & Fernández-Santos 2005). In some cases, the decrease of the number and cover of annual herbs could also be connected with a decrease of plant diversity (Tischew & Kirmer 2007).
In later colonizer phase, when environmental conditions are much improved, native woody and shrubby species, coming mostly from the surroundings, replace the previous vegetation (e.g. Martínez-Ruiz & Fernández-Santos 2005; Zhang & Chu 2011) according to their reproductive and dispersal ability (Campbell et al. 2003; Holec & Frouz 2005). At the end of the succession, the vegetation of the site of intervention tends to be in dynamic equilibrium with the (semi)natural surrounding communities, towards their floristic composition and diversity, characteristics and fluctuations (e.g. Martínez-Ruiz et al. 2001; Konvalinková & Prach 2010).

1.3.1 The input of human efforts for restoration purposes

Quarry areas represent a particular case of land degradation both in plan and in hill/mountain regions. In fact, extractive activities destroy wide portions of habitats for plants and animals, interrupting ecological networks, representing an obstacle for species movement and affecting local biodiversity (e.g. Savoldi et al. 2011; Phillips 2012). Thus, quarries represent a real challenge for the realization of successful restoration projects able to persist in the future, taking into account that "*we do not inherit the Earth from our Ancestors, but we borrow it from our children*" (Native American Proverb).
A successful naturalistic quarry restoration, by use of the most suitable amount of human interventions (Pamukçu & Simsir 2006; Tischew & Kirmer 2007), requires a careful plan based on a deep site-specific scientific study (also considering geomorphological heterogeneity), field experiments and a comparative ecological study over a larger geographical area (e.g. Yundt & Lowe 2002; Muzzi & Rossi 2003). Stated this, three main approaches can be selected: a) to completely leave the area subjected to spontaneous processes to progress on their own (i.e. "spontaneous succession"); b) to exclusively adopt technical measures, i.e. "technical restoration", and c) to combine previous approaches (by varying intensity and extend of human efforts) by manipulating spontaneous succession towards a target habitat (e.g. Hodačová & Prach 2003; Savoldi et al. 2011) in order to accelerate the regeneration processes towards an earlier establishment of perennial taxa (e.g. Prach 2003; Khater & Arnaud 2007). For the selection of the most suitable approach, a very general guideline can be deduced according to the productivity-stress gradient (Fig. 1.3).

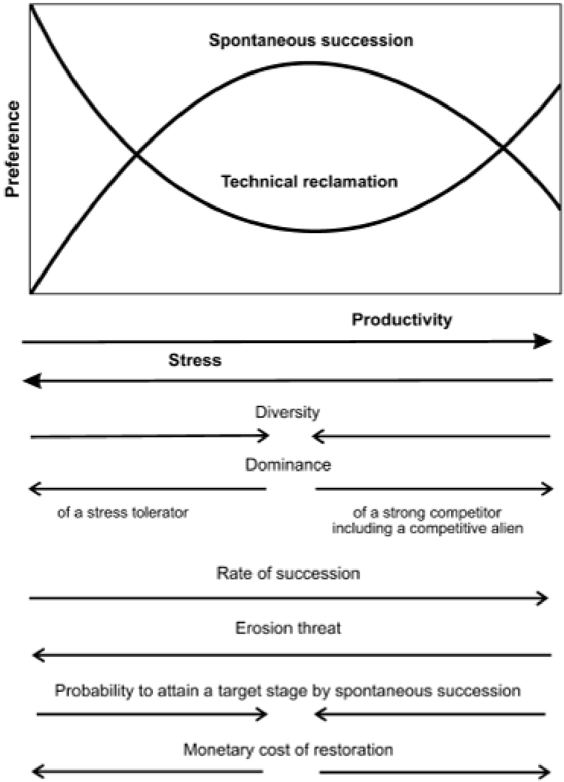

Fig. 1.3 Preference of "spontaneous succession" and "technical restoration" along the productivity-stress gradient (from: Prach & Hobbs 2008)

Considering that one of the most restrictive criteria in large-scale restoration projects is the minimization of the economic costs, the "spontaneous succession" is generally considered an useful approach to obtain a rapid, economical and efficient restoration (Tischew & Kirmer 2007). Nevertheless, its use is limited at moderate levels of stress/productivity, when the probability of obtaining a target ecosystem is higher; on the other hand, increasing human interventions are necessary and justified with increasing stress or productivity (Prach & Hobbs 2008).

"Technical restoration" and plant species selection. The realization of a technical restoration in quarry areas usually follows five key steps, i.e.: a) landform modeling, b) substrate preparation, c) plant species selection, d) plants seeding and plantation, e) monitoring and possible next interventions (e.g. Warman 1988; Bernini et al. 2003).

Among the different phases, plant species selection has a key role (Bernini et al. 2003), since only the most fitting species can successfully establish, survive, adapt and compete on local stressing conditions (especially where human efforts are minimized), and can form the basis for the development of vegetation communities and ecosystems. For this reason, a deep knowledge of local conditions is always required and regards: a) site conditions (e.g. agroecological constraints, natural surrounding vegetation, spontaneous vegetation dynamics, presence of geomorphologic processes such as soil erosion, mass movements and debris flow), b) economic feasibility, c) autoecology of selected species (e.g. life history, physiology, type of reproduction and seed dispersal) and d) population biology (e.g. Warman 1988; Tischew & Kirmer 2007).

1.4 Aim of the thesis

An extensive bibliography was made in the past about the study of quarries and the methods for their restoration: many studies investigated vegetation successions and microbiological communities, many others focused on the amelioration of soil fertility for restoration purposes. Nevertheless, only few studies investigated accurately the temporal phases of vegetation succession from quarry abandonment, that often have represented the base for the species selection for restoration purposes (which still maintained a high degree of subjectivity). In addition, literature data regarding the comparison of different methods of restoration of quarry areas are lacking, especially in Italy where the attention to such a field is limited to isolated experiments, few technical manuals of naturalistic engineering and rare scientific studies.

The present thesis focuses on hill limestone quarries and proposes a multidisciplinary approach, mainly based on vegetation analysis, for their study and restoration; the reference area is the “Botticino extractive basin” (Brescia, Lombardy), the second biggest extractive basin in Italy. Specifically the aim of this work was the identifcation of the most suitable restoration practice, applicable on large-scale, in order to ensure the establishment of a long-term and self-sustaining vegetation with high naturalistic value. In order to reach such an aim, in the thesis we investigated:

a) the vegetation dynamics on the quarries over the whole Botticino extractive basin, in order to identify the local vegetation succession and the main plant functional traits that are selected according to geomorphological features;

b) the specific composition and density of the tree/shrub layer of the semi-natural vegetation in the surrounding of the Botticino quarries. The seed germination of some common species was also considered in order to select the most suitable plants for a pilot field restoration experiment;

c) the root systems of selected herbaceous species which can contribute to the stability of superficial soil layers;

d) three different restoration techniques through a pilot field experiment, planned on the basis of the results from preliminary analyses, in order to select the most successful restoration approach from a naturalistic and economic point of view.

1.5 References, chapter 1

- Arienzo M., Adamo P., Cozzolino V. 2004. The potential of *Lolium perenne* for revegetation of contaminated soil from a metallurgic site. The Science of the Total Environment 319: 13-25
- Bay R.F., Sher A.A. 2008. Success of active revegetation after *Tamarix* removal in riparian ecosystems of the Southwestern United States: a quantitative assessment of past restoration projects. Restoration Ecology 16(1): 113-128
- Bernini F., Di Fidio M., Villa M. 2003. Operatore nei cantieri d'ingegneria naturalistica. Quaderni della Scuola d'Ingegneria Naturalistica 2. Scuola Regionale di Ingegneria Naturalistica, Centro Regionale per la Flora Autoctona. 177 pages
- Bradshaw A.D. 1984. Ecological principles and land reclamation practice. Landscape Planning 11: 35-48
- Brändle M., Durka W., Altmoos M. 2000. Diversity of surface dwelling beetle assemblages in open-cast lignite mines in Central Germany. Biodiversity and Conservation 9: 1297-1311
- Brofas G., Varelides C. 2000. Hydro-seeding and mulching for establishing vegetation on mining spoils in Greece. Land Degradation Development 11: 375-382
- Campbell D.R., Rochefort L., Lavoie C. 2003. Determining the immigration potential of plants colonizing disturbed environments: the case of milled peatlands in Quebec. Journal of Applied Ecology 40: 78-91
- Carò F., Im S. 2012. Khmer sandstone quarries of Kulen Mountain and Koh Ker: a petrographic and geochemical study. Journal of Archaeological Science 39: 1455-1466
- Claassen V.P., Hogan M.P. 2002. Soil nitrogen pools associated with revegetation on disturbed sites in the lake Tahoe area. Restoration Ecology 10(2): 195-203
- Cullen W.R., Wheater C.P., Dunleavy P.J. 1998. Establishment of species-rich vegetation on reclaimed limestone quarry faces in Derbyshire, UK. Biological Conservation 84: 25-33
- Del Tredici P. 2010. Spontaneous urban vegetation: reflections of change in a globalized world. Nature and Culture 5(3): 299-315
- Duan W., Ren H., Fu S., Wang J., Yang L., Zhang J. 2008. Natural recovery of different areas of a deserted quarry in South China. Journal of Environmental Sciences 20: 476-481
- Forbes B.C., Jefferies R.L. 1999. Revegetation of disturbed artic sites: constraints and applications. Biological Conservation 88: 15-24
- Frouz J., Prach K., Pižl V., Háněl L., Starý J., Tajovský K., Materna J., Balík V., Kalčík J., Řehounková K. 2008. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology 44: 109-121
- Gimblett H.R., Fitzgibbon J.E., Bechard K.P., Wightman J.A., Itami R.M. 1987. Procedure for assessing visual quality for landscape planning and management. Environmental Management Vol. 11 No. 3: 359-367
- Hobbs R.J., Harris J.A. 2001. Restoration Ecology: repairing the Earth's ecosystems in the new millennium. Restoration Ecology 9(2): 239-246
- Hobbs R.J., Norton D.A. 1996. Towards a conceptual framework for restoration ecology. Restoration Ecology Vol. 4 No. 2: 93-110
- Hodačová D., Prach K. 2003. Spoil heaps from brown coal mining: technical reclamation versus spontaneous revegetation. Restoration Ecology Vol. 11 No. 3: 385-391

- Hofmann L., Ries R.E., Gilley J.E. 1983. Relationship of runoff and soil loss to ground cover of native and reclaimed grazing land. Agronomy Journal 75: 599-602
- Holec M., Frouz J. 2005. Ant (*Hymenoptera*: *Formicidae*) communities in reclaimed and unreclaimed brown coal mining spoil dumps in the Czech Republic. Pedobiologia 49: 345-357
- Kauffman J.B., Case R.L., Lytjen D., Otting N., Cumming D.L. 1995. Ecological approaches to riparian restoration in northeast Oregon. Restoration and Management Notes 13(1): 12-15
- Khater C., Arnaud M. 2007. Application of Restoration Ecology principles to the practice of limestone quarry rehabilitation in Lebanon. Lebanese Science Journal Vol. 8 No. 1: 19-28
- Khater C., Martin A., Maillet J. 2003. Spontaneous vegetation dynamics and restoration prospects for limestones quarries in Lebanon. Applied Vegetation Science 6: 199-204
- Konvalinková P., Prach K. 2010. Spontaneous succession of vegetation in mined peatlands: a multi-site study. Preslia 82: 423-435
- Knut R., Jørn-Frode N., Ingvild A., Inger A., Einar H. 2010. Recreating semi-natural grasslands: a comparison of four methods. Ecological Engineering 36: 1672-1679
- Lencová K., Prach K. 2011. Restoration of hay meadows on ex-arable land: commercial seed mixture vs. spontaneous succession. Grass and Forage Science 66: 265-271
- Marqués M.J., Jiménez L., Pérez-Rodríguez R., García-Ormaechea S., Bienes R. 2005. Reducing water erosion in a gypsic soil by combined use of organic amendment and shrub revegetation. Land Degradation & Development 16: 339-350
- Martínez-Ruiz C., Fernández-Santos B., Gómez-Gutiérrez J.M. 2001. Effects of substrate coarness and exposure on plant succession in uranium-mining wastes. Plant Ecology 155: 79-89
- Martínez-Ruiz C., Fernández-Santos B. 2005. Natural revegetation on topsoiled mining-spoils according to the exposure. Acta Oecologica 28: 231-238
- Matthews J.W., Spyreas G. 2010. Convergence and divergence in plant community trajectories as a framework for monitoring wetland restoration progress. Journal of Applied Ecology 47: 1128-1136
- McDonnell M.J., Williams N.S.G. 2000. Directions in revegetation and regeneration in Victoria. Proceedings of a forum held at Greening Australia, May 5 and 6, 1999, Heidelberg, Victoria. Australian Research Centre for Urban Ecology, 132 pages
- McVicar T.R., Li L.T., Van Niel T.G., Zhang L., Li R., Yang Q., Zhang X.P., Mu X.M., Wen Z.M., Liu W.Z., Zhao Y.'A., Liu Z.H., Gao P. 2007. Developing a decision support tool for China's re-vegetation program: simulating regional impacts of afforestation on average annual streamflow in the Loess Plateau. Forest Ecology and Management 251: 65-81
- Muzzi E., Rossi G. 2003. Il recupero e la riqualificazione ambientale delle cave in Emilia – Romagna. Manuale teorico – pratico. Regione Emilia-Romagna. Bologna, 491 pp.
- Novák J., Prach K. 2003. Vegetation succession in basalt quarries: pattern on a landscape scale. Applied Vegetation Science 6: 111-116
- Pamukçu C., Simsir F. 2006. Example of reclamation attempts at a set of quarries located in Izmir, Turkey. Journal of Mining Science Vol. 42 No. 3: 304-308
- Phillips J. 2012. The level and nature of sustainability for clusters of abandoned limestone quarries in the Southern Palestinian West Bank. Applied Geography 32: 376-392
- Prach K. 2003. Spontaneous succession in Central-European man-made habitats: what information can be used in restoration practice? Applied Vegetation Science 6: 125-129

- Prach K., Hobbs R.J. 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restoration Ecology Vol. 16 No. 3: 363-366
- Regione Lombardia 2011. Inerbimenti tecnici ad alta quota. Quaderni della Ricerca n. 134 – settembre 2011. 47 pages.
- Ruth-Balaganskaya E., Myllynen-Malinen K. 2000. Soil nutrient status and revegetation practices of downhill skiing areas in Finnish Lapland – a case study of Mt. Ylläs. Landscape and Urban Planning 50: 259-268
- Savoldi S., Agostini M., Lucchini F., Papa F., Quecchia G., Serena C., Bellini R., **Gilardelli F.**, Motta M., Nicoli B., Testa R., Zola G. 2011. S.I.A. di bacino. Bacino estrattivo delle pietre ornamentali e dei pietrischi. Regione Lombardia, Provincia di Brescia, Comune di Botticino, Comune di Nuvolento, Comune di Nuvolera, Comune di Paitone, Comune di Serle. 974 pages.
- Society for Ecological Restoration International Science & Policy Working Group 2004. The SER international primer on ecological restoration. www.ser.org & Tucson: Society for Ecological Restoration International
- Sopper W.E. 1989. Revegetation of a contaminated zinc smelter site. Landscape and Urban Planning 17: 241-250
- Shu W.S., Ye Z.H., Zhang Z.Q., Lan C.Y., Wong M.H. 2005. Natural colonization of plants on five lead/zinc mine tailings in Southern China. Restoration Ecology Vol. 13 No. 1: 49-60
- Tischew S., Kirmer A. 2007. Implementation of basic studies in the ecological restoration of surface-mined land. Restoration Ecology Vol. 15 No. 2: 321-325
- Tormo J., Bochet E., García-Fayos P. 2007. Roadfill revegetation in semiarid mediterranean environments. Part II: topsoiling, species selection, and hydroseeding. Restoration Ecology 15(1): 97-102
- Tropek R., Kadlec T., Karesova P., Spitzer L., Kocarek P., Malenovsky I., Banar P., Tuf I.H., Hejda M., Konvicka M. 2010. Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. Journal of Applied Ecology 47: 139-147
- Tsuyuzaki S., Kanda F., Narita K. 1994. Revegetation patterns on abandoned pasture in northern Japan. Acta Œcologica 15(4): 461-467
- Tyser R.W., Asebrook J.M., Potter R.W., Kurth L.L. 1998. Roadside revegetation in Glacier National Park, U.S.A.: effects of herbicides and seeding treatments. Restoration Ecology 6(2): 197-206
- Van Diggelen R., Grootjans A.P., Harris J.A. 2001. Ecological Restoration: state of the art or state of the science? Restoration Ecology Vol. 9 No. 2:115-118
- Velázquez A., Durán E., Ramírez I., Mas J.-F., Bocco G., Ramírez G., Palacio J.-L. 2003. Land use-cover change process in highly biodiverse areas: the case of Oaxaca, Mexico. Global Environmental Change 13: 175-184
- Wali M.K. 1999. Ecological succession and the rehabilitation of disturbed terrestrial ecosystems. Plant and Soil 213: 195-220
- Wallace A., Romney M. 1980. The role of pioneer species in revegetation of disturbed desert areas. Great Basin Naturalist Memoirs 4: 31-33
- Warman P.R. 1988. The gays river mine tailing revegetation study. Landscape and Urban Planning 16: 283-288

- Wehr J.B., Fulton I., Menzies N.W. 2006. Revegetation strategies for bauxite refinery residue: a case study of Alcan Gove in northern territory, Australia. Environmental Management 37(3): 297-306
- Wong J.W.C., Ho G. 1994. Sewage sludge as organic amelioration for revegetation of fine bauxite refining residue. Resources, Conservatione and Recycling 11: 297-309
- Yetka L.A., Galatowitsch S.M. 1999. Factors affecting revegetation of *Carex lacustris* and *Carex stricta* from rhizomes. Restoration Ecology 7(2): 162-171
- Young T.P., Petersen D.A., Clary J.J. 2005. The ecology of restoration: historical links, emerging issues and unexplored realms. Ecology Letters 8: 662-673
- Yundt S., Lowe S. 2002. Quarry rehabilitation – cliffs, landforms and ecology. Proceedings of the 26th Annual British Columbia Mine Reclamation Symposium in Dawson Creek, BC. The Technical and Research Committee on Reclamation
- Zhang C.-B., Huang L.-N., Wong M.-H., Zhang J.-T., Zhai C.-J., Lan C.-Y. 2006. Characterization of soil physic-chemical and microbial parameters after revegetation near Shaoguan Pb/Zn smelter, Guangdong, P.R. China. Water, Air, and Soil Pollution 177: 81-101
- Zhang H., Chu L.M. 2011. Plant community structure, soil properties and microbial characteristics in revegetated quarries. Ecological Engineering 37: 1104-1111
- Zhuang X. 1997. Rehabilitation and development of forest on degraded hills of Hong Kong. Forestry Ecology and Management 99: 197-201

2 Study area

The study area is located on the "Botticino extractive basin", the second greatest Italian extractive basin after the Carrara's one (Tuscany). The Botticino basin is focused on the extraction of calcareous limestone that, according to the nature of the material and the treatment (e.g. cut as slates, broken in small pieces, grinded, pulverized) is mainly used as: a) structural and ornamental stone for buildings, b) raw material for the production of concrete, cement, mortar and plaster c) lime for agriculture, d) raw material for the preparation of road layers, e) factor for metals refining and f) element for the chemical and alimentar industry (e.g. for calcium addiction in animals breeding).

2.1 Geographical location

The Botticino basin is located on the hill area at north-east of the city of Brescia (Province of Brescia; Lombardy Region) which connects the Alps and the high Po Valley, and extends over 5 Municipalities: Botticino, Nuvolento, Nuvolera, Serle and Paitone (Fig. 2.1).

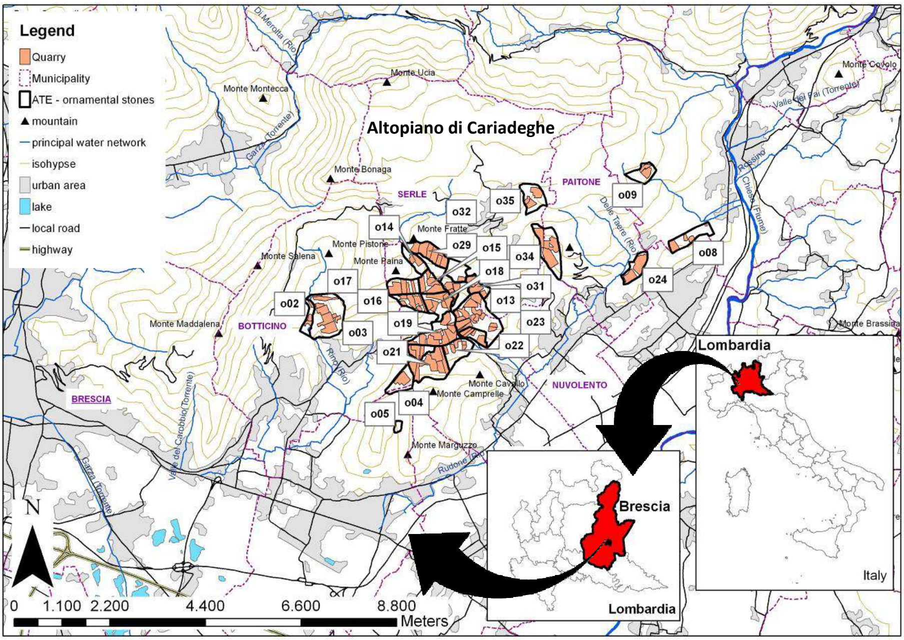

Fig. 2.1 Geographical location of the "Botticino extractive basin" (reference scale: 1:50000; data from: Geoportale della Lombardia; database Ufficio Autorizzazioni Cave, Provincia di Brescia) [2]

[2] the letter "o", which refers to "ornamental stones", will be omitted in the rest of the thesis

The area range from 185 to 665 m a.s.l.; it is limited at east and south by the valley of the Chiese river, at north by Garza and Vrenda streams and at west by a mountain ridge that begins from Mount Ucia (1168 m) on the karst plateau “Altopiano di Cariadeghe” and continues towards south-west, through the Monte Salena (862 m) and Monte Maddalena.

According to the “Quarry Plan of the Province of Brescia for the sector of clay, ornamental stones and limestone” (see the regional law *D.C.R. 21.12.2000 n. VI/120* as modified by *D.C.R. 19.03.2008 n. VIII/582*), the extractive basin includes 21 ATE (out of 36 ATE located on the provincial territory) and can be divided into three main sub-basins: a) the western basin, including two ATE on the Municipality of Botticino (ATE o02, o03), b) the central basin of the Nuvolera valley, including 17 ATE on the Municipalities of Nuvolera, Nuvolento and Serle (ATE o04, o13, o14, o15, o16, o17, o18, 19, o20, o21, o22, o23, o29, o30, o31, o32, o33), and c) the eastern basin, including two ATE on the Municipalities of Paitone and Serle (ATE o34, o35).

2.2 Geology and geomorphology

2.2.1 Geological features

Rocky formations that characterize the study area (Fig. 2.2) are mainly sedimentary and carbonatic (pure or with a variable content of clay according to the sedimentation conditions), being originated by the deposition of sediments mainly made by calcium carbonate ($CaCO_3$) in a marine environment during the Mesozoic Era (250-66 millions years ago; Servizio Geologico d'Italia 2001; Savoldi et al. 2011a).

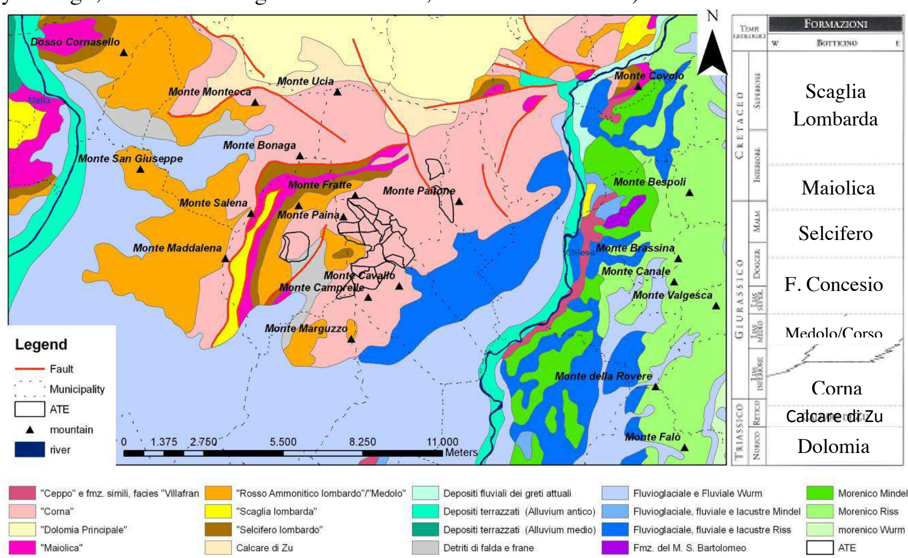

Fig. 2.2 Geological map (reference scale: 1:250000) and stratigrafic scheme of the rocky formation cropping out on the study area (data from: Geoportale della Lombardia; progetto CARG)

The local stratigraphic succession, that covers for thousand of meters the metamorphic crystalline basement known as "*Massiccio delle tre valli bresciane*", is made by the "*Dolomia principale*" (dolostone and dolomitic limestone; Triassic, 220 millions years), the "*Calcare di Zu*" (limestone; Triassic, 215 millions years), the "*Corna*" (limestone; Inferior Giurassic, 205 millions years), the "*Medolo*" (limestone and marlstone; Giurassic, 195 millions years) and the "*Corso*" (limestones; Giurassic, 195 millions years), the "*Selcifero Lombardo*" (marlstone, limestone and flintstone; Giurassic, 170-150 millions years), the "*Maiolica*" (limestone; Cretaceous, 150-115 millions years) and the "*Scaglia Lombarda*" (marlstone; Cretaceous, 93-89 millions years) (regional law *D.C.R. 21.12.2000 n. VI/120*; Schirolli 2008).

The "Corna". The *Corna* (i.e. *Horns*, deriving its name by the projections originated by rocky outcrops) is the most extended formation on the study area, besides representing the exploited ore body of the 21 ATE of the Botticino extractive basin. The Karst plateau "Altopiano di Cariadeghe", the east slopes of Monte Maddalena, Monte Fratta, Monte Paina and Monte Camprelle are typical outcrop areas of such a formation.
The *Corna* is a carbonatic and sedimentary rock (made by almost pure $CaCO_3$), that was originated on a carbonatic platform of a lagoon sea basin, characterized by mostly subtidal conditions and a peritidal cyclicity, with moderate but continuous oscillations and temporary emersions (Schirolli 2008). For this reason, the content of fossils is interesting, and made by an association of low sea, with *Algae Dasycladacee* (*Thaumatoporella*, *Palaeodasycladus*) and *Rodoficee* (*Lithoporella*, *Solenopora*), *Foraminifera*, *Ostracods*, *Corals*, *Lamellibranchs*, *Gasteropods*, *Brachipods* and *Echinoderms*. Also oncolites (known as "*mandole*") and stromatolites with a diameter of 1-2 cm are abundant (Clerici & Meda 2005).
The typical facies of the *Corna* is the calcareous one (characterizing the upper part of the formation): an almost pure and compact limestone, with a white-nut, white-ivory or even gray color (according to the amount of impurities) and a general aspect of massive banks of many meters, with seams or indistinct stratification (Clerici & Meda 2005). The typical cropping area of such facies is the territory of Botticino, where it is extracted and commercially known as "*Marble Botticino Classico*", because of the aspect of such not metamorphosed limestone, once polished. Also the dolomitic and breccia facies are present: dolomitic limestone and not stratified crystalline dolostones can be locally identified (Clerici & Meda 2005), while polychrome breccias (e.g. "*Breccia aurora*" and "*Breccia oniciata*") are extracted on the hill area of Serle and Paitone (Schirolli 2008).

2.2.2 Structural elements

The Brescian Pre-Alps refer to the paleogeographical-structural domain of the "*Sudalpino*" (i.e. "Southern Alps") of the east part of the "*Lombardy Basin*" (Clerici & Meda 2005). All the tectonic structures at east of Brescia were originated during the rearrangemnt of the territory following the Alpine orogeny, and especially during the period of intense activity of the Neo-Alpine phase, 29-10 millions years ago (Savoldi et al. 2011a). The evidences of such an activity are revealed by the direction of the rocky formations and by the huge presence of faults, folds and thrusts on the *Corna*, thanks to a less plastic behaviour than the other formations because of the lower marly content (Table 2.1). The line of Monte Maddalena is responsible of the thrust of the *Corna* on the *Scaglia Lombarda*.

Type	**Name**	**Direction**
synclinal	Cariadeghe	SW-NE
	Botticino Sera-S.Gallo-Castello	first SSW-NNE and then WSW-ENE
	Molvina	WSW-ENE
anticline	Monte Bonaga, Monte S. Bartolomeo	E-W
	MontePaina	knee fold; N-NW (N-slopes), S-SW (S-slopes)
	Monte Camprelle	E-NE
line	Monte Maddalena	NNE-SSW
	Botticino Mattina	

Table 2.1 Folds present on the study area

Attitudes are very heterogeneous, mainly orientated parallel or less inclinated to the direction of the slope ("*franapoggio*"), with local variations: attitudes almost horizontal are present on ATE 19, attitudes with an orientation more or less normal to the direction of the slope ("*reggipoggio*") characterize ATE 14, 29 and part of ATE 2 and 3, low differentiated stratification (i.e. massive rocky body) characterize ATE 34 and 35 (Savoldi et al. 2011a).

2.3 Hydrology

The calcareous nature of the *Corna* allows meteoric waters to infiltrate rapidly on the substrate because of the direct dissolution of the calcium carbonate, being facilitated by the fracturing system and eventually by the limited soil depth (Savoldi et al. 2011a). Because of such a feature, the outcrop area of the *Corna* coincides with one of the most important ancient and "mature" Karst area of the Brescian territory, i.e. the "*Carso Bresciano*" ("*Brescian Karst*"; Morelli 1997). On the surface, the *Carso Bresciano* is revealed by a huge presence of dolinas (of normal dissolution and collapse), caves, underground shafts, tunnels, Karren and Lapiez (Savoldi et al. 2011a, 2011b). The number of natural cavities on the area is very high and represents 15% of the total number of natural cavities on the whole territory of the Province of Brescia. Some cavities also present a high naturalistic value, such as the *Bus del Cugnol* (9 Lo), located in the extractive basin. The Karst nature of the area is also detectable by the large-scale topographical and geomorphological modeling, so that three principal sectors can be locally identified (Fig. 2.3):

- the "plateau area", which presents many vertical cavities and extended fields of dolinas of normal dissolution (with variable depth and dimension) with a density of about 150-180 dolinas/Km^2 (250-300 on the "Altopiano di Cariadeghe");

- the "middle sector", which is constituted by slopes connecting the plateau with the plain, including the whole extractive basin. The fault system and the dissolution processes control the particular local morphology, characterized by little valleys with a main NNW-SSE orientation, regular slopes, big deposit of residual ground, Karst cones, ridges and rises;
- the "piedmont area", which is a plain area charactetrized by a relevant presence of springs.

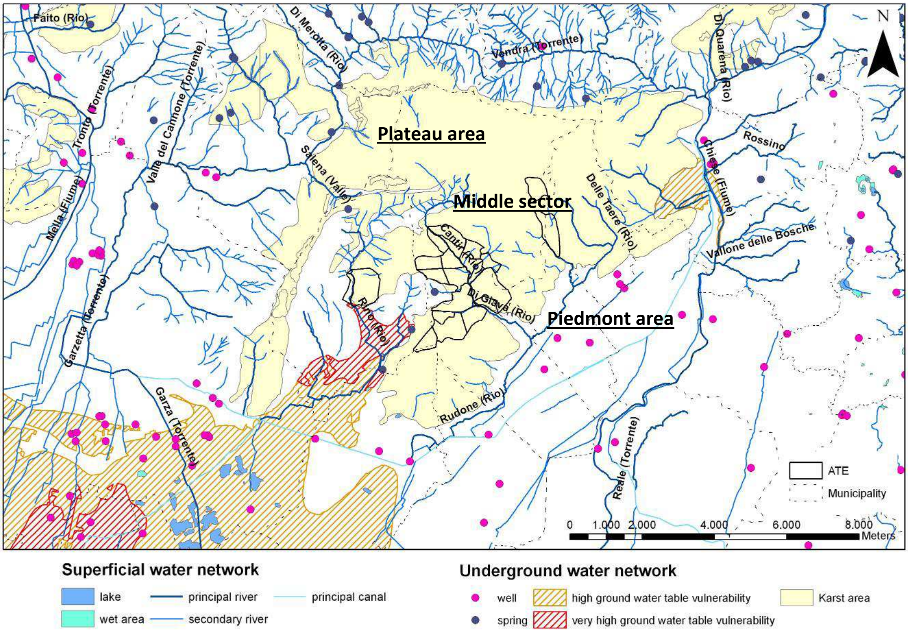

Fig. 2.3 Superficial and underground water network (reference scale: 1:10000; data from: Geoportale della Lombardia)

Superficial water network. Because of the Karst nature of the *Corna*, the surface water network is not very developed: only the *Vrenda* stream and the *Chiese* river (at north and at east of the extractive basin, respectively) have built two important valleys over time.
In general, the few streams that are located on the extractive basin have significant flows only during intense rainfalls. In particular, *Rio Cantir*, which flows with a NW-SE direction in the Nuvolera valley (becoming *Rio La Valle* on the locality "Fontanone" and *Rio di Giava* on the plain) is here the most important stream. *Rio Rino*, which has a N-S direction in the Botticino valley, is characterized by a high initial water erosion potential (near Monte Pistone) that decrease towards the plain. The superficial flow of *Torrente Rino* (Valle di Virle, Monte Camprelle) is visible only during very intense rainfalls: in such cases, it shows firstly a E-W direction and then a N-S direction (along the fault of Val Trompia), before

flowing into the artificial channel *Naviglio Grande Bresciano*, on the urban area of Virle. Also *Rio Rudone* (which born on locality Magrena near Serle and ends on the piedmont plain at north of the urban area of Paitone) is visible only during intense and particularly prolonged rainfalls, since 73% of its basin (4.94 Km^2) is included on the Karst area (Savoldi et al. 2011a).

Underground water network. The Karst area is characterized by a very complex, developed and vulnerable underground water network (Morelli 1997). In particular, two hydrological domain can be identified: the “mountain acquifer”, that is made by fractured and Karst rocks of the *Corna* on the mountain and hill areas, and the “plain acquifer”, that is made by incoherent and mainly granular deposits of the piedmont and plain areas (Savoldi et al. 2011a). Taking into account that the principal flow seems to be mostly affected by the orientation of the relieves (attitude, slope), it is not clear if the two acquifer are connected, even partly (e.g. superficially or in depth).
From the hydrological point of view, the “nourishment area” mainly corresponds to the Karst area of the *Altopiano di Cariadeghe* and it is characterized by both a diffused and localized infiltration (waters deriving from not Karst rocks flows into active sinkholes). The “resurgences area”, which is the lowest area from the topographical point of view (on the plain), presents perennial and temporal springs with very different flow according to infiltration apports. Many of them are or have been used by man, such as: the active, occasional and/or perennial *Sorgente Fontanone* characetrized by a high and fast flood variation (Paitone; annual mean discharge of 200 l/sec), *Sorgente Pedimonte* and *Sorgente Molinetto* with ground water table cropping out during flood events (Botticino; annual mean discharge 20 l/sec), *Sorgente Fontanone-Fontanino* (Nuvolera) and *Sorgente Fonte Sole* (Nuvolento) (Savoldi et al. 2011a).

2.4 Pedology

Soil characteristics in the Botticino extractive basin are heterogeneous according to geomorphological variability, slope, rockiness and aspect (Savoldi et al. 2011a). More in general, the study area is located between the “*brescian Pre-Alps*” and the “*high plain*” soil subregions, belonging to the “*Basso Mella-Chiese district*” (Fig. 2.4a). The last is characterized by steep slopes, altitudes generally lower than 800 m a.s.l., accumulation of alluvional materials on the valley floor and of colluvial ones on the slopes (ERSAL 1997).

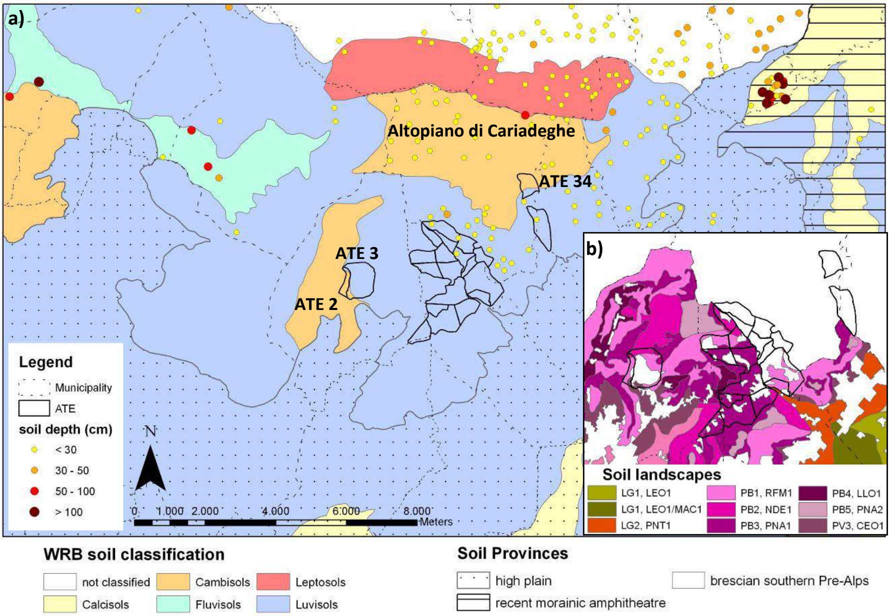

Fig. 2.4 Pedological map according to a) WRB classification and b) Soil Taxonomy classification (reference scale: 1:250000; data from: Geoportale della Lombardia)

World Reference Base classification. According to the World Reference Base for Soil Resources (WRB; FAO 1998), the dominant Typologic Soil Units (UTS) on the study area are a) Luvisols, that are the most extended unit and b) Cambisols, which are present on Botticino Municipality and on the *Altopiano di Cariadeghe*, thus interesting ATE 2, 3 and 34 (ERSAL 1997; Savoldi et al. 2011a; Fig. 2.4a).

Luvisols, which are characteristic of plain forestry regions, are characterized by a high content of calcium, the presence of illuvial and eluvial layers (where clay silicate are accumulated) and sometimes of a superficial humic layer (separated by the mineral ones) due to litter accumulation (Savoldi et al. 2011a). On the study area, "*gravelly Luvisols*" (also known as "*gravelly soils of the high plain*") prevail on the boundary of the Pre-Alps, while "*ancient Luvisols*" (or "*brown soil leached with fragipan*") are locally present on glacial and fluvioglacial deposits on ancient alluvium of the tributaries of the Po.

Cambisols, which prevails on hill and mountain areas, are brown soil with a well developed structure and an altered cambic layer with a loam-fine or fine texture and a darker color than lower layers. On the study area, the "*Forestry Cambisols*" (also known as "*brown soil of the Pre-Alps area*") are present (Savoldi et al. 2011a, 2011b).

Soil Taxonomy classification. According to the Soil Taxonomy classification (USDA; Soil Survey Staff 2010), the soil *cartographic units* (UC) and the *lanscape units* (UDP) in the study area belong to the "*P system*", which includes the mountain reliefs of the Lombardy Alps and Pre-Alps, characterized by bedrock and rocky outcrops (Fig. 2.4b). In particular, the "*PB sub-system*" prevails on the extractive basin, which refers to the baseline plan, below 700 m a.s.l. and including the sub-Mediterranean horizon with sclerophyllous and the sub-mountain horizon with deciduous heliophilous species. The "*PV sub-system*" is localized on limited areas of mountain valley floors of alluvial origin, including the connecting surfaces (of colluvial origin) with the near slopes (Brenna 2001). A very limited area at south of the extractive basin is classified as "*L system*", i.e. fluvioglacial and fluvial plain which constitute the "*Livello Fondamentale della Pianura*" (LFdP, i.e. "*fundamental level of the Po*"). In the study area, the "*LG sub-system*" is present, i.e. large gravelly conoids with a sub-plain or slightly convex morphology, consisting of coarse fluvioglacial materials not altered, that are included between the reliefs and the upper limit of the area of springs. Most soil carthographic units are characterized by a very low land capability, being suitable only for naturalistic-recreative purposes, because of very high limitations due to high slopes (45-100%) and the following high risk of erosion (Table 2.2).

System	Sub-system	UDP	UDP_description	UC_name (number)	Type of soil	Land Capability
L	LG	LG2	ancient surfaces, without significant morphological differences in height, and characterized by almost fine materials, as a result of a deep alteration in place of the original materials	PNT1 (397)	Typic Paleudalfs: fine, mixed, superactive, mesic	II
P	PB	PB1	slopes with slope from high to very high; vegetation of thermophilous deciduous woodlands (sometimes mesophilous), due to a prevailing south aspect; pastures, vineyards and orchards are frequent on less sloping surfaces or artificially terraced	RFM1 (24)	Lithic Hapludolls: loamy, mixed, active, mesic	VII
		PB2	slopes with slope from high to very high; vegetation of thermophilous deciduous woodlands, and few pasture because of the prevailing	NDE1 (27)	Typic Dystrudepts: fine silty, mixed, active, mesic	VII

		north aspect			
	PB3	rounded ridges, peaks gently convex slopes and slopes with moderate to moderately high slope, mainly used for pasture, meadow and arable land	PNA1 (28)	Typic Hapludalfs: very fine, mixed, active, mesic	VII
	PB4	morphological or morphotectonic terraces, sub-flat or with low slope, often with a very alterable substrate; intensively used for pastures	LLO1 (29)	Typic Eutrudepts: fine, mixed, superactive, mesic	VII
	PB5	plains and strongly corrugated surfaces with hydrosoluble substrate and Karst morphology (presence of sink holes, funnels, sinkholes, and furrowed fields)	PNA2 (30)	Ultic Hapludalfs: very fine, mixed, active, mesic	VI
PV	PV3	piedmont connecting mountains with the high plain, corresponding to the main sections of colluvial slopes; low or moderate slopes and subject to anthropogenic modeling	CEO1 (32)	Typic Eutrudepts: fine, mixed, superactive, mesic	III

Table 2.2 Soil Cartographic Unit (data from: Geoportale della Lombardia); Legend for Land Capability: II: soil suitable for agriculture, with moderate limitations due to a mediocre drainage because of the fine texture (selection of the crop type and/or moderate conservative practices are required); III: soils suitable for agriculture, with high limitations mostly due to high slopes and risk of erosion (limited selection of type of crop and specific conservative practices required); VI soils on karst plains only suitable for pasture, forestation or natural habitat, because of high limitations due to frequent rocky outcrops; VII: soils only suitable for naturalistic-recreative purposes, with very high limitations due to high slopes (45-100%) and high risk of erosion

2.5 Climate

Daily data on precipitations, temperature and relative moisture were collected from a) the ARPA (Regional Meteorological Service) meteorological station located on *Caino* (station 876, coordinate Gauss Boaga: 5051557 1603128), b) the ARPA meteorological station located on *Brescia – ITAS Pastori* (station 130, coordinate Gauss Boaga: 5042196 1598530), and c) the meteorological station of the Provincial Agrometeorological Centre of the Agriculture Sector of the Brescia Province, located on *Botticino* (250 m a.s.l., coordinate Gauss Boaga: 5044394 1604650).

Precipitations. Mean annual rainfall is 1026.13 mm (Table 2.3). Winter is the driest season and January is the driest month in all the stations. The most rainiest season is autumn and secondly spring: the most rainiest month is November in Caino, August in Brescia – ITAS Pastori and October in Botticino.

	Caino	Brescia – ITAS Pastori	Botticino
January	62.7	54.5	50.1
February	78.1	56.0	51.1
March	65.1	66.4	73.5
April	96.2	78.4	88.8
May	103.8	84.8	117.8
June	83.0	72.1	77.4
July	78.1	58.1	90.6
August	98.3	98.8	107.8
September	102.2	93.5	106.2
October	94.4	80.1	123.4
November	143.1	97.5	114.3
December	107.6	70.0	54.7
Total	**1112.6**	**910.2**	**1055.6**

Table 2.3 Mean precipitations (mm) on Caino (sensor 8139; data from 2001 to 2010), Brescia – ITAS Pastori (sensor 2417; data from 1990 to 2010) and Botticino (data from 1997 to 2010). Pale gray: lowest values, dark gray: highest values

Temperature. Mean annual temperature is 13.5°C (Table 2.4). Winter is the coldest season and January is the coldest month across the stations. The hottest season is summer and the hottest months are July in Caino and Botticino, and August in Brescia – ITAS Pastori.

	Caino	Brescia – ITAS Pastori	Botticino
January	3.8	2.2	3.1
February	5.4	4.8	5.1
March	9.0	8.8	9.3
April	13.5	12.6	13.1
May	18.1	17.5	18.7
June	21.9	21.4	22.6
July	23.8	23.1	24.2
August	23.3	24.0	23.9
September	19.1	18.0	19.3
October	14.0	13.2	14.2
November	8.8	7.5	8.1
December	4.7	3.1	3.9
Mean	**13.8**	**13.0**	**13.8**

Table 2.4 Mean temperature (°C) on Caino (sensor 8140; data from 2001 to 2010), Brescia – ITAS Pastori (sensor 2414; data from 1995 to 2010) and Botticino (data from 1997 to 2010). Pale gray: lowest values, dark gray: highest values

Relative moisture. Mean annual relative moisture is 71.95% (Table 2.5). Summer and July are the season and the mounth with the lowest relative moisture, respectively. The highest relative moisture is recorded on late autumn and early winter, with the highest values on December in Brescia – ITAS Pastori and on November in Botticino.

	Brescia – ITAS Pastori	**Botticino**
January	82.0	79.6
February	73.0	69.0
March	65.4	66.9
April	65.9	70.7
May	62.9	67.6
June	62.0	66.2
July	61.7	64.4
August	68.6	66.6
September	70.2	70.4
October	81.1	81.6
November	83.6	83.1
December	85.4	79.3
Mean	**71.8**	**72.1**

Table 2.5 Mean relative moisture (%) on Brescia – ITAS Pastori (sensor 2415; data from 1995 to 2010) and Botticino (data from 1997 to 2010). Pale gray: lowest values, dark gray: highest values

Climate. The climate of the study area is continental, with cold winters, hot summers, absence of dry periods and a bimodal regime of precipitations (Fig. 2.5).

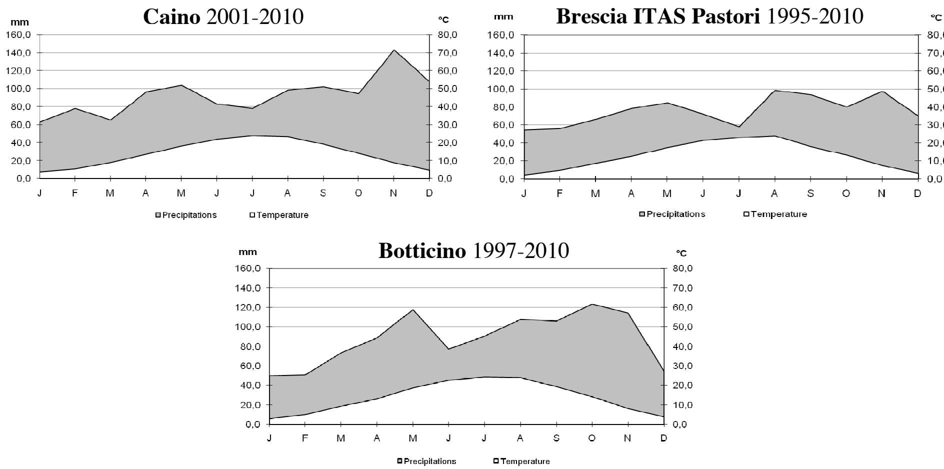

Fig. 2.5 Temperature-precipitations diagram on Caino, Brescia – ITAS Pastori and Botticino

Such a climate presents both the characteristics of the climate of the plain, i.e. the "*Padan meso-climate*", and by the one of the Pre-Alps, i.e. the "*Insubric meso-climate*" (Savoldi et al. 2011a). The first is characterized by cold winters (with fog and freeze), hot and sultry summers, high moisture, irregular rainfalls with peaks on fall and spring and low windiness. The second is characterized by high frequency of clear sky (especially on winter), high sun radiation on summer, higher winter temperature on slopes than on valley floors, not very high summer temperature, wind of channeling on the direction of the valleys, abundant rainfalls with maximum on summer and minimum on winter.

2.6 Vegetation and floristic elements

Flora and vegetation of the study area have been deeply managed by human activities in historical times (Savoldi et al. 2011a), so that past vegetation can survive only in rows and residual woodlands on the plain (Fig. 2.6), or have been altered or replaced on the hills (e.g. by the spontaneous revegetation mostly following the abandonment of agricultural and pastoral activities; DCR 21.12.2000 n. VI/120; DCP 20.04.2009 n. 26).

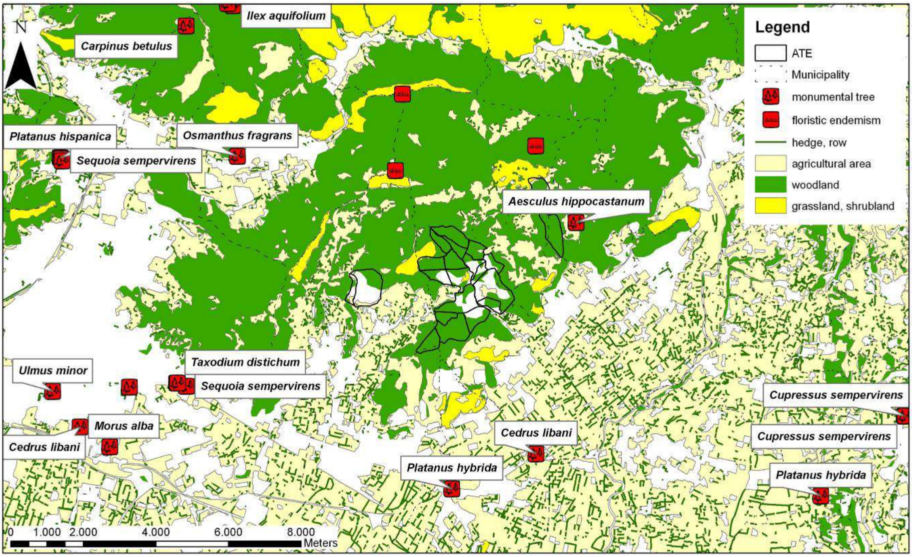

Fig. 2.6 Vegetation, monumental trees and floristic endemism on the study area (data from: Geoportale della Lombardia)

2.6.1 "Potential" vegetation

The study area is included into the phytoclimatic zone of the *Castanetum* (Pavari 1916), and the "vegetation plan" of the "*sub-mountain horizon of the basal plan*" (Fenaroli & Giacomini 1957), where the typical vegetation ("climax") is the woodland of heliophilous broadleaves characterized by the dominance of deciduous oaks and of the chestnut. According to the classification of "vegetation belts", the extractive basin is located on the "*hill environment of the middle-european area*", where two not always distinguishible belts can be identified: the "*middle-european belt*", where mixed decidous woodlands dominated by oaks (*Quercus pubescens* and *Q. petraea*) prevail, and the "*illiric belt*", dominated by oriental and illiric-balcanic species, such as *Ostrya carpinifolia* and *Fraxinus ornus* (Pignatti 1979). The Forestry Region which includes the study area and the morainail hills before the plan (*"regione avanalpica*", i.e. "*Pre-Alps Region*"), should be characterized by hill oak-hornbeam woods (Gallinaro 2004). Considering the classification of the "vegetation successions" (Blasi 2010), the study area belongs to the *temperate macroclimate region*, where the potential natural vegetation of both the high plain (*Padan system*) and the Pre-Alps (*Insubric system*) is the deciduous woodland of the *Querco-Fagetea* phytosociological class. In particular, the high plain is referable to the *succession n. 111a* ("succession of the oriental and neutral-basophil Padan high Plain dominated by *Quercus robur* and *Carpinus betulus*; *Erythronio–Carpinion betuli*"), while the hill area is included into the *succession n. 146* ("mosaic of the morenic anphiteathre of the Garda lake, between neutral-basophil and sub-acidophil succession dominated by *Quercus pubescens*, *Q. cerris* and *Ostrya carpinifolia*; *Erythronio-Carpinion, Carpinion orientalis*").

2.6.2 Real vegetation

Natural and semi-natural vegetation on the surrounding of the extractive basin is mainly constituted by woodlands and mowed grasslands, that are typical of a sub-Mediterranean environment (Morelli 1997). Agricultural areas and vineyards also occupied great portions of the territory, especially on plain areas (Fig. 2.7).

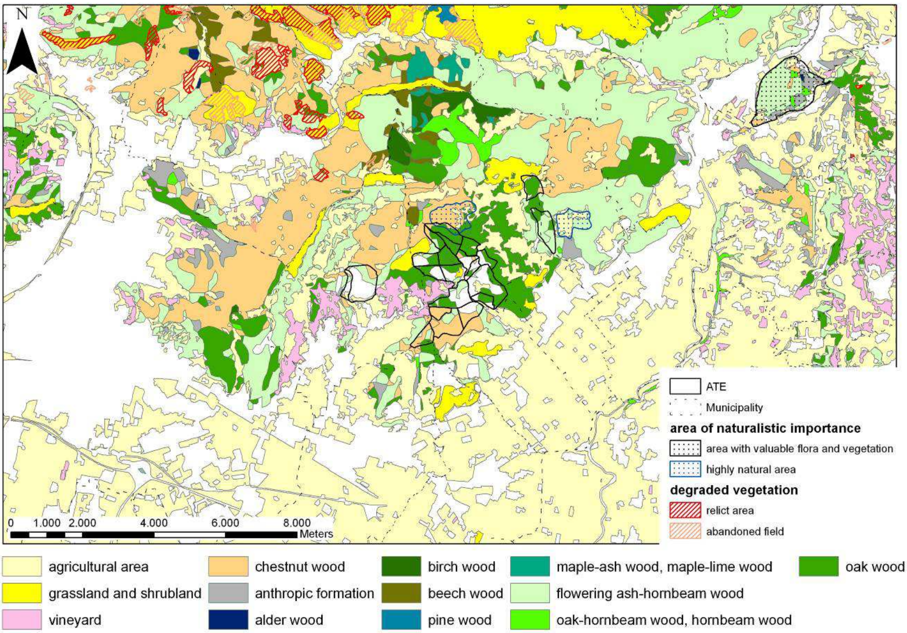

Fig. 2.7 Vegetation on the study area (data from: Del Favero 2002, Geoportale della Lombardia)

Well-structured woodlands. Mesophilous and thermophilous woodlands, that are usually managed as copse (almost in the recent past) present generally a good structural complexity and can be classify into different vegetation communities: flowering ash-hornbeam woods ("*orno-ostrieti*"), hornbeam-oak and oak woods ("*ostrio-querceti*"), copse chestnut woods and, locally, mixed broadleaves woodlands and hornbeam dominated by *Carpinus betulus* (Cappelli & Stefani 1986; DCR 21.12.2000 n. VI/120; Savoldi et al. 2011a).

Flowering ash-hornbeam woods (mainly managed as copse) are termophilous formations, that grow on less developed soils with low water availability, so that they prevail where vegetation development is limited by cropouts of limestone rocky substrate, high slopes and south aspect. Dominant tree species are *Ostrya carpinifolia* and *Fraxinus ornus*, with a low presence of *Quercus pubescens*. Eliophilous and almost xerophilous species belonging to the *Prunetalia-spinosae*, such as *Crataegus monogyna*, *Cornus sanguinea*, *Viburnum lantana*, *Amelanchier ovalis*, *Coronilla emerus* and *Ligustrum vulgare*, are present in the shrub layer. The herb layer is made by termo-heliophilous and low exigent species that are strongly connected with the presence of the limestone substrates.

Hornbeam-oak woods and oak woods are termophilous copse woodlands growing on developed and fresh limestone soils with variable slopes. Except for *Amelanchier ovalis* and *Coronilla emerus*, they present the same dominant species of the flowering ash-hornbeam woods, with a higher presence of *Quercus pubescens* in the tree layer, a higher structural and floristic complexity and a more mesophilous character. In the shrub layer other abundant species are: *Berberis vulgare*, *Euonymus europaeus*, *Corylus avellana*, *Frangula alnus*, *Sorbus aria* and *S. torminalis*. Such oak-woods belong to the *Querco-Fagetea* Br.-Bl. Et Vlieger in Vlieger 1937, *Quercetalia pubescentis-petreae* Klika 1933 em. Blasi et al. 2004, *Carpinion orientalis* Horvat 1958, as defined by Andreis & Sartori (2009).

Chestnut woodlands are dominated by *Castanea sativa* and managed as copse with generally a turnover of 20 years: thus, individuals are usually young, and the old ones (e.g. individuals of 40 years) are rare. Besides *Castanea sativa*, are also present in the tree layer: *Carpinus betulus*, *Quercus petraea*, *Q. pubescens* and, in some cases, *Q. cerris*. Because of the high density of the stumps, the development of the shrub and herb layers, that are made by mesophilous and/or termophilous species, is usually low.

Hornbeam woodlands dominated by *Carpinus betulus* are copse woodlands growing on small plain area characterized by karst phenomena. The floristic composition is poor and mainly dominated by *Carpinus betulus* and *Castanea sativa* and/or oaks; the shrub cover is low, probably because of the management by man (cleaning of the underwoods).

Mixed broadleaves woodlands, that are locally present, include almost mesophilous woodlands growing on less sunny slopes, with a main north aspect or located on the shadowy areas of the valleys. The tree layer is dominated by *Q. robur*, *Q. petraea*, *Acer campestre*, *Castanea sativa* and *Carpinus betulus*, besides *Ulmus minor*, *Fraxinus excelsior* and *Prunus avium*. The main shrub species are *Corylus avellana*, *Crataegus monogyna* and *Cornus sanguinea*.

Not well-structured woodlands. Because of the relevant impacts of the human activities on the Brescia sub-urban areas, many woodlands are characterized by a high artificiality and degradation, so that they can be considered as anthropic fomations (see law DCR 21.12.2000 n. VI/120). In particular, two levels of degradation can be identified: woodland degradation at the structural level (a) and woodland degradation at the ecosystem level (b).
Woodland formations of destructured broadleaves (a) are degraded in quantity and quality according to the amount of human disturbance. Even where the floristic composition is close to the natural formation, the structure is simplified because of the tree thinning out.
Woodlands of deeply degraded broadleaves (b) are the most degraded areas, usually dominated by *Robinia pseudoacacia*, that could be an element of disturbance or could completely replaces the original vegetation. The presence of the original (natural) species is generally low and shrub layer is poor in cover, species diversity and value, being constituted by species widely distributed (e.g. *Corylus avellana*, *Crataegus monogyna*) and associated with ruderal ones (e.g. *Rubus* spp., *Sambucus nigra*). Also the herbs cover is very low and mainly made by widely distributed (and eventually nitrophilous) species, such as *Poa trivialis*, *Galium aparine* and *Urtica dioica*.

Shrublands and grasslands. Shrublands are mainly represented by termo-xerophilous shrub formations typical of a limestone substrate, that developed after the abandonment of agricultural or forestry-pastoral activities. Principal species in the shrub layer are: *Quercus pubescens*, *Ostrya carpinifolia*, *Fraxinus ornus*, *Cotinus coggygria*, *Amelanchies ovalis*, *Juniperus communis* and *Rosa* spp., besides some other Mediterranean species. The herb layer is well developed and structured and composed by termo-xerophilous species such as *Sesleria varia*, *Polygala chamaebuxus*, *Dactylis glomerata* and *Globularia nudicaulis*.
Termo-eliophilous shrublands are also present, being connected with the anthropic thinning out of woodlands dominated by *Acer* spp., *Fraxinus excelsior* or other mesophilous broadleaves. The shrub layer is dominated by *Corylus avellana*, *Ostrya carpinifolia* and *Salix caprea* and by almost eliophilous species linked to the destructuring of the woodlands, such as *Crataegus monogyna*, *Cornus sanguinea*, *Euonymus europaeus* and *Viburnum opulus*.
Stable grasslands and submountain pastures are artificial or semiartificial grasslands with a high landscape and floristic value. The floristic composition is affected by human disturbances (such as periodic mowing and/or fertilization); abundant species are: *Arrhenatherum elatius*, *Holcus lanatus*, *Lolium perenne*, *Anthoxanthum odoratum*, *Dactylis glomerata*, *Poa pratensis*, *Festuca pratensis*, *Phleum pretense*, *Lotus corniculatus*, *Trifolium pretense*, *T. repens*, and some termo-xerophilous species such as *Salvia pratensis*, *Achillea millefolium*, *Silene vulgaris* and *Galium mollugo*.
Degraded herb formations are also present on the study area, that are usually characterized by low (but sometimes continuous) vegetation cover and pioneer species. Typical areas are a) uncultivated lands at the initial phases of the revegetation after the agriculture abandonment, that are characterized by a high per cent of nithrophilous species because of

the the previous fertilizations, and b) quarry areas, that are chracterized by a discontinuos, often effimere and ruderal vegetation.

2.6.3 Floristic elements

The structure of the hill woodlands on the study area is determined by very common and autoctonous tree and shrub species, such as: *Acer campestre*, *Castanea sativa*, *Cornus sanguinea*, *Corylus avellana*, *Crataegus monogyna*, *Fraxinus ornus*, *Genista germanica*, *Juniperus communis*, *Ligustrum vulgare*, *Ostrya carpinifolia*, *Prunus avium*, *P. spinosa*, *P. mahaleb*, *Quercus petraea*, *Q. pubescens*, *Rosa arvensis*, *R. canina*, *Sorbus torminalis*, *Ulmus minor*, *Viburnum lantana*, besides *Cotinus coggygria* and *Pistacia terebinthus* on south slopes (Cappelli & Stefani 1986; De Carli et al. 1999; Bona & Zanotti 2005). Nevertheless, because of the climatic influence of the Garda lake, also species with a Mediterranean distribution, such as *Dictamnus albus*, *Erica arborea* and *Rhamnus alaternus*, represent a consistent percent of the floristic heritage, especially at north of Mazzano and Nuvolento, on Monte Budellone, Monte Mascheda, Monte Maddalena, Monte Denno and Monte Paina (Morelli 1997). Euri-Mediterranean species (e.g. *Eryngium campestre*, *Pistacia terebinthus*, *Teucrium chamaedrys*), steno-Mediterranean ones (e.g. *Centranthus ruber*), Mediterranean species with an eastern distribution (e.g. *Coronilla emerus*, *Fraxinus ornus*), and sub-Mediterranean species (e.g. *Artemisia alba*) are all present (Savoldi et al. 2011a). On the most thermophilous and south-exposed cropout areas of the calcareous substrate (e.g. Monte Mascheda, Monte Trinità, Monte Fieno, Monte Fratta, Monte Camprelle) some populations of *Phyllirea latifolia* can also be found (Crescini 1983; Morelli 1997).
The consistent presence of past and current man activities is revealed by the presence of some species that were used for past reforestations, such as *Cupressus sempervirens* and *Laurus nobilis* at lower altitude, *Larix decidua*, *Picea abies* and *Pinus nigra* in chestnut woods and *Alnus glutinosa* and *Populus* spp. along rivers (Cappelli & Stefani 1986). Also the presence of some exotic and invasive species (e.g. *Acer negundo*, *Ailanthus altissima*, *Ambrosia artemisiifolia*, *Amorpha fruticosa*, *Artemisia verlotorum*, *Buddleja davidii*, *Parthenocissus quinquefolia*, *Robinia pseudoacacia*, *Sycios angulatus*) are symptomatic of such a presence (Savoldi et al. 2011a; De Carli et al. 1999).
On the other hand, the naturalistic value of the study area is high thanks to the presence of many valuable species, even protected by laws (see Convention of Washington 1979; LR 33 27.07.1977; Convention of Berna 1979; Council Directive 92/43/EEC 21.05.1992; Credaro & Pirola 1992; Conti et al. 1997a, 1997b; DGR 8/7736 24.07.2008), such as orchids: *Ophrys apifera*, *Op. bertolonii*, *Op. fuciflora*, *Op. insectifera*, *Op. sphecodes*, *Orchis simia*, *O. sambucina*, *O. maculata*, *O. mascula*, *O. militaris*, *O. morio*, *O. pallens*, *O. papilionacea*, *O. purpurea*, *O. tridentate*, *O. ustulata*, *Platanthera bifolia*, *P. chlorantha* and *Serapias vomeracea* (Cappelli & Stefani 1986; Fenaroli & Tonni Bazza 1994; Cristini et al. 1995; Gobbini 2006). Endemic and rare species also grow on the quarry surroundings: the endemic *Campanula elatinoides* can be found on Monte Maddalena and Monte Denno,

some populations of *Aphyllanthes monspeliensis* are present between Colle S. Vito and Costa Sabbioni (Morelli 1997). Many naturalistic emergencies grow on the *Altopiano di Cariadeghe* and on the Municipality of Botticino: *Centaurea rhaetica*, *Cephalanthera longifolia*, *Crocus biflorus*, *Corydalis cava*, *Cyclamen purpurascens*, *Euphrasia tricuspidata*, *Gentiana cruciata*, *Globularia cordifolia*, *Lilium buliferum*, *Listera ovata*, *Pedicularis acaulis*, *Paeonia officinalis*, *Rosa gallica* and *Ruscus aculeatus* (data from: carta naturalistica della Regione Lombardia 2011). The Municipality of Botticino also hosts: *Anacamptis pyramidalis*, *Anemonoides nemorosa*, *Aphyllanthes monspeliensis*, *Argyrolobium zannonii*, *Aruncus dioicus*, *Biscutella cichoriifolia*, *Campanula rapunculoides*, *C. rapunculus*, *C. rotundifolia*, *C. spicata*, *C. trachelium*, *Cephalanthera damasonium*, *Conium maculatum*, *Convallaria majalis*, *Cyclamen hederifolium*, *Daphne alpina*, *D. laureola*, *Dianthus carthusianorum*, *D. seguieri*, *D. sylvestris*, *Erythronium dens-canis*, *Ferulago campestris*, *Fragaria vesca*, *Galanthus nivalis*, *Geranium macrorrhizum*, *Gladiolus italicus*, *G. palustris*, *Gratiola officinalis*, *Groenlandia densa*, *Herminium monorchis*, *Himantoglossum adriaticum*, *Ilex aquifolium*, *Iris graminea*, *I. pallida*, *Lemna trisulca*, *Limodorum abortivum*, *Peucedanum raiblense*, *P. schottii*, *Primula vulgaris*, *Pseudolysimachion spicatum*, *Pulsatilla montana*, *Quercus ilex*, *Rhamnus saxatilis*, *Sempervivum tectorum*, *Sparganium erectum* and *Verbascum phoeniceum* (data from: Museo di Storia Naturale di Brescia 2011).

2.7 Fauna

Organic studies on faunal populations living on the study area are laking, thus, data on mammals (Prigioni et al. 2001; Spegnesi 2002), reptiles and amphibians (Bennati et al. 1996; Bernini et al. 2004) living on similar habitats of the surroundings of the Botticino extractive basin are here reported (Table 2.6), with particular reference to those that are considered priority for conservation (see Council Directive 92/43/CEE; LN 11.02.1992 n. 157; DGR 20.4.2001 n. 7/4345; IUCN 2001).

Class/order	Family	Species (IUCN)
Mammals – Insectivore	Soricidi	*Sorex minutes*, *Sorex alpines*, *Neomys fodiens*, *Crocidura suaveolens*
Mammals – Rodent	Sciuridi	*Sciurus vulgaris* (LR)
	Gliridi	*Eliomys quercinus* (VU), *Glis glis* (LR), *Muscardinus avellanarius*
	Muridi	*Apodemus sylvaticus*
Mammals – Carnivore	Mustelidi	*Martes martes*, *Mustela putorius*
Chiropterans	Rinolofidi	*Rhinolophus euryale* (VU), *Rhinolophus ferrumequinum* (LR), *Rhinolophus hipposideros* (VU)
	Vespertilionidi	*Barbatella barbastellus* (VU), *Myotis bechsteinii* (VU), *Myotis capaccinii* (VU), *Myotis daubentonii*, *Myotis mystacinus*, *Myotis emarginatus* (VU), *Myotis myotis* (LR), *Myotis nattereri*, *Myotis blithii*, *Nyctalus*

		leisleri (LR), *Nyctalus noctula*, *Pipistrellus nathusii*, *Plecotus auritus*, *Plecotus austriacus*, *Miniopterus schreibersii* (LR)
	Molossidi	*Tadarida teniotis*
Reptiles – Squamatae	Anguidae	*Anguis fragilis fragilis*
	Lacertidae	*Lacerta bilineata**
	Colubridae	*Hierophis viridiflavus**, *Coronella austriaca*, *Elaphe longissima*, *Natrix natrix**, *Natrix tassellata*
	Viperidae	*Vipera aspis francisciredi**
Amphibians – Caudata	Salamandridae	*Salamandra salamandra salamandra**, *Triturus carnifex**, *Triturus vulgaris meridionalis**, *Bombina variegata*
Amphibians – Anura	Bufonidae	*Bufo bufo**, *Bufo viridis viridis**
	Hylidae	*Hyla intermedia*
	Ranidae	*Rana dalmatina**, *Rana latastei**

Table 2.6 Species that are or might be present on the study area (Legend: * sure presence)

Birds. Data on birds (Brichetti e Cambi 1985; Brichetti e Fasola 1990; Fornasari et al. 1992; Brichetti 1993; Morelli 1997) only regards species that are considered priority for conservation purpose (see Directive 409/79/CEE; Council Directive 92/43/CEE; LN 11.02.1992 n. 157; Tucker & Heath 1994; LIPU & WWF 1999; DGR 20.4.2001 n. 7/4345; IUCN 2001) are here reported (Table 2.7).

Order	**Family**	**Species**	**Fenology**	**IUCN, SPEC**
Falconiformes	Falconidae	*Falco tinnunculus*	MP	SPEC 3
Accipitriformes	Accipitriformidae	*Accipiter nisus*	MP	-
		*Circaetus gallicus**	MN	EN; SPEC 3
		*Pernis apivorus**	MN	VU
		*Milvus migrans**	MN	VU; SPEC3
Strigiformes	Tytonidae	*Tyto alba*	MP	LR; SPEC 3
	Strigidae	*Strix aluco**	MP	LR
		*Otus scops**	MN	LR; SPEC 2
		Athene noctua	NR	SPEC 3
		Asio otus	MP	LR
Columbiformes	Columbidae	*Streptopelia turtur**	MN	SPEC 3
Caprimulgiformes	Caprimulgddae	*Caprimulgus europaeus*	MN	LR; SPEC 2
Coraciiformes	Upupidae	*Upupa epops*	MN	SPEC 3
Galliformes	Phasianidae	*Coturnix coturnix**	MP	LR; SPEC 3
Piciformes	Picidae	*Picus viridis**	NR	-
		*Dendrocopos major**	MP	-
		*Jynx torquilla**	MN	SPEC 3
Passeriformes	Alaudidae	*Alauda arvensis*	MP	SPEC 3
	Hirundinidae	*Hirundo rustica*	MN	SPEC 3
		*Ptyonoprogne rupestris**	MP	-

	Delichon urbicum	MN	SPEC 3
Motacillidae	*Anthus campestris*	MN	SPEC 3
Tichodromadidae	*Tichodroma muraria**	MP	-
Sylviidae	*Hippolais polyglotta*	MN	-
	*Acrocephalus palustris**	MN	-
	Sylvia melanocephala	NR	-
	*Sylvia hortensis**	MN	EN; SPEC 3
	Sylvia nisoria	MN	-
Muscicapidae	*Muscicapa striata*	MN	SPEC 3
	Oenanthe hispanica	MN	VU; SPEC 2
	Phoenicurus phoenicurus	MN	-
	Monticola solitarius	MP	SPEC 3
Laniidae	*Lanius colllurio*	MN	SPEC 3
Sturnidae	*Sturnus vulgaris*	MP	SPEC 3
Passerinae	*Passer domesticus italiae*	NR	SPEC 3
	Passer montanus	MP	SPEC 3
Fringillidae	*Coccothraustes coccothraustes**	MP	-
	Carduelis cannabina	MP	SPEC 2
Emberizidae	*Emberiza hortulana*	MN	LR
	Emberiza calandra	MP	SPEC 2
	*Emberiza cia**	MP	SPEC 3

Tab. 2.7 Species that are or might be present on the study area. Legend: * sure presence; MP partial migrant; :MN nest-builder migrant; NR resident nest-builder; SPEC 2 species with an unfavoreble conservation state with >50% of populations or areal in Europe; SPEC 3 species with an unfavoreble conservation state with populations or areal not in Europe

Invertebrates. The invertebrate fauna of the caves of the Brescian Karst Pre-Alps is very interesting from the biogeographic point of view, also counting endemic species, even exclusive of single caves. For example, in the caves of Monte Maddalena, interesting beetles were found, such as *Antisphodrus boldorii*, *Boldoria breviclavata*, *Boldoriella humeralis boldorii*, *Trechus quadristriatus*, *Nebria brevicollis*, *Choleva cisteloides* and *Batrisodes oculatus*, together with some myriapods such as *Crobainosoma fonticolorum*, *Atractosoma ghidinii* and *Polymicron latzeli,* two spiders, i.e. *Troglohyphantes Gestroi* and *Chthonius tenuis*, and two isopods, i.e. *Androniscus dentiger* and *Trichonischus mancinii* (Ghidini e Allegretti 1937).

2.8 Landscape and ecological network

The Municipalities of Botticino, Nuvolento, Nuvolera and Serle are included in the category of the "*morainal slope of the high plain and piedmont area till the karst area*", while the Municipality of Paitone is included on the "*area of valley floor: Valle, Gavardo e Vobarno*" (Morelli 1997; regional law D.C.R. 21.04.2004 n. 22). The Botticino extractive basin is very heterogeneous and made by different landscape units: historical centres, built areas, productive areas, quarries, degraded areas, agricultural areas, sowable lands, meadows, chestnut woods, vineyards (which coexist with quarries in the locality of Molvina and Casella in the Nuvolera Valley, and in the locality Marguzzo on Paitone), deciduous woodlands, grasslands, shrublands, debris and rocks and hydric network (Fig. 2.8).

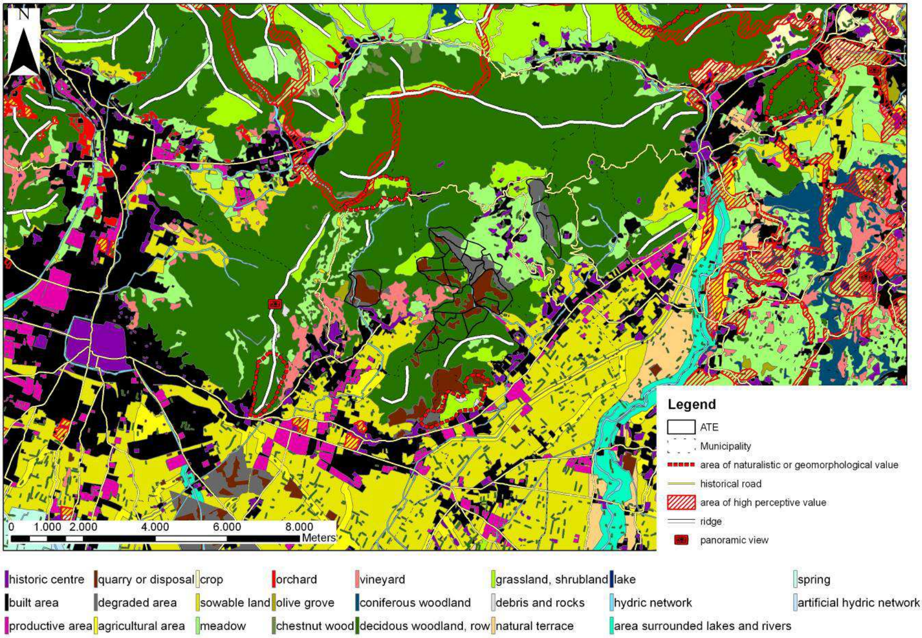

Fig. 2.8 Landscape overview of the study area (data from: Geoportale della Lombardia)

The semi-natural and natural landscape units (mainly woodlands and grasslands) are part of the ecological network of the Brescian pre-Alps (Fig. 2.9). In particular, most area of the Botticino extractive basin is located on an *element of second level* of the Regional Ecological Network (RER), being also classified as a "*ambit of biogeographic specificness*" (BS3) of the Provincial Ecological Network (REP). The area on the surrounding of ATE 34 is also near one of the *elements of first level* of the RER, of higher naturalistic value, being also classified as a "*polyvalent area for the ecosystemic reconstruction on hill-mountain ambit*" (BS7) by the REP.

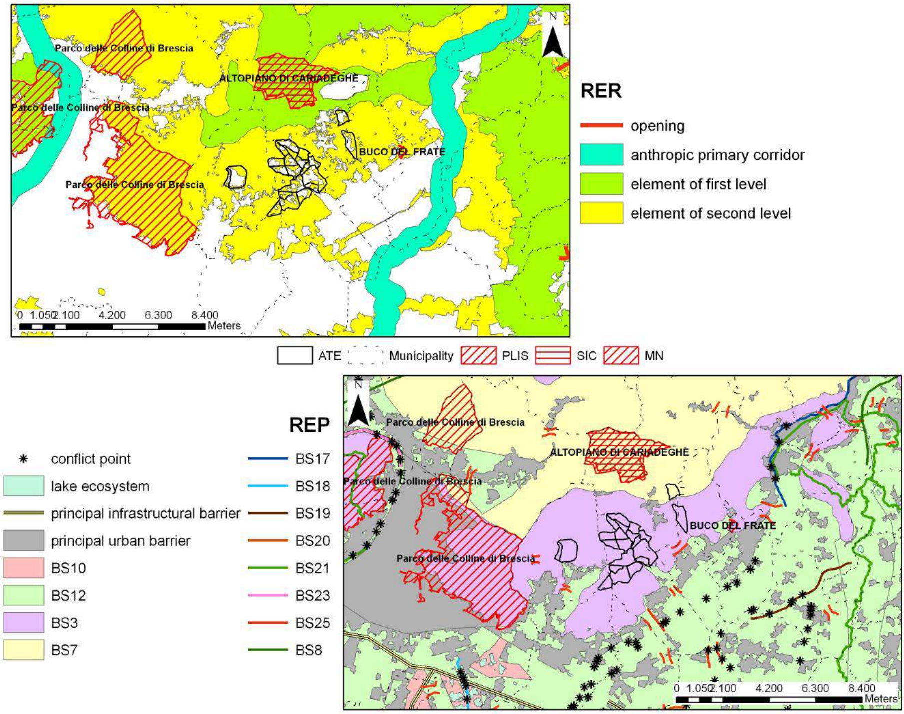

Fig. 2.9 RER and REP on the study area (data from: Geoportale della Lombardia)

The nearest protected areas to the Botticino extractive basin are a) the Natural Monument "Altopiano di Cariadeghe", which boundaries almost coincide with those of the homonymous S.I.C. (Site of European Comunity Interest IT2070018); b) the Natural Monument "Buco del Frate"; c) the Local Park on Super-Municipalities Interest (PLIS) "Colline di Brescia".

2.9 The local quarry activity

The exploitation of the *Corna* formation in the Botticino extractive basin has a very long history, as testified by the archaelogical evidences of the monumental centre of *Brixia* and on the east slopes of Monte Trinità dated I century A.D. (Beluffi & Bettinzoli 2010). The Botticino stone was firstly appreciated by Romans for its easy availability, besides its good technical (e.g. resistance to compression, tractability to chisel) and aesthetical properties: they considered such a stone as belonging to the group of *marmora* (i.e. stone of different origin that can be polished), by which the actual commercial name. Today, quarries are recognised as a part of the local cultural heritage, and can be observed by a tour itinerary, known as "*La Via del Marmo*" (i.e. "*Marble Street*") that allows to get close to the "work landscape" (not considered as a "not-landscape") of the quarries (data from: Provincia di Brescia, Area Ambiente).

2.9.1 From the Romans age to the twentieth-century

During the age of the Roman Empire, many buildings were built in the city of Brescia, such as the *Tempio di Vespasiano*, the *Theatre*, the *Forum* and the *Thermae* (Clerici & Meda 2005; Beluffi & Bettinzoli 2010). The extraction technique consisted on the insertion of wedges and levers on natural or artificial fractures on the stone (by use of a pick, known as *fossoria dolabra*) to undermine the rocky blocks (Savoldi et al. 2011a). After the fall of the Roman Empire, the limestone exploitation decreased till the Medieval age: many quarries closed and material used for Roman buildings were re-employed for the construction of some Brescian buildings; *Brixia* itself became an "open-pit quarry" (Beluffi & Bettinzoli 2010). It is only with the re-found charm for the antiquity during the Renaissance, that the interest and the attention for the conservation for Roman heritage increased togheter with the exploitation of new extractive areas (Clerici & Meda 2005; Savoldi et al. 2011a).

First evidences about the management of the extraction activity in Botticino date back to the second half of the Sixtheeth century: the Municipality owned and let the principal quarries (known as *medoli*), first "category associations" born, the transport of the materials was still made by use of different types of handcart, buckets and oxcarts. Altough limestone was mainly used to produce slaked lime for town fortifications, the art of the stone-cutters of Rezzato (known as *picaprede* o *lapicidi*) was required for civic and military buildings inside and outside the Brescia Province, such as the *Porta di San Giorgio* of the fortress of Orzinuovi, made on 1544-1548 (Savoldi et al. 2011a).

After the fall on the production during the Eighteenth century because of the fall of the *Serenissima* (*Repubblica Veneta*) and the transition to the *Repubblica Cisalpina* (Beluffi & Bettinzoli 2010), the extraction of the Botticino increased and peaked during the Nineteenth century, thanks to the coming of the Neoclassicism. New borderlines for the extraction of the Botticino were opened with the job order of the *Monument to Vittorio Emanuele II* in Rome (also known as *Vittoriano* or *Altare della Patria*; unveiled on 4 june 1911 on the project of Giuseppe Sacconi), for which the use of the Botticino marble (10000 m^3) was promoted by the stastesman Giuseppe Zanardelli and other Brescian entrepreneurs (as Brescian was the artist, Angelo Zanelli, who realized the sculptural frieze above the tomb of the Unknown Soldier) (data from: Museo del Marmo di Botticino). At this time, the first industrial development took place, and new technological innovations were introduced. The quarry exploitation was limited to three main and characteristics extractive areas: a) the western slopes of Monte Fratta (near the urban center of Botticino Mattina), b) the southern slopes of Monte Paitone (near the urban centre of Paitone) and c) the southern slopes of Monte Marguzzo (near the urban centre of Mazzano).

During the Twentieth century, except for some recession phases in stone extraction connected with the First and the Second World Wars (Beluffi & Bettinzoli 2010), the quarry activity techniques much improved, thanks to the replacement of traditional extraction systems by explosive, pneumatic hammer, helical wire (and then diamond wire) and derricks. Thus, while first quarrymen organization (cooperatives) were borning, quantities of extracted materials increased, till the boom of the 60s-70s (10000 m^3/year, with the peak of 903000 t in 1983). By this time, the Botticino began to be appreciated more as a facing element, than a structural one: it was used for the *Nations Palace* in Ginevra (1931-1937), *Piazza della Vittoria* in Brescia (1929-1932) and the facing of the *Banca Popolare* of Verona (1973-1978; project by Carlo Scarpa) (Beluffi & Bettinzoli 2010; Savoldi et al. 2011a). Such a boom caused the development of a new exctration area: the Nuvolera Valley, between the Municipality of Nuvolento, Nuvolera and Serle.

2.9.2 The actual situation

Today the "*Botticino marble*" is known all over the world, being mainly exported in India, and secondly in Japan, United Stated and United Arab Emirates (Clerici & Meda 2005).

Extraction techniques. All over the extractive basin, the quarry activity is organized by 6 different phases, i.e. a) site preparation, b) creation of the track for the access to the working area, c) barring and placing in security of the area, d) tracing of the cultivation workings, e) open-pit exploitation of the ore body; f) rehabilitation of the degraded area. As for the exploitation of the ore body, the most used tecnique for the limestone extraction is the "*technique to terraced face*" ("*a fronte gradonato*"): the ore body is exploited sub-horizontally, with one or more advancing faces. In particular, two methods are generally used (Fig. 2.10): a) long and inclined cuts ("*metodo per tagli lunghi inclinati*") and b) descending slices ("*metodo per trance discendenti*"). The last is used on the quarries of ATE 34 and 35, and often associated to the first method.

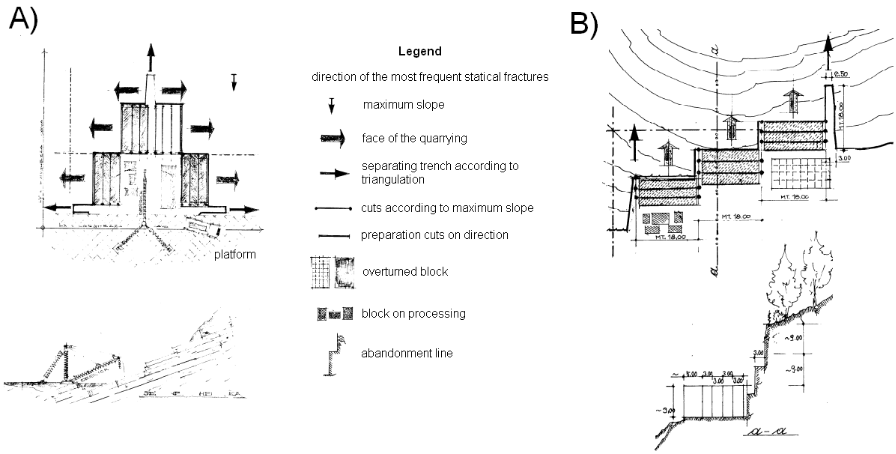

Fig. 2.10 Quarrying methods as illustrated by engineer Carlo Costa: A) "*metodo per tagli lunghi inclinati*", and B) "*metodo per trance discendenti*" (from: DCR 21.12.2000 n. VI/120, modified)

Taking into account that techniques vary according to the local characteristics of the ore body, the exploitation and the cutting of the stone material proceed generally according to weakness surfaces, such as the *stiloliti* (solution surfaces due to the pressure of the overhanging sediments; known by quarrymen as "*vena grassa*", i.e. "*big vein*") (Clerici & Meda 2005).

Extracted materials. According to the local geological characteristics and to the sedimentary conditions, the exploited ore body of the *Corna* presents many local aesthetic and mechanical differences, which could affect its use in architecture and building (Clerici & Meda 2005). In particular, four main commercial categories can be identified (Fig. 2.11; Bettinzoli & Beluffi 2010): a) the "marble *Botticino Classico*", extracted on Monte Fratta, near Botticino (ATE 2, 3, 4); b) the marble "*Botticino Semiclassico*", extracted in the Nuvolera valley (ATE 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23); c) the marble "*Botticino Fiorito*", extracted in the Nuvolera valley (ATE 13, 29, 30, 31, 32, 33); d) the polychromatic breccia "*Breccia Oniciata*", extracted by the hill area of Serle and Paitone (ATE 34, 35).

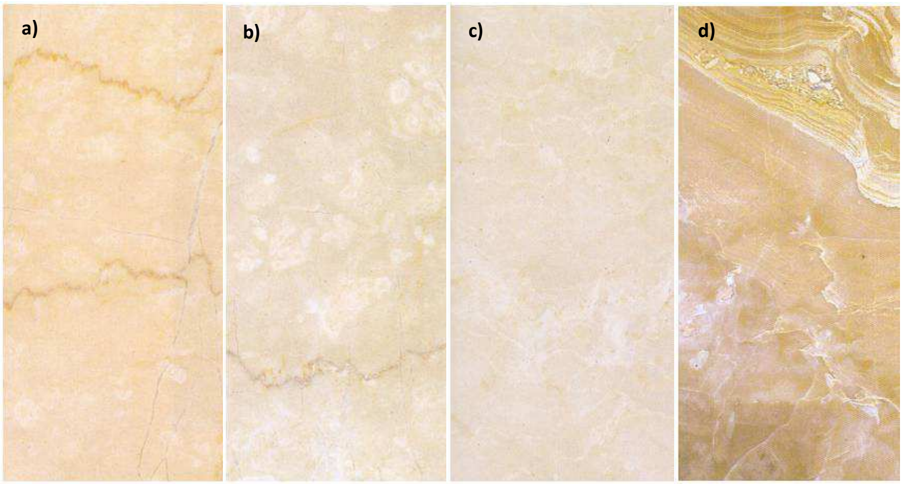

Fig. 2.11 Main commercial categories: a) *Botticino classico*, b) *Botticino semiclassico*, c) *Botticino fiorito*, d) *Breccia Oniciata*

Quantities of extracted material. With reference to the years 2006-2010 (Table 2.8), 740319 t/year were extracted on the Botticino sub-basin with a mean daily production of 2692 t of material. 2675149 t/year were extracted in central basin of the Nuvolera valley with a mean daily production of 9728 t of material; 573306 t/year were extracted on the western sub-basin of Serle and Paitone with a mean daily production of 2096 t of material.

	Type of material	Botticino	Nuvolera	Nuvolento	Paitone	Serle	Total
2006	Ornamental	179265	183813	38232	73225	13103	487638
	Crusched	328693	787165	189528	425038	319174	2049598
2007	Ornamental	180367	181780	58866	78886	9016	508915
	Crusched	556253	719850	291815	495431	503401	2566750
2008	Ornamental	168350	140673	50090	64710	6782	430605
	Crusched	397751	1032020	307642	597302	460226	2794941
2009	Ornamental	138477	98511	48713	45604	5574	336879
	Crusched	235982	859320	125543	423978	312844	1957667
2010	Ornamental	150218	105215	45129	48193	6053	354808
	Crusched	312741	946920	86821	367159	274848	1988489

Table 2.8 Total production (t) of ornamental stone and crusche stone on the Botticino extractive basin from 2006 to 2010 (data from: Savoldi et al. 2011a)

A general decline is recorded on the last two years because of the global economic crisis.

2.10 Databases consulted, chapter 2

- Carta naturalistica della Lombardia - Regione Lombardia. http//www.cartografia.regione.lombardia.it
- Carta turistica "La Via del Marmo". Provincia di Brescia, Area Ambiente
- Centro Agrometeorologico Provinciale – Settore Agricoltura – Provincia di Brescia http//meteo.provincia.brescia.it
- Database Museo di Storia Naturale di Brescia
- Database Ufficio Autorizzazione Cave, Settore Ambiente - Provincia di Brescia
- Geoportale della Regione Lombardia. Dati, mappe, servizi geografici del territorio lombardo disponibili in rete. Sistema Informativo per la consultazione dell'Infrastruttura per l'Informazione Territoriale della Lombardia. Unità Organizzativa Infrastruttura per l'Informazione Territoriale, Direzione Generale Territorio e Urbanistica – Regione Lombardia http://www.cartografia.regione.lombardia.it/geoportale
- Mostra permanente presso il Museo del Marmo di Botticino, via Cave 74, Botticino Mattina
- Progetto CARG – Regione Lombardia. Fogli D5c4, D5b4 http://www.cartografia.regione.lombardia.it/CARGWEB
- Servizio Meteorologico Regionale - Arpa Lombardia http://ita.arpalombardia.it/meteo/meteo.asp

2.11 References, chapter 2

- Andreis C., Sartori F. 2009. Sintassonomia dei boschi lombardi. Natura Bresciana 36: 173-178
- Beluffi E., Bettinzoli M. 2010. Il museo diffuso del Botticino. Proposte per la valorizzazione di territorio, cultura e lavoro del bacino marmifero bresciano. Tesi di Laurea in Architettura degli Interni. Politecnico di Milano, Facoltà di Architettura e Società. Relatore: Basso Peressut L., Correlatore: Sacchetti M.

- Bennati R., Bonetti M., Mazzi F., Povinelli G. 1996. Sintesi delle conoscenze su l'erpetofauna bresciana. Commentari dell'Ateneo di Brescia
- Bernini F., Bonini L., Ferri V., Gentilli A., Razzetti E., Scali S. (a cura di) 2004. Atlante degli Anfibi e dei Rettili della Lombardia, Monografie di Pianura, n. 5, Provincia di Cremona, Cremona
- Blasi C. (a cura di) 2010. La vegetazione d'Italia. Palombi and Partner Srl, Roma
- Bona E., Zanotti E. 2005. Bibliografia botanica delle piante vascolari nel Bresciano primo aggiornamento. Addenda ed emendanda 1993-2003. Natura Bresciana 34: 187-206
- Brenna S. 2001. Carta dei pedopaesaggi della Lombardia – Prima approssimazione della base dati georeferenziata dei suoli d'Italia alla scala 1:250.000. Programma Interregionale Agricoltura e Qualità – Misura 5, Ersal
- Brichetti P. 1993. Situazione dell'avifauna della provincia di Brescia – aggiornamento
- Brichetti P., Cambi D. 1985. Atlante degli uccelli nidificanti in provincia di Brescia (Lombardia) 1980-1984. Natura Bresciana, Monografia 8
- Brichetti P., Fasola M. 1990. Atlante degli uccelli nidificanti in Lombardia (1983-87). Editoriale Ramperto, Brescia
- Cappelli M., Stefani A. 1986. Caratteri ecologici di un ceduo del Monte Maddalena (Brescia). Natura Bresciana 21: 91-122
- Conti F., Manzi A., Pedrotti F., 1997a, Libro Rosso delle Piante d'Italia. Associazione Italiana per il W.W.F., Roma
- Conti F., Manzi A., Pedrotti F., 1997b., Liste Rosse Regionali delle Piante d'Italia. Dipartimento di Botanica ed Ecologia, Università di Camerino, Camerino
- Convention on the Conservation of European Wildlife and Natural Habitats. Berna, 19.09.1979
- Convention on International Trade in Endangered Species of Wild Fauna and Flora. Washington, D.C., 03.03.1973
- Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
- Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds
- Credaro V., Pirola A., 1992, Revisione della flora vascolare da proteggere. Regione Lombardia, Pavia
- Crescini A. 1983. La Phyllirea latifolia L. nel territorio bresciano. Natura Bresciana 20: 73-92
- Cristini P., Formenti S., Piai G., Prati G., Rossi G. 1995. Primo contributo per la flora di Botticino. Specie di Licofite, Sfenofite, Pterofite e Spermofite presenti nel Comune di Botticino. 57 pag.
- Clerici A., Meda A. 2005. Confronto tra le caratteristiche meccaniche di diversi livelli di estrazione del Botticino Classico. Giornale di Geologia Applicata 2: 307-312
- Decreto del Consiglio Provinciale 21.04.2004 n. 22 – Piano Territoriale di Coordinamento Provinciale (e successive modifiche)
- Decreto del Consiglio Provinciale 20.04.2009 n. 26 –Piano di Indirizzo Forestale (e successive modifiche)
- Decreto della Giunta Regionale 24.07.2008 n. 8/7736 – Determinazione in ordine agli elenchi di cui all'art. 1, comma 3 della legge regionale 31 marzo 2008 n. 10. Disposizioni per la tutela e la conservazione della piccola fauna, della flora e della vegetazione spontanea

- De Carli C., Tagliaferri F., Bona E. 1999. Atlante corologico degli alberi e degli arbusti del territorio bresciano (Lombardia orientale). Monografie di "Natura Bresciana" n. 23, Museo Civico di Scienze Naturali di Brescia
- Del Favero R. (a cura di) 2002. I tipi forestali della Lombardia. Regione Lombardia, CIERRE ed., Sommacampagna (VR)
- Deliberazione Consiglio Regionale 19 marzo 2008, n. VIII/582 – Variazione e rettifica del vigente piano cave della Provincia di Brescia relativo ai settori merceologici argilla, pietre ornamentali e calcari, ai sensi della l.r. n. 14/1998. Bollettino Ufficiale della Regione Lombardia 13 maggio 2008, n. 20, 1° supplemento straordinario
- Deliberazione Consiglio Regionale 21 dicembre 2000 n. VI/120 – Nuovo Piano delle attività estrattive della Provincia di Brescia - settori argille, pietre ornamentali e calcari, ai sensi dell'art. 8 della l.r. n. 14/1998. Bollettino Ufficiale della Regione Lombardia 20 marzo 2001, n. 12, 1° supplemento straordinario
- Deliberazione della Giunta Regionale 20.04.2001 n. 7/4345 – Programma regionale per gli interventi di conservazione e gestione della fauna nelle aree protette.
- ERSAL 1997. I suoli dell'area morenica gardesana – settore bresciano SSR 23''1:25000
- FAO 1998. World Reference Base for Soil Resources. Rome: Food and Agriculture Organization of the United Nations
- Fenaroli F., Tonni Bazza C. 1994. Orchidee spontanee nel Bresciano. Ecoservizi
- Fornasari L., Bottoni L., Massa R., Fasola M., Brichetti P., Vigorita V. 1992. Atlante degli uccelli svernanti in Lombardia. Regione Lombardia e Università degli Studi di Milano, Milano
- Gallinaro N. (a cura di) 2004. Boschi di Lombardia. Un patrimonio da vivere. Regione Lombardia, Cierre Edizioni, 155 pages
- Ghidini G.M., Allegretti C. 1937. Le caverne del Monte Maddalena e la loro fauna
- Giacomini V., Fenaroli L. 1957. La flora. Conosci l'Italia. Touring Club Italiano, Milano
- Gobbini M. 2006. Orchidee a Paitone. Comune di Paitone
- IUCN 2001. IUCN Red List Categories and Criteria version 3.1 http://www.iucnredlist.org/technical-documents/categories-and-criteria/2001-categories-criteria
- Legge 11.02.1992 n. 157 – Norme per la protezione della fauna selvatica omeoterma e per il prelievo venatorio.
- Legge Regionale 27.07.1977 n. 33 - Provvedimenti in materia di tutela ambientale ed ecologica
- LIPU, WWF 1999. Nuova Lista Rossa degli ucceli nidificanti in Italia. Rivista Italiana di Ornitologia 69: 3-43
- Morelli C., 1997. Il Piano Territoriale Paesistico della Provincia di Brescia. Provincia di Brescia. Grafo
- Pavari A. 1916. Studio preliminare sulle colture di specie forestali esotiche in Italia. Annali del Regio Istituto Superiore Forestale Nazionale
- Pignatti S. 1979. I piani di vegetazione in Italia. Giornale Botanico Italiano CXIII: 411-428
- Prigioni C., Cantini M., Zilio A. 2001. Atlante dei Mammiferi della Lombardia. Regione Lombardia e Università degli Studi di Pavia, 324 pp.
- Savoldi S., Agostini M., Lucchini F., Papa F., Quecchia G., Serena C., Bellini R., Gilardelli F., Motta M., Nicoli B., Testa R., Zola G. 2011a. S.I.A. di bacino. Bacino estrattivo delle pietre ornamentali e dei pietrischi. Regione Lombardia, Provincia di Brescia, Comune di Botticino, Comune di Nuvolento, Comune di Nuvolera, Comune di Paitone, Comune di Serle. 974 pages.

- Savoldi S., Agostini M., Lucchini F., Papa F., Quecchia G., Serena C., Bellini R., Gilardelli F., Motta M., Nicoli B., Testa R., Zola G. 2011b. S.I.A. di bacino. Bacino estrattivo delle pietre ornamentali e dei pietrischi. Studio di Incidenza Ambientale Sito di Interesse Comunitario (S.I.C.) Altopiano di Cariadeghe. Regione Lombardia, Provincia di Brescia, Comune di Botticino, Comune di Nuvolento, Comune di Nuvolera, Comune di Paitone, Comune di Serle. 46 pages.
- Servizio Geologico d'Italia – ISPRA, a cura di Compagnoni B., Galluzzo F., Bonomo R., Capotorti F., D'Ambrogi C., Di Stefano R., Graziano R., Martarelli L., Pampaloni M.L., Pantaloni M., Ricci, Tacchia V.D., Masella G., Pannuti V., Ventura R., Vitale V. 2001. Carta geologica d'Italia - scala 1:1.000.000 (V edizione). S.EL.CA. Firenze
- Schirolli P. 2008. Corna. Carta Geologica d'Italia 1:50000 – Catalogo delle Formazioni. ISPRA
- Soil Survey Staff 2010. Keys to Soil Taxonomy, 11th ed. USDA – Natural Resources Conservation Service, Washington, DC.
- Spegnesi M., De Marinis A.M. (a cura di) 2002. Mammiferi d'Italia. Quad. Cons. Natura, 14, Min. Ambiente – Ist. Naz. Fauna Selvatica
- Tucker G.M., Heath M.F. 1994. Birds in Europe: their conservation status. Conservation Series no. 3. BirdLife International, Cambridge.

3 Vegetation dynamics

- Nature never breaks her own laws - Leonardo da Vinci

In order to plan a successful restoration, a detailed knowledge of initial site conditions is essential. In addition to the general information regarding biotic and abiotic factors (e.g. climate, lithology, pedology), detailed site-specific analyses are needed. In particular, the knowledge of spontaneous vegetation dynamics should be the basis to plan any restoration project, especially if its principal aim is to increase the speed of the revegetation and to direct it towards later successional phases with a high naturalistic value. In fact, the vegetation type growing on an area and its surroundings allow to check the environmental quality and the recolonization dynamics until the climacic stadium. The reconstruction of the vegetation succession (eventually by hypothesizing the later phases where they can not be identified) allows to understand the most suitable time and degree of human efforts that are required in order to obtain a successful restoration. The identification of biological indicators also allows to understand what species (and species traits) are positively and negatively selected by local limiting environmental conditions. This feature is fundamental in order to maximize restoration success and minimize restoration costs, taking into account that the influence of environmental site condition and spontaneous vegetation dynamics can not never be overcame.

3.1 Manuscript to be submitted: Time and features of successional phases of vegetation on abandoned limestone quarries

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Abstract

Despite relevant environmental impacts connected with quarry activity, little attention has been paid to different phases of vegetation dynamics. In abandoned quarries, revegetation starts from very adverse environmental conditions (i.e. bare, low fertile and not well structured soil with problems of water availability) and may follows the course of a succession often similar to a primary one. We studied plant communities succession across the limestone quarries of the Botticino extractive basin (Lombardy, Italy) by means of a classification-ordination approach of vegetation plots linked to an environmental data set. Particular attention was paid to time phases of vegetation succession after quarry abandonment and to temporal trend of the most abundant species by surveying surface ages. We found that vegetation dynamics follow the course of a primary-like succession. Vegetation establishment and development during first years after abandonment ("pioneer phase") are affected by abiotic filters which determine the dominance of few ruderal and annual species. After that, we identified an "early phase", an "intermediate phase" and then a "later phase", characterized by an increasing presence of perennial species, included trees and shrubs, with a progressive increase of inter-specific competition and the consequent influence of biotic filters. Nevertheless, abiotic filters always play a key role, so that different types of vegetation can be identified according to environmental heterogeneity from the "early phase". On the basis of such differences, different "advanced phases", such as different types of woodlands and grasslands, can be hypothesized according to environmental characteristics. Nevertheless, because of the great differences on vegetation features between such phase and the previous ones, human efforts are recommended for restoration purposes, almost on platforms and dump deposits, in order to recreate a self-sustaining vegetation valuable from the naturalistic point of view.

Keywords: Limestone quarries, vegetation succession, morphological heterogeneity, species richness, biological forms

Introduction

Vegetation dynamics on abandoned quarries generally starts from very adverse environmental conditions (i.e. bare, low fertile and not well structured soil with problems of water availability) and follows the course of a succession that is often similar to a primary one (e.g. Dana & Mota 2006; Frouz et al. 2008). In such a succession, that proceeds by progressive changes in plant species and vegetation, four principal phases can be generally identified according to the relative presence of plant ecological groups (e.g. pioneer species, woodland species): "pioneer phase", "intermediate phase", "late colonizer phase" and "fluctuating phase" (Martínez-Ruiz & Fernández-Santos 2005). Nevertheless, the different phases are not often immediately and clearly distinguishable and can present directions sometimes unforeseeable (Frouz et al. 2008). In fact, they depend by many environmental factors, that could affect pattern of vegetation and species diversity, phases duration (Prach 2003; Dana & Mota 2006) and animal community (e.g. Holec & Frouz 2005). Even if previous authors described the successional sequences on quarry or mining areas (e.g. Novák and Prach 2002; Martínez-Ruiz & Fernández-Santos 2005; Novák and Konvička, 2006), exhaustive quantitative studies on time series are scarce. Novák and Konvička (2006) used an ordination approach to investigate the relationship between successional vegetation, ages of individual sites, and distances to the closest natural habitats (xerophilous grasslands). Other studies based their analyses on the regeneration stages of vegetation or on toposequence (Kater et al. 2003; Duan et al. 2008; Gentili et al. 2011): colonizers, herbs, shrubs, woodlands. However, dynamics of secondary successions, late-successional or climax phases are in large part unknown. The temporal, successional sequence after quarry abandonment requires multi-years, time expensive, field researches and/or to have a complete knowledge of the ages of (new and abandoned) excavation areas across big extractive basins. Precise information on a quarry surface age may provide the possibility to estimate the colonization rate and the type of communities developing in a certain time.

Many biotic and abiotic factors affect succession, such as species dispersal and competition, aspect, slope, grain size of dump deposits, soil development and characteristics, natural or human disturbance, distance to human settlements (Martínez-Ruiz & Fernández-Santos 2005). However, one of the main factor affecting vegetation dynamics is the geomorphological heterogeneity which characterize quarries, which generally presents three main different man-made landforms: artificial cliffs, embankments and platforms (e.g. Yuan et al. 2006). Some studies were conducted in order to investigate such heterogeneity within-quarries, but very few studies were conducted over a large excavation area (Weather and Cullen 1997; Gentili et al. 2011).

The aim of this study was to investigate the spontaneous vegetation succession of several abandoned quarries with ages of abandonment starting from about 80 years ago. We applied an original approach to assign plant community to a precise successional phase and detected time length of each successional phase, based on the relative abundance of colonizer (annual herbs) and late successional species (e.g. perennial woodlands). As a case study, we considered the Botticino extractive basin in the Brescia Province (Lombardy, Italy), that is internationally known for the extraction of ornamental limestone and where age of site abandonment of extractive areas is known. In this area, working and abandoned quarries offer the great possibility to study spontaneous vegetation dynamics by a synchronic approach, from the early to the late phases of colonization process. In particular, we tried to assess and discuss: a) how many plant successional phases can be recognized and which abiotic factors affect each step of the succession; b) the role of time in determining species composition; c) similarities and differences of spontaneous vegetation dynamics on the studied quarries with respect to primary natural ones.

Materials and methods

Site description. The Botticino basin is the second most important extractive basin in Italy, after the Carrara's one, for dimension, number of quarries, quantity of extracted materials, staff and economic relevance. The exploited limestone, commercially known as "Botticino Marble", is an ornamental stone, which is mainly used as facing and structural element for buildings, such as the *Monument to Vittorio Emanuele II* in Rome (also known as *Vittoriano* or *Altare della Patria*). The demand of such a stone (today in decline because of the economic crisis) greatly increased by the nineteenth century; now the export interests all the world, and especially India, Japan, United States of America and United Arab Emirates (Clerici & Meda 2005).

The extractive basin is located on the hill area of the Brescia Province (Lombardy), at north-east of the city of Brescia and includes 135 quarries (of which only 2 are abandoned) over 5 Municipalities: Botticino, Nuvolento, Nuvolera, Paitone and Serle (Fig. 1). Altitude varies from less of 180 to more than 650 m a.s.l.

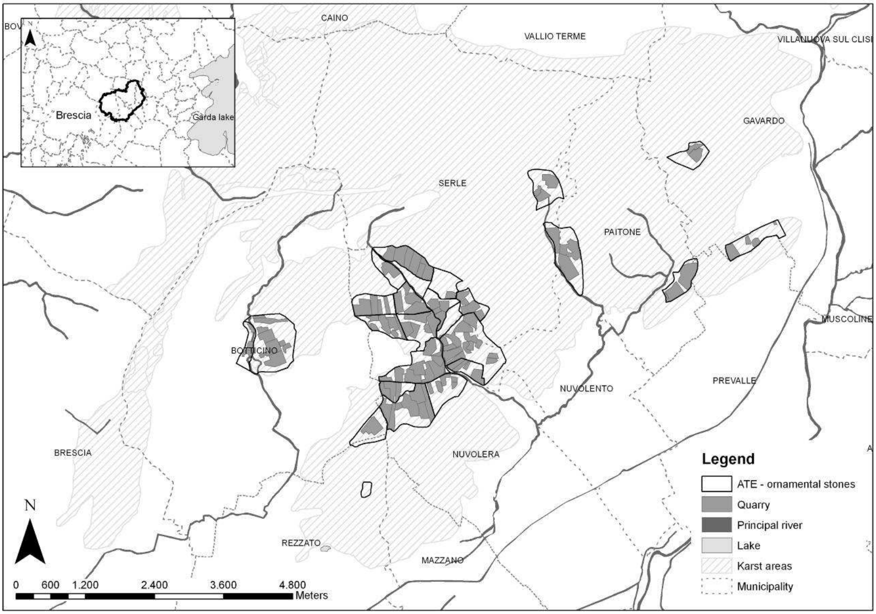

Fig. 1 Location of the study area

The main lythology is made up of limestone and karst rocks of the *Corna* formation, with its calcareous and breccia facies (Servizio Geologico d'Italia 2008). According to data recorded on the meteorological stations of ARPA – Regional Meteorological Service, located on Caino (years from 2001 to 2010), and Brescia – ITAS Pastori (years from 1990 to 2010), the climate is continental, with cold and dry winters, rainy springs and autumns. The mean annual temperature is 13.5°C and the mean annual rainfall is 1026 mm. The vegetation on the quarries surroundings is mainly characterized by woodlands often managed as copse, dominated by *Quercus pubescens* and with a high presence of *Ostrya carpinifolia* and *Fraxinus ornus*. In many area, such plant community has been locally replaced by copse woodlands of *Castanea sativa*.

Sampling. In order to investigate vegetation dynamics, we carried out 108 vegetation plots of 5x5 m, on inactive areas of 52 working quarries. We used a random stratified sampling all over the extractive basin, according to geomorphological surfaces artificially created by extraction activities: artificial cliffs, embankments and quarry platforms. Plant species cover has been estimated in each plot according to Braun-Blanquet (1928) modified by Pignatti (1953). In order to identify abiotic ecological trends in plant communities, we collected the following stational data: a) elevation (m a.s.l.); b) aspect (°); c) slope (°), recorded with a

compass (Bunton Clino Master); d) per cent stoniness and rockiness (visually estimated); e) grain size (cm); f) per cent cover of tree, shrub, herbs and moss layers (visually estimated).
In order to identify the time step of each vegetation dynamics phase, surface age of each sampling site was collected by interviewing local experts and quarries' chiefs. For numerical (statistical) reasons, semi-natural revegetation surfaces outside the quarries were artificially considered 100 hundred years old.
Additional sampling plot data, in number of 35, surveyed on grasslands and woodlands growing in the surrounding area were collected from the database of the Museum of Natural History of Brescia (BS-MU) and from previous studies about grasslands of the Brescia area (degree thesis of Stefano Nodari, Milan University and BS-MU).

Data analysis. For the following analysis, a matrix of 226 species x 143 plots was used: to reduce significance of occasional species across the dataset, we processed only those present in almost 3 plots. To identify plant communities and succession across quarries of different ages, data on species cover were converted according to Van der Maarel (1979) and analysed by *cluster analysis* using *Paired Group* as algorithm and *Chord* as similarity measure (software: PAST 2.14; Hammer et al. 2001). We then built a synoptic table indicating each vegetation community (Supplementary material 1). The per cent frequency of each species was calculated and then converted into 5 classes: V = species present in more than 80% of the plots; IV = species present in 80-60% of the plots; III = species present in 60-40% of the plots; II = species present in 40-20% of the plots; I = species present in less than 20% of the plots).
To define the duration of each phase of the vegetation succession, we considered the 50 most abundant species in the extractive basin, and, among them, those whose cover significantly increases (Group A; late successional species) or decreases (Group B; initial successional species) within 100 years after the quarry abandonment. We then calculated the expected species cover of the considered species by their regression curves for the whole period and then the total cover of the species belonging to Group A and Group B. We considered five successional phases based on the expected per cent cover of the two groups of specie A and B (Table 1).

Time	**t=0**	**t=1**	**t=2**	**t=3**	**t=4**
Phase	Pioneer	Early	Intermediate	Later	Advanced
Group A (% cover)	<20	20-40	40-60	60-80	>80
Group B (% cover)	>80	80-60	60-40	40-20	<20

Table 1 Classification of the successional phases according to the expected relative cover of the late successional species (Group A: from time of abandonment species cover increase) and initial successional species (Group B: from time of abandonment species cover decrease)

To detect the main abiotic gradients affecting species distribution we analysed vegetation plots by means of *Detrended Canonical Analysis*. We plotted only the 25 most frequent species in scattergrams to reduce unexplained variance as, generally, across quarry areas, only few dominant species are present. To evaluate the vegetation gradients across the quarry basin, we used the *Canonical Correspondence Analysis* (CCA) ordination method. The CCA allowed us to compare the plots matrix (abundance values) that were associated with the environmental factors: age (from abandonment), aspect (cosine), slope (°), elevation (m), geomorphology (1= dump deposits; 2 = platforms; 3= artificial cliffs), stone size of top deposits (cm), rockiness (%), stoniness (%).We performed DCA and CCA with the software CANOCO (Hill & Gauch 1980).
We calculated the mean age of each species (index of species age: ISA) as the mean age of the plots where it was present. Thus, we calculated an index of age for each community (index of community age: ICA) as the mean age of the more abundant species (species belonging to the V, IV and III class of the frequency table). To investigate species abundances along time (measured as % cover), we used regression analysis. At this aim we grouped plots according to five classes of age: a) 0-2 years (t=0); b) 3-10 years (t=1); c) 11-22 years (t=2); b) 23-44 years (t=3); e) >44 years (t=4). In the regression we then considered the mean age of each class. To investigate species diversity trends at different times, we then calculated the linear correlations between the following calculated variables: mean surface age; mean species age, number of species, and number of alloctone species.

Results

Types of vegetation. Out of a total we found 392 vascular plant species on the studied area, of which 226 present in almost 3 plots (57.6% of the total), 65 in only 2 plots (16.6%) and 101 in only one plot (25.8%). We classified the 143 plots into ten vegetation communities by means of *cluster analysis* (Fig. 2), as described as follows (see Supplementary material 1).

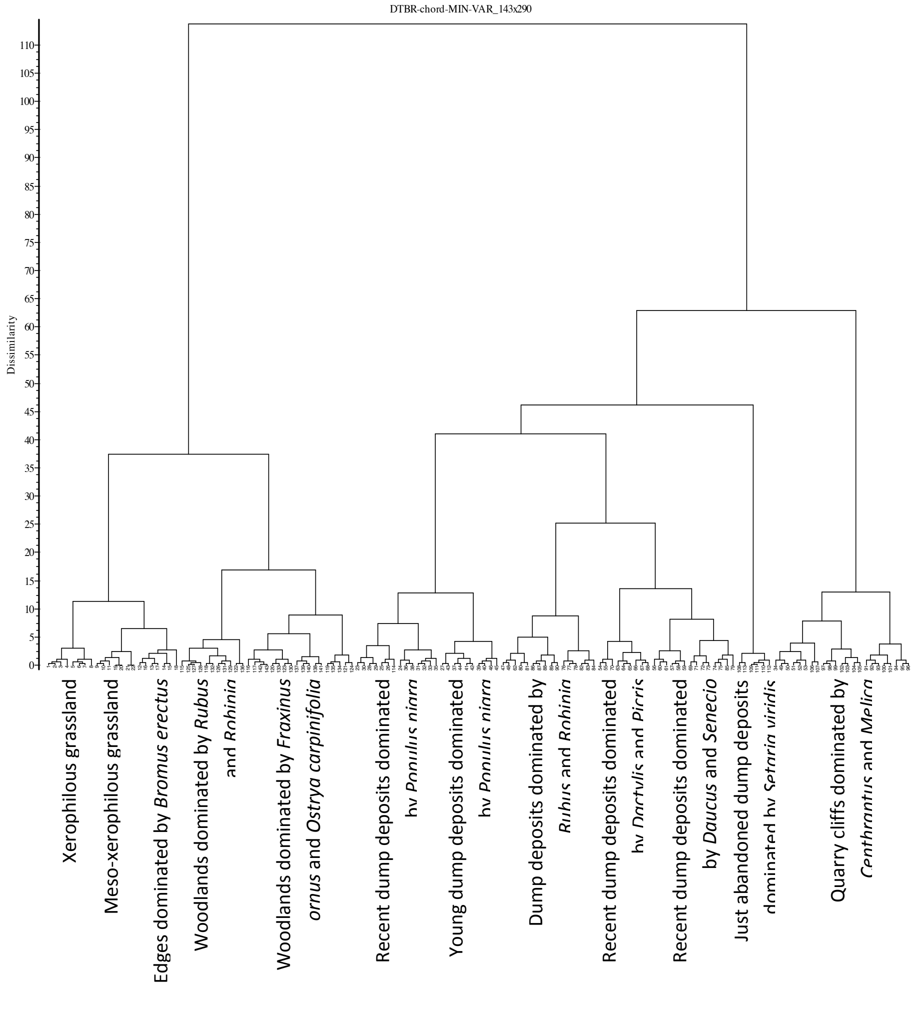

Fig. 2Cluster analysis (algorithm: *Paired group*, similarity measure: *Chord*)

1) Three types of grasslands (xerophilous, meso-xerophilous and edges) dominated by *Bromus condensatus* and *Bromus erectus* (22 plots) are associated to slopes outside the extractive basin at 389 m a.s.l., with a southern aspect, average slope of 23° and mean relative insolation of 15. Other abundant species are *Carex flacca*, *Teucrium chamaedrys*, *Stachys recta*, *Helianthemum nummularium*, *Globularia punctata*, *Teucrium montanum*, *Brachypodium rupestre*, *Euphorbia cyparissias*, *Artemisia alba*

and *Thymus pulegioides*. Hemicryptophytes are the dominant biological form (Fig. 3). Mean surface age: 100 years (all plots were outside the quarries). ICA: 85.5 years. The mean number of species per plot is 44 (±9); alloctone species are absent.

2) Woodlands dominated by *Rubus ulmifolius* and *Robinia pseudoacacia* (11 plots) mostly appear on slopes outside the extractive basin at 239 m a.s.l., with mainly a west and north-west aspect, average slope of 18° and mean relative insolation of -8. Other abundant species are *Crataegus monogyna*, *Cornus sanguinea*, *Fraxinus ornus* and *Ligustrum vulgare*. Phanaerophytes are the dominant biological form. Mean surface age: 100 years (all plots were outside the quarries). ICA: 81 years. The mean number of species is 22 (±7), with 4.67% of alloctone species on each plot on average.
3) Woodlands dominated by *Fraxinus ornus* and *Ostrya carpinifolia* (18 plots) mostly appear on slopes outside the extractive basin at 416 m a.s.l., with mainly a west and north-west aspect, average slope of 21° and mean relative insolation of 7. Other abundant species are *Crataegus monogyna*, *Clematis vitalba*, *Carex flacca*, *Peucedanum cervaria*, *Brachypodium rupestre* and *Ligustrum vulgare*. Phanaerophytes are the dominant biological form. Mean surface age: 92 years (most of plots were outside the quarries and some inside). ICA: 79 years. The mean number of species is 31 (±8), with 0.46% of alloctone species on each plot on average.
4) Recent quarry surfaces (dump deposits and platforms) dominated by *Populus nigra* (14 plots) mostly appear on dump deposit (and quarry platforms) at 373 m a.s.l., with a variable aspect (mainly south), average slope of 23° and mean relative insolation of -1. Other abundant species are *Picris hieracioides*, *Senecio inaequidens*, *Lactuca serriola*, *Sonchus oleraceus* and *Daucus carota*. Both terophytes and hemycryptophytes dominate. Mean surface age: 4 years from abandonment. ICA: 17 years. The mean number of species is 17 (±7), with 14.9% of alloctone species on each plot on average.
5) Young quarry surfaces (dump deposits, platforms and artificial cliffs) dominated by *Rubus ulmifolius* and *Robinia pseudo-acacia* (16 plots) only appear on dump deposits at 287 m a.s.l. on mean, with a various aspect (mainly east), average slope of 29° and mean relative insolation of 4. Other abundant species are *Lactuca serriola*, *Sonchus oleraceus*, *Populus nigra*, *Picris hieracioides*, *Clematis vitalba* and *Lotus corniculatus*. Hemycryptophytes dominate, but the presence of terophytes and phanaerophytes is high. Mean surface age: 9 years from abandonment. ICA: 27 years. The mean number of species is 24 (±6), with 10.4% of alloctone species on each plot on average.
6) Young quarry surfaces (mostly dump deposits) dominated by *Populus nigra* (10 plots) mostly appear on dump deposits at 313 m a.s.l., with a variable aspect, average slope of 30° and mean relative insolation of 4. Other abundant species are *Picris hieracioides*, *Senecio inaequidens*, *Dactylis glomerata*, *Lotus corniculatus* and *Daucus carota*. Hemycryptophytes dominate, but the presence of terophytes and phanaerophytes is high.

Mean surface age: 11 years from abandonment. ICA: 29 years. The mean number of species is 20 (±7), with 9.63% of alloctone species on each plot on average.

7) Recent quarry surfaces (dump deposits, platforms and artificial cliffs) dominated by *Dactylis glomerata* and *Picris hieracioides* (9 plots) mostly appear on dump deposits (and quarry walls) of the extractive basin at 302 m a.s.l., with various aspects (mainly north), average slope of 41° and insolation of -13. Other abundant species are *Lactuca serriola*, *Daucus carota*, *Bromus hordeaceous*, *Dorycnium pentaphyllum*, *Senecio inaequidens* and *Sonchus oleraceus*. Hemycryptophytes are the dominant biological form, but the presence of terophytes is high. Mean surface age: 11 years from abandonment. ICA: 22 years. The mean number of species is 5 (±8), with 6.62% of alloctone species on each plot on average.
8) Recent quarry surface (mostly dump deposits) dominated by *Daucus carota* and *Senecio inaequidens* (15 plots) mostly appear on dump deposits of the extractive basin at 340 m a.s.l., with various aspects (mainly south), average slope of 27° and insolation of -2. Other abundant species are *Picris hieracioides*, *Melilotus alba*, *Lactuca serriola*, *Stachys recta* and *Peucedanum cervaria*. Hemycryptophytes are the dominant biological form, but the presence of terophytes is high. Mean surface age: 10 years from abandonment. ICA: 21 years. The mean number of species is 16 (±8), with 8.5% of alloctone species on each plot on average.
9) Just abandoned quarry surface (dump deposits) dominated by *Setaria viridis* (5 plots) mostly appear on dump deposit of the extractive basin at 394 m a.s.l., with a south-west aspect, average slope of 17.4° and mean relative insolation of 11. Other abundant species are *Senecio inaequidens* and *Lactuca serriola*. Therophytes are the dominant biological forms. Mean surface age: 6 months from abandonment. ICA: 19 years. The mean number of species is 11 (±5), with 13.4% of alloctone species on each plot on average.
10) Quarry cliffs dominated by *Centranthus ruber* and *Melica ciliata* (23 plots) mostly appear on artificial cliffs in the extractive basin at 356 m a.s.l., with a main south, south-west aspect, average slope of 55° and mean relative insolation of 7. Another abundant species is *Picris hieracioides*. Hemycryptophytes are the dominant biological form; the per cent of terophytes, phanaerophytes and chamaephytes is similar. Mean surface age: 24 years from abandonment. ICA: 32 years. The mean number of species is 13 (±7), with 8.72% of alloctone species on each plot on average.

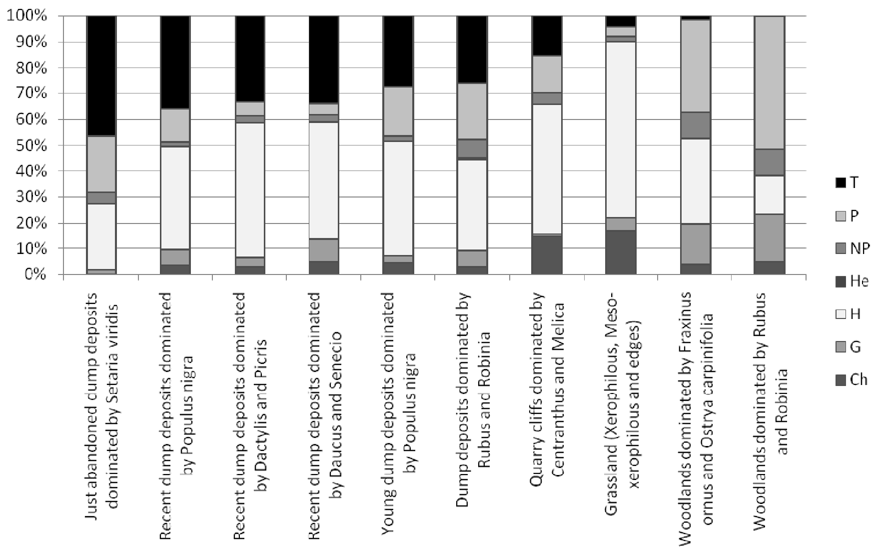

Fig. 3 Life forms of the ten plant communities

The ordination diagram obtained by the DCA (Fig. 4A, Table 2A) shows the relative relationship between the ten communities and the 25 most frequent species in the whole study area.

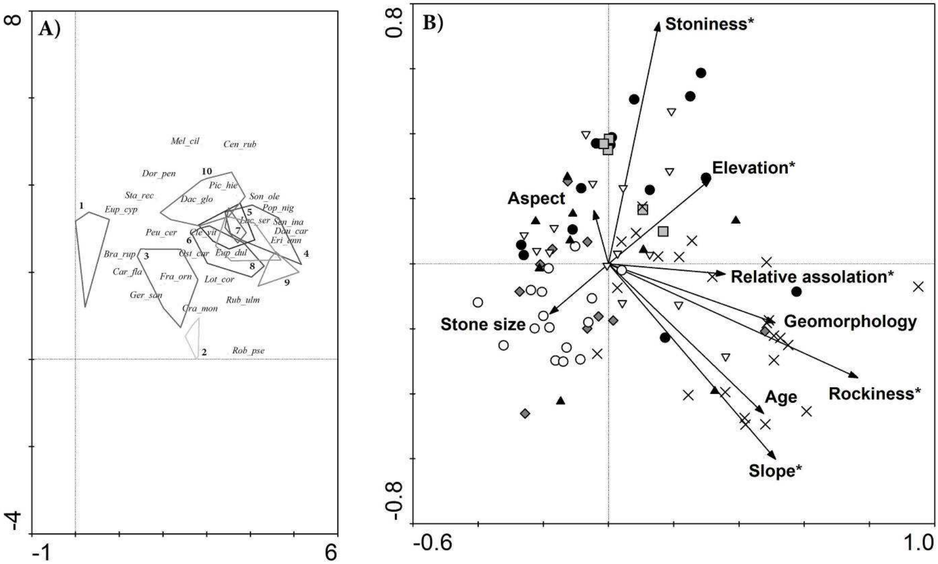

Fig. 4 A) DCA diagram of the ten identified communities and 25 more abundant species and B) CCA of the communities inside the working quarries

Legend: Species: Mel_cil: *Melica ciliata*, Cen_rub: *Centranthus ruber*, Dor_pen: *Dorycnium pentaphyllum*; Pic_hie: *Picris hieracioides*, Sta_rec: *Stachys recta*, Dac_glo: *Dactylis glomerata*, Son_ole: *Sonchus oleraceus*, Eup_cyp: *Euphorbia cyparissias*, Pop_nig: *Populus nigra*, Lac_ser: *Lactuca serriola*, Sen_ina:*Senecio inaequidens*, Peu_cer: *Peucedanum cervaria*, Cle_vit: *Clematis vitalba*, Dau_car: *Daucus carota*, Eri_ann: *Erigeron annuus*, Bra_rup: *Brachypodium rupestre*, Ost_car: *Ostrya carpinifolia*, Eup_dul: *Euphorbia dulcis*, Car_fla: *Carex flacca*, Fra_orn: *Fraxinus ornus*, Lot_cor: *Lotus corniculatus*, Ger_san:*Geranium sanguineum*, Cra_mon: *Crataegus monogyna*, Rub_ulm: *Rubus ulmifolius*, Rob_pse: *Robinia pseudoacacia*

Vegetation: 1: Grasslands (xerophilous, meso-xerophilous, and edges), 2: Woodlands dominated by *Fraxinus ornus* and *Ostrya carpinifolia*, 3: Woodlands dominated by *Robinia pseudoacacia* and *Rubus ulmifolius*, 4, cross: Quarry cliffs dominated by *Centranthus ruber* and *Melica ciliata*, 5, gray square: Just abandoned dump deposits dominated by *Setaria viridis*, 6, white down-triangle: Recent dump deposits dominated by *Daucus carota* and *Senecio inaequidens*, 7, black up-triangle: Recent dump deposits dominated by *Dactylis glomerata* and *Picris hieracioides*, 8, black circle: Recent dump deposits dominated by *Populus nigra*, 9, gray diamond: Dump deposits dominated by *Rubus ulmifolius* and *Robinia pseudoacacia*, 10, white circle: Young dump deposits dominated by *Populus nigra*

The CCA (Fig. 4B, Table 2B) shows that most environmental variables are significant, and in particular rockiness, stoniness, elevation and insolation (Table 2C).

A) Axes	1	2	3	4	Total inertia
Eigenvalues	0.684	0.281	0.210	0.165	8.244
Lengths of gradient	5.167	4.297	3.172	3.125	
Cumulative percentage variance of species data	8.3	11.7	14.2	16.3	
Sum of all eigenvalues					8.244

B) Axes	1	2	3	4	Total inertia
Eigenvalues	0.125	0.121	0.074	0.071	3621
Species-environment correlations	0.845	0.724	0.727	0.785	
Cumulative percentage variance of					
- species data	3.4	6.8	8.8	10.8	
- species-environment relation	22.7	44.6	58.1	71.0	
Sum of all eigenvalues					3621
Sum of all canonical eigenvalues					0.549

C) Effect	Marginal	Conditional		
	Lambda1	LambdaA	P	F
Rockiness	**0.10**	**0.10**	**0.001**	**3.01**
Stoniness	**0.09**	**0.09**	**0.001**	**2.36**
Elevation	**0.07**	**0.08**	**0.001**	**2.37**
Relative insolation	**0.07**	**0.07**	**0.001**	**2.20**
Slope	**0.09**	**0.06**	**0.003**	**2.08**
Geomorphology	0.08	0.05	0.088	1.30
Aspect	0.04	0.04	10.21	1.33
Stone size	0.04	0.03	10.22	1.32
Age	0.07	0.03	11.44	1.28

Table 2 A) Eingenvalues of the DCA; B) Eingenvalues of the CCA; C) Significance of the environmental variables

Successional phases. Out of the considered 50 most abundant species, only ten showed a significant variation ($p<0.05$) on vegetation cover with time from the quarry abandonment (Table 3, Supplementary material 2). In particular, five species showed a significant increase in cover (Group A) and five a significant decrease (Group B).

Group	Species	Slope	Error	Intercept	Error	r	p
A	*Bromus condensatus* Hackel	0.4308	0.0694	-2.4868	3.4719	0.9632	0.01
A	*Fraxinus ornus* L.	0.1457	0.0384	2.0844	1.9217	0.9095	0.03
A	*Ostrya carpinifolia* Scop.	0.2468	0.0627	5.2870	3.1332	0.9154	0.03
A	*Hedera helix* L.	0.2034	0.0579	-2.2837	2.8931	0.8970	0.04
A	*Tamus communis* L.	0.1126	0.0322	0.4155	1.6111	0.8959	0.04
B	*Dactylis glomerata* L.	-0.0443	0.0016	6.3720	0.0796	-0.9981	0.00
B	*Senecio inaequidens* DC.	-0.0652	0.0146	6.2650	0.7302	-0.9323	0.02
B	*Lactuca serriola* L.	-0.0461	0.0111	3.9734	0.5537	-0.9233	0.03
B	*Melilotus alba* Medicus	-0.0401	0.0119	3.4947	0.5942	-0.8898	0.04
B	*Torilis arvensis* (Hudson) Link	-0.0514	0.0159	4.2371	0.7927	-0.8819	0.05

Table 3 Linear regression parameters of the species cover which significantly increases or decreases with time

According to the relative cover of the species belonging to Group A and Group B (Fig. 5), we identified five successional phases: 1) pioneer phase (0-2 years; t=0), 2) early phase (3-10 years; t=1), 3) intermediate phase (11-22 years; t=2), 4) later phase (23-44 years; t=3), and 5) advanced phase (over 44 years; t=4).

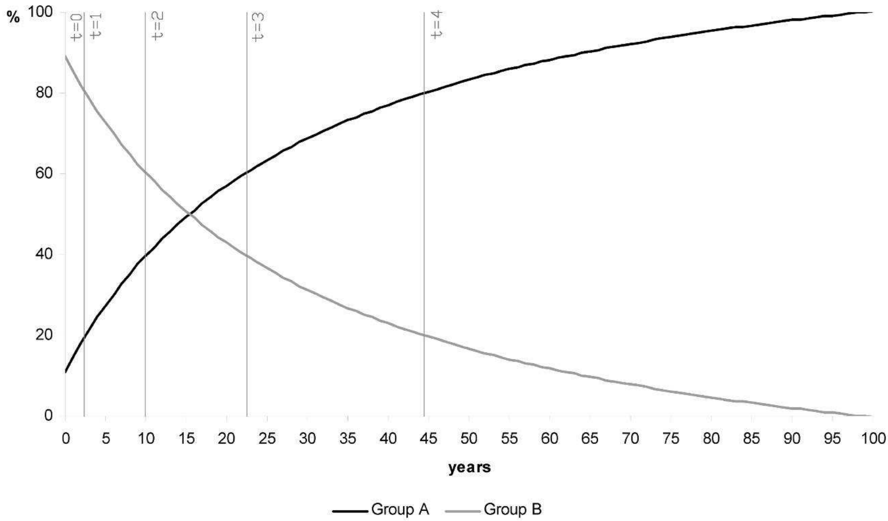

Fig. 5 Relative per cent cover of the species of Group A and Group B with time

The Sd and Hd species showed significant increasing and decreasing trends, respectively. The linear correlation revealed significant trend in the pair wise comparison between the following variables related to surface and mean species age and diversity (number of species and number of alloctone species; Table 4). We then calculated the linear correlations between the following calculated variables: mean surface age; mean species age, number of species, and number of alloctone species.

	Surface Age	**Species Age**	**N° species**	**Alloctonous (%)**
Surface Age	-	2.76E-09	0.014625	0.0012462
Species Age	0.99498	-	0.0075045	0.00093984
N° species	0.73892	0.78215	-	0.035153
Alloctonous (%)	-0.86456	-0.87416	-0.66697	-

Table 4 Linear correlation among surface age, species age, number of species and per cent of alloctone species

On the basis of the previous results, and according to the mean age of each vegetation type, we identified the vegetation succession (Table 5).

Phase	years	Structure of the vegetation	Differences within phase	Vegetation	Characterizing species**
t=0 Pioneer	0-2	Vegetation patches mostly made by annual grasses	-	Just abandoned dump deposits dominated by *Setaria viridis*	*Setaria viridis*, *Polygonum lapathifolium*, *Solanum nigrum*
t=1 Early	3-10	Vegetation patches mostly made by perennial grasses, with a consistent presence of annual grasses	high stoniness	Recent dump deposits dominated by *Populus nigra*	*Picris hieracioides*, *Medicago lupulina*, *Tussilago farfara*
			average conditions of stoniness, slope and rockiness	Young dump deposits dominated by *Rubus ulmifolius* and *Robinia pseudoacacia*	***Torilis arvensis***, *Rubus ulmifolius*, *Robinia pseudoacacia*
			high slope, high rockiness	Recent dump deposits dominated by *Daucus carota* and *Senecio inaequidens*	***Melilotus alba***, *Peucedanum cervaria*, *Stachys recta*
t=2 Intermediate	11-22	Vegetation patches mostly made by perennial grasses, with a consistent presence of annual grasses, and shrub and tree species	high stone size	Young dump deposits dominated by *Populus nigra*	***Populus nigra*, *Lotus corniculatus***, *Poa compressa*
			low slope	Recent dump deposits dominated by *Dactylis glomerata* and *Picris hieracioides*	*Daucus carota*, *Bromus hordeaceus*, *Dorycnium pentaphyllum*
t=3 Later	23-44	Vegetation patches mostly made by perennial grasses, shrubs and trees; decreasing presence of annual grasses, increasing presence of chamaephytes	-	Quarry cliffs and dumps dominated by *Centranthus ruber* and *Melica ciliata*	*Melica ciliata*, *Centranthus ruber*
t=4 Advanced*	>44	Grasslands mostly made by perennial herbaceous species	continuous human efforts	Grasslands (Xerophilous, meso-xerophilous and edges)	*Helianthemum nummularium*, *Teucrium chamaedrys*, *Globularia punctata*
		Woodlands with poor shrub and herb layers	high human disturbance	Woodlands dominated by *Rubus ulmifolius* and *Robinia pseudoacacia*	***Hedera helix***, *Prunus avium*, *Ruscus aculeatus*
		Woodlands with well structured tree, shrub and herb layers	"Potential" vegetation	Woodlands dominated by *Fraxinus ornus* and *Ostrya carpinifolia*	*Quercus pubescens*, *Carex flacca*, *Tanacetum corymbosum*

Table 5 Vegetation succession on the quarries of the Botticino extractive basin; *: hypothesized (external site), ** significant species in bold

Discussion

The present work proposes an objective procedure for determining the time-step of a successional phases, being based on the knowledge of the time after quarry abandonment and on the significant increase or decrease of species cover. Revising the model of Martínez-Ruiz & Fernández-Santos (2005) our results highlighted that on quarry areas vegetation succession can be subdivided into five main different phases: “pioneer phase”, “early phase”, “intermediate phase”, “later phase” and “advanced phase”. During time, phases replace each others in a continuous and progressive way due to human induced disturbance activity present in quarry areas (Baroni et al. 2000; Gentili et al. 2011). DCA supported such findings showing different overlapping areas between different plant communities growing on the extractive basin.

In the earlier stages of the succession (“pioneer phase”), when areas are still very degraded (0-2 years from abandonment), very low vegetation cover is observed (data not reported), tree and shrub layers are almost absent and only few pioneer, annual therophytes, ruderal, light-requiring, fast-growing, and R-strategy herbs are able to colonize and prevail in number and cover, thanks mostly to a very effective capability of anemochorous dispersal (e.g. Novák & Prach 2003; Tropek et al. 2010; Zhang & Chu 2011). In the study area, a *Setaria viridis* community prevails on every type of morphological surface and many annual species, of which many alien ones, are abundant (e.g. *Ambrosia artemisiifolia*, *Solanum nigrum* and *Xanthium italicum*). In fact, abiotic filters such as the low availability of resources (mainly water and nutrients that are almost absent in the first phases of the succession), adverse soil chemical (from literature data) and physical properties (stoniness in this case) affect vegetation dynamics (Shu et al. 2005; Tishew & Kirmer 2007). Such a phase show low level of species richness: we recorded only 11 species on each plots on average, underlining the extreme environmental conditions immediately after the quarry abandonment. On the contrary, previous authors have recorded high levels of plant diversity in quarries since the initial colonization phases, often in relation to the high spatial and environmental heterogeneity (Brändle et al. 2000; Martínez-Ruiz & Fernández-Santos 2005; Tischew & Kirmer 2007). Our results are in contrast with such findings, probably because of the high human disturbance typical of the working quarries of the study area, that are not definitively abandoned like in the previous studies.

Once the annual flora is well established and abiotic conditions improved, from 3 to 10 years after abandonment (“early phase”), first perennial and more exigent species begin to colonize the area, increasing inter-species competition and the importance of biotic filters (Kather et al. 2003; Novák & Prach 2003; Duan et al. 2008). The presence of pioneer species decreases (*Setaria viridis* in the study area), while the cover of ruderal, but not merely pioneer species increase, such as the hemicriptophytes *Picris hieracioides, Daucus carota* and *Sonchus oleraceus*. Nevertheless, abiotic filters, such as water and nutrient availability, still greatly affect vegetation dynamics, so that vegetation cover increases but it is anyway constituted mainly by a discontinuous herb layer. Plant diversity increases during such a phase (since we recorded almost 17 species on average in each plots), on the contrary of what found by other authors who observed an increasing dominance by more competitive species and a consequent decrease of plant diversity, due to the decrease of plant cover and species number of annual herbs (Martínez-Ruiz & Fernández-Santos 2005). The influence of quarry geomorphological heterogeneity affects vegetation dynamics so that different vegetation communities grow on quarry surfaces according primarily to stoniness, slope, rockiness and relative insolation. In particular, where primarily stoniness and stone size are higher, vegetation cover is dominated by young individuals of *Populus nigra*. Where they are smaller, vegetation cover is dominated by the herbaceous *Dactylis glomerata* and *Picris hieracioides* community and by *Daucus carota* and *Senecio inaequidens* community; the first one prevails on areas characterized by higher slope and insolation.

Then, in the "intermediate phase" (11-22 years from abandonment in the study area), perennial species become dominant and native woody and shrubby species, coming mostly from the natural surroundings, begin to appear, as already observed by previous authors (e.g. Martínez-Ruiz et al. 2001; Holl 2002; Duan et al. 2008). Such patterns are due to the amelioration of environmental conditions primarily established in the soil characters. Species richness little increases and some differences among different geomorphological surface are still recognizable: on surfaces with low stoniness, the vegetation dominated by *Populus nigra* successfully establishes (also the tree layer develops), while, on surfaces with low stoniness, vegetation is dominated by *Rubus ulmifolius* and *Robinia pseudoacacia*.

With time increasing from abandonment, a "later phase" can be recognized (last until 44 years from abandonment in the study area) in which hemicriptophytes prevail and chamaephytes strongly increase. Many shrub and some wood species become dominant in the succession, such as *Ostrya carpinifolia* and *Fraxinus ornus*, along with species typical of rocky surfaces or cliffs like *Centranthus ruber*. The closest surrounding vegetation patches (woodlands and grasslands) affect the succession more and more strongly, the more they are large and/or near, depending even on plant and animal species immigration potentiality and colonization abilities (Shu et al. 2005), their fecundity and their ability to disperse by an available vector (Campbell et al. 2003). Biotic filters, that are the principal factors for species selection (Mota et al. 2004; Martínez-Ruiz & Fernández-Santos 2005) maintain almost the same plant diversity, while the number of alien species decreases.

We hypothesized the last phase of the succession ("advanced phase", over 44 years for the study area) according to the vegetation growing on the surroundings of the Botticino extractive basin. Biotic filters will become the principal factors for species selection (e.g. Novák & Prach 2003; Martínez-Ruiz & Fernández-Santos 2005; Zhang & Chu 2011) and vegetation will tend towards the floristic composition and species diversity of (semi)natural surrounding communities (Martínez-Ruiz et al. 2001; Martínez-Ruiz & Fernández-Santos 2005), according to size and distance of the surrounding natural patches and environmental heterogeneity (Verhoef & Morin 2010). Thus, we could expect *Quercetalia pubescentis* woodlands and *Xerobromion* grasslands. Biodiversity is also expected to increase till more than 40 species per plots on grasslands and almost 30 on woodlands, while the number of alien species is expected to decrease because of increasing species competition.

Conclusion

Our study on the vegetation succession phases on limestone quarries of the Botticino extractive basin allowed us to clearly recognize five theoretical phases based on the relative abundance of colonizer (annual herbaceous) and late successional (perennial woodland) species. Quarry spontaneous revegetation begins in general immediately after quarry abandonment, in very extreme environmental conditions, and follows a general trend parallel to those of a natural primary succession, according to the findings of previous authors in different regions. However, our results showed that the species implicated in the succession, mostly during the initial phases (but also in the later) are completely different from those that characterize the natural surrounding vegetation also on medium-term. Thus, the vegetation dynamics difficultly will be able to reach the advanced (hypothetical) phase in short time.

Moreover, quarry morphological heterogeneity, which is not so evident in the first phase of the succession, is relevant after about 3 years from quarry abandonment, by which different plant community can be distinguished on artificial cliffs and the other morphological surfaces.

For restoration purposes, spontaneous succession is then recommended on artificial cliffs because of the very adverse environmental conditions that are responsible of the very slow vegetation succession and that could make any intervention fruitless. On the other hand, human efforts are needed on dump deposits and quarry platforms, in order to redirect the vegetation succession towards the establishment of a valuable self-sustaining community.

Acknowledgments

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References

1. Baroni C., Bruschi G., Ribolini A. 2000. Human-induced hazardous debris flows in Carrara marble basins (Tuscany, Italy). Earth Surface Processes and Landforms 25: 93–103.
2. Bluvshtein N., Mahrer Y., Sandler A., Rytwo G. 2011. Evaluating the impact of a limestone quarry on suspended and accumulated dust. Atmospheric Environment 45: 1732-1739
3. Bradshaw A.D. 1984. Ecological principles and land reclamation practice. Landscape Planning 11: 35-48
4. Brändle M., Durka W., Altmoos M. 2000. Diversity of surface dwelling beetle assemblages in open-cast lignite mines in Central Germany. Biodiversity and Conservation 9: 1297-1311
5. Braun-Blaunquet J. 1928. Pflanzensoziologie. Sprinter, Verl. Wien; II ed. nel 1951, III ed. nel 1964. Schippmann U., 1991- Revisionder europaischen Arten der Gattung Brachypodium

Palisot de Beauvois. Boissiera, Genève, 45: 1-249
6. Campbell D.R., Rochefort L., Lavoie C. 2003. Determining the immigration potential of plants colonizing disturbed environments: the case of milled peatlands in Quebec. Journal of Applied Ecology 40: 78-91
7. Clerici A., Meda A. 2005. Confronto tra le caratteristiche meccaniche di diversi livelli di estrazione del Botticino Classico. Giornale di Geologia Applicata 2: 307-312
8. Dana E.D., Mota J.F. 2006. Vegetation and soil recovery on gypsum outcrops in semi-arid Spain. Journal of Arid Environments 65: 444-459
9. Duan W., Ren H., Fu S., Wang J., Yang L., Zhang J. 2008. Natural recovery of different areas of a deserted quarry in South China. Journal of Environmental Sciences 20: 476-481
10. Frouz J., Prach K., Pižl V., Háněl L., Starý J., Tajovský K., Materna J., Balík V., Kalčík J., Řehounková K. 2008. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology 44: 109-121
11. Galetakis M., Alevizos G., Leventakis K. 2012. Evaluation of fine limestone quarry by-products, for the production of building elements – an experimental approach. Construction and building materials 26: 122-130
12. Gentili R., Sgorbati S., Baroni C. 2011. Plant species patterns and restoration perspectives in the highly disturbed environment of the Carrara marble quarries (Apuan Alps, Italy). Restoration Ecology 101: 32-42
13. Gimblett H.R., Fitzgibbon J.E., Bechard K.P., Wightman J.A., Itami R.M. 1987. Procedure for assessing visual quality for landscape planning and management. Environmental Management Vol. 11 No. 3: 359-367
14. Hammer Ø, Harper D.A.T, Ryan P.D. 2001. Past: Paleontological Statistics Software Package for education and data analysis. Palaeontologia Electronica vol. 4, issue 1, art. 4: 9 pp. http: //palaeo-electronica.org/2001_1/past/issue1_01.htm
15. Heger T., Böhmer H. J. 2005. The invasion of Central Europe by Senecio inaequidens DC. – a complex biogeographical problem. Erdkunde 59: 34-49
16. Hill M.O., Gauch H.G. 1980. Detrended Correspondence Analysis: an improved ordination technique. Vegetatio 42: 47-58
17. Holec M., Frouz J. 2005. Ant (Hymenoptera: Formicidae) communities in reclaimed and unreclaimed brown coal mining spoil dumps in the Czech Republic. Pedobiologia 49: 345-357
18. Holl K.D. 2002. Long-term vegetation recovery on reclaimed coal surfaces mines in the eastern USA. Journal of Applied Ecology 39: 960-970
19. Khater C., Martin A., Maillet J. 2003. Spontaneous vegetation dynamics and restoration prospects for limestones quarries in Lebanon. Applied Vegetation Science 6: 199-204
20. Martínez-Ruiz C., Fernández-Santos B., Gómez-Gutiérrez J.M. 2001. Effects of substrate coarness and exposure on plant succession in uranium-mining wastes. Plant Ecology 155: 79-89
21. Martínez-Ruiz C., Fernández-Santos B. 2005. Natural revegetation on topsoiled mining-spoils according to the exposure. Acta Oecologica 28: 231-238
22. Mohamed M.T. 2009. Artificial neural network for prediction and control of blasting vibrations in Asiut (Egypt) limestone quarries. International Journal of Rock Mechanic & Mining Science 46: 426-431
23. Mouflis G.D., Gitas I.Z., Iliadou S., Mitri G.H. 2008. Assessment of the visual impact of marble quarry expansion (1984-2000) on the landscapes of Thasos island, NE Greece. Landscape and

Hurban Planning 86: 92-102

24. Mota J.F., Sola A.J., Jiménez-Sánchez M.L., Pérez-garcía F.J., Merlo M.E. 2004. Gypsicolous flora, conservation and restoration of quarries in the southeast of the Iberian Peninsula. Biodiversity and Conservation 13: 1797-1808
25. Novák J., Konvička M. 2006. Proximity of valuable habitats affects succession patterns in abandoned quarries. Ecological Engineering 26: 113-122
26. Novák J., Prach K. 2003. Vegetation succession in basalt quarries: pattern on a landscape scale. Applied Vegetation Science 6: 111-116
27. Pamukçu C., Simsir F. 2006. Example of reclamation attempts at a set of quarries located in Izmir, Turkey. Journal of Mining Science Vol. 42 No. 3: 304-308
28. Pignatti S. 1953. Introduzione allo studio della pianura veneta orientale. Archivio botanico 29: 131-158
29. Prach K. 2003. Spontaneous succession in Central-European man-made habitats: what information can be used in restoration practice? Applied Vegetation Science 6: 125-129
30. Servizio geologico d'Italia 2008. Carta geologica d'Italia alla scala 1: 50000. Foglio 99 Iseo. Agenzia per la Protezione dell'Ambiente e per I Servizi Tecnici.
31. Shu W.S., Ye Z.H., Zhang Z.Q., Lan C.Y., Wong M.H. 2005. Natural colonization of plants on five lead/zinc mine tailings in Southern China. Restoration Ecology Vol. 13 No. 1: 49-60
32. Ter Braak C.J.F. 1986. Canonical Correspondence Analysis: a new eingenvector technique for multivariate direct gradient analysis. Ecology Vol. 65 No. 5: 1167-1179
33. Tischew S., Kirmer A. 2007. Implementation of basic studies in the ecological restoration of surface-mined land. Restoration Ecology Vol. 15 No. 2: 321-325
34. Tropek R., Kadlec T., Karesova P., Spitzer L., Kocarek P., Malenovsky I., Banar P., Tuf I.H., Hejda M., Konvicka M. 2010. Spontaneous succession in limestone quarries as an effective restoration tool for endangered arthropods and plants. Journal of Applied Ecology 47: 139-147
35. Van der Maarel E. 1979. Trasformation of cover-abundance values in phytosociology and is effect on community similarity. Vegetatio, Den Haag, vol. 39 no. 2: 97-154
36. Verhoef H.A., Morin P.J. 2010. Community Ecology. Processes, models, and applications. Oxford University Press, New York 247 pag.
37. Wheater C.P., Cullen W.R. 1997. The flora and invertebrate fauna of abandoned limestone quarries in Derbyshire, United Kingdom. Restoration Ecology Vol. 5 No. 1: 77-84
38. Yuan J.-G., Fang W., Fan L., Chen Y., Wang D.-Q., Yang Z.-Y. 2006. Soil formation and vegetation establishment on the cliff face of abandoned quarries in the early stages of natural colonization. Restoration Ecology Vol. 14 No. 3: 349-356
39. Zhang H., Chu L.M. 2011. Plant community structure, soil properties and microbial characteristics in revegetated quarries. Ecological Engineering 37: 1104-1111

Supplementary material 1

Synoptic table. Classes of species frequency: V: species present in more than 80% of the plots; IV: species present in 80-60% of the plots; III: species present in 60-40% of the plots; II: species present in 40-20% of the plots; I: species present in less than 20% of the plots

	1 Grasslands	3 Woodlands Fraxinus & Ostrya	2 Woodlands Rubus & Robinia	5 Dump deposits Rubus & Robinia	4 Recent dump deposits Populus nigra	6 Young dump deosits Populus nigra	7 Dump deposits Dactylis & Picris	8 Dump deposits Daucus & Senecio	9 Recent dump deposits Setaria	10 Artificial cliffs Centhranthus & Melica
Aspect (°)	173	199	273	169	180	168	181	190	225	154
Slope (°)	23	21	18	27	23	30	41	27	17	55
Elevation (m a.s.l.)	389	416	239	306	373	313	302	340	394	356
Main habitat (1: dump deposit, 2: quarry platform, 3: quarry cliff; 4: woodland; 5: grassland)	5	4	4	1	1	1	1, 3	1	1	3
Age (years from abandonment)	100	92	98	9	4	11	11	10	1	24
Species										
Chrysopogon gryllus and Artemisia alba group										
Artemisia alba Turra	IV	.	.	.	I	I	.	I	.	II
Hippocrepis comosa L.	II	I	.	.	.	.	.	.	.	.
Chrysopogon gryllus (L.) Trin.	IV	.	.	.	.	.	.	.	.	.
Cleistogenes serotina (L.) Keng	II	.	.	.	.	.	.	.	.	.
Xerobromion										
Bromus condensatus Hackel	III	.	.	I	I	.	I	.	.	II

Sedum montanum Perr. et Song.	I	.	.	I	.	I	.	I	.	I
Globularia punctata Lapeyr.	V	I	.	.	.	I	.	.	.	I
Carex humilis Leyser	III	.	.	.	.	.	.	I	.	.
Centaurea maculosa Lam.	III	.	.	.	.	.	.	.	.	.
Campanula sibirica L.	III	.	.	.	.	.	.	.	.	.
Dianthus sylvestris Wulfen	II	.	.	.	.	.	.	.	.	.
Lactuca perennis L.	I	.	.	.	.	.	.	.	.	.
Festuco-Brometea (and Brometalia erecti)										
Stachys recta L.	V	.	.	II	II	II	II	IV	II	III
Melica ciliata L.	II	I	.	III	I	II	III	II	.	V
Euphorbia cyparissias L.	V	II	.	II	II	I	I	I	.	II
Sanguisorba minor Scop.	III	.	.	II	II	III	II	I	.	I
Hypericum perforatum L.	II	.	.	I	I	II	II	I	.	I
Scabiosa gramuntia L.	II	I	.	I	I	I	.	.	.	I
Festuca rupicola Heuffel	III	.	.	I	I	II	.	.	.	I
Teucrium chamaedrys L.	V	I	.	.	.	I	.	.	.	I
Bromus erectus Hudson	IV	II	I	.	.	.	.	.	.	I
Helianthemum nummularium (L.) Miller	V	.	.	I	.	I	.	.	.	I
Galium lucidum All.	IV	.	.	.	.	I	.	.	.	I
Polygala comosa Schkuhr	I	I	.	.	.	.	.	.	.	.
Teucrium montanum L.	IV	.	.	.	.	.	.	.	.	I
Salvia pratensis L.	III	II	.	.	.	.	.	.	.	.
Carex caryophyllea La Tourr.	III	.	I	.	.	.	.	.	.	.
Filipendula vulgaris Moench	III	II	.	.	.	.	.	.	.	.
Allium carinatum L.	I	I	.	.	.	.	.	.	.	.
Briza media L.	III	.	.	.	.	.	.	.	.	.
Plantago media L.	II	.	.	.	.	.	.	.	.	.
Anacamptis pyramidalis (L.) L. C. Rich.	I	.	.	.	.	.	.	.	.	.
Campanula glomerata L.	I	.	.	.	.	.	.	.	.	.
Orchis tridentata Scop.	I	.	.	.	.	.	.	.	.	.
Prunella grandiflora (L.) Scholler	I	.	.	.	.	.	.	.	.	.

Aster linosyris (L.) Bernh.	III	.	.	.	.	.	.	.	.	.
Trinia glauca (L.) Dumort	III	.	.	.	.	.	.	.	.	.
Eryngium campestre L.	III	.	.	.	.	.	.	.	.	.
Anthericum ramosum L.	II	.	.	.	.	.	.	.	.	.
Koeleria macrantha (Ledeb.) Sprengel	II	.	.	.	.	.	.	.	.	.
Asperula aristata L. fil.	I	.	.	.	.	.	.	.	.	.
Centaurea scabiosa L.	I	.	.	.	.	.	.	.	.	.
Galium verum L.	I	.	.	.	.	.	.	.	.	.
Koeleria pyramidata (Lam.) Domin	I	.	.	.	.	.	.	.	.	.
Linum catharticum L.	I	.	.	.	.	.	.	.	.	.
Scabiosa columbaria L.	I	.	.	.	.	.	.	.	.	.
Thymus pulegioides L.	IV	I	.	.	.	.	.	.	.	I
Anthyllis vulneraria L. (Agg.)	III	.	.	.	.	.	.	.	.	I
Ranunculus bulbosus L.	I	.	.	.	.	.	.	.	.	.
Cirsium pannonicum (L.fil.) Link	I	.	.	.	.	.	.	.	.	.
Laserpitium siler L.	I	.	.	.	.	.	.	.	.	.
Trifolio-Geranietea sanguinei										
Geranium sanguineum L.	III	III	.	III	.	.	I	II	III	I
Brachypodium rupestre (Host) R. et S.	V	IV	.	I	I	I	.	.	.	I
Carex flacca Schreber	III	IV	II	II	.	.	.	.	.	I
Vincetoxicum hirundinaria Medicus	III	II	.	.	.	.	.	.	.	.
Anthericum liliago L.	I	III	.	.	.	.	.	.	.	.
Dictamnus albus L.	II	I	.	.	.	.	.	.	.	.
Silene nutans L.	I	I	.	.	.	.	.	.	.	.
Inula hirta L.	III	.	.	.	.	.	.	.	.	.
Peucedanum oreoselinum (L.) Moench	II	.	.	.	.	.	.	.	.	.
Centaurea triumfetti All.	I	.	.	.	.	.	.	.	.	.
Aster amellus L.	I	.	.	.	.	.	.	.	.	.
Melampyrum cristatum L.	I	.	.	.	.	.	.	.	.	.
Ostryo-Carpinion orientalis										
Ostrya carpinifolia Scop.	I	IV	III	III	II	III	II	I	.	II

Coronilla emerus L.	I	II	I	I	I	II	I	.	.	I
Celtis australis L.	.	I	I	I	.	.	.	.	.	.
Iris graminea L.	I	.	I	.	.	.	.	.	.	.
Knautia drymeia Heuffel	.	I	.	.	.	.	.	.	.	.
Lamiastrum galeobdolon (L.) Ehrend. et Polatschek	.	.	II	.	.	.	.	.	.	.
Quercetalia pubescentis										
Peucedanum cervaria (L.) Lapeyr.	IV	IV	.	II	II	III	II	IV	.	I
Fraxinus ornus L.	III	V	IV	III	.	III	.	I	.	II
Prunus mahaleb L.	I	II	.	I	.	II	.	I	.	I
Quercus pubescens Willd.	I	V	I	I	.	.	.	.	.	.
Hedera helix L.	.	IV	V	I	.	II	.	.	.	.
Tamus communis L.	.	V	V	I	.	.	.	.	.	.
Ruscus aculeatus L.	.	III	V	.	.	I	.	.	.	.
Sorbus torminalis (L.) Crantz	.	II	I	.	I	.	.	.	.	.
Acer campestre L.	.	II	II	I	.	.	.	.	.	.
Cephalanthera longifolia (Hudson) Fritsch	I	III	I	.	.	.	.	.	.	.
Potentilla alba L.	I	III	.	.	.	.	.	I	.	.
Melittis melissophyllum L.	I	II	I	.	.	.	.	.	.	.
Tanacetum corymbosum (L.) Sch.-Bip.	I	IV	.	.	.	.	.	.	.	.
Serratula tinctoria L.	I	II	.	.	.	.	.	.	.	.
Buglossoides purpurocaerulea (L.) Johnston	.	II	I	.	.	.	.	.	.	.
Cornus mas L.	.	I	I	.	.	.	.	.	.	.
Asparagus tenuifolius Lam.	.	I	I	.	.	.	.	.	.	.
Mespilus germanica L.	.	I	.	.	.	.	.	.	.	.
Querco-Fagetea										
Rubus ulmifolius Schott	.	III	V	V	I	I	I	II	IV	II
Euphorbia dulcis L.	.	III	I	III	I	II	II	II	.	I
Prunus avium L.	.	III	V	.	.	I	.	.	II	.
Rosa arvensis Hudson	.	II	II	.	.	.	.	I	.	I
Castanea sativa Miller	.	II	IV	.	.	II	.	.	.	.
Chamaecytisus hirsutus (L.) Link	II	II	.	.	.	.	.	.	.	I

Euphorbia amygdaloides L.	.	.	I	I	I	.	.	.	.	.
Vinca minor L.	.	II	IV	.	.	.	.	.	.	.
Euonymus europaeus L.	.	I	II	.	.	.	.	.	.	.
Lathyrus niger (L.) Bernh.	.	II	I	.	.	.	.	.	.	.
Quercus petraea (Mattuschka) Liebl.	.	II	II	.	.	.	.	.	.	.
Corylus avellana L.	.	I	II	.	.	.	.	.	.	.
Lonicera caprifolium L.	.	II	II	.	.	.	.	.	.	.
Festuca heterophylla Lam.	.	I	I	.	.	.	.	.	.	.
Brachypodium sylvaticum (Hudson) Beauv.	.	I	II	.	.	.	.	.	.	.
Ulmus minor Miller	.	I	II	.	.	.	.	.	.	.
Melica uniflora Retz.	.	I	I	.	.	.	.	.	.	.
Ajuga reptans L.	.	.	I	I	.	.	.	.	.	.
*Carpinus bet*ulus L.	.	.	II	.	.	.	.	.	.	.
Hepatica nobilis Miller	.	I	.	.	.	.	.	.	.	.
Ilex aquifolium L.	.	I	.	.	.	.	.	.	.	.
Salvia glutinosa L.	.	.	I	.	.	.	.	.	.	.
Rhamno-Prunetea										
Clematis vitalba L.	I	IV	I	IV	I	IV	II	II	V	II
Crataegus monogyna Jacq.	I	V	V	II	.	I	.	.	.	I
Ligustrum vulgare L.	I	IV	IV	I	.	I	.	.	.	I
Cornus sanguinea L.	.	II	V	I	.	II	.	.	II	I
Viburnum lantana L.	I	III	II	I	I	I	.	.	.	.
Rosa canina L. sensu Bouleng.	I	II	.	II	.	II	.	.	.	I
Cotinus coggygria Scop.	II	IV	.	I	I	.	.	.	.	.
Juniperus communis L.	.	II	.	.	.	I	.	.	.	I
Prunus spinosa L.	I	I	I	.	.	.	.	.	.	.
Cytisus sessilifolius L.	I	II	.	.	.	.	.	.	.	.
Crataegus oxyacantha L.	.	I	I	.	.	.	.	.	.	.
Rhamnus catharticus L.	.	I	.	.	.	.	.	.	.	.
Robinia and Rubus group										
Robinia pseudoacacia L.	.	I	**V**	**IV**	I	I	.	II	III	I

Populus nigra group										
Populus nigra L.	.	I	I	IV	**V**	**V**	II	.	IV	III
Setaria viridis group										
Setaria viridis (L.) Beauv.	.	.	.	I	II	I	II	II	V	I
Ambrosia artemisiifolia L.	.	.	.	I	II	I	.	.	IV	.
Echinochloa crus-galli (L.) Beauv.	.	.	.	.	.	.	.	.	III	.
Centranthus ruber and Melica ciliata group										
Centranthus ruber (L.) DC.	.	.	.	III	II	IV	III	III	.	V
Dauco-Melilotion										
Senecio inaequidens DC.	.	.	.	III	V	V	IV	V	V	III
Lactuca serriola L.	.	I	.	V	IV	IV	V	IV	V	III
Erigeron annuus (L.) Pers.	.	.	.	III	III	II	III	II	.	II
Picris hieracioides L.	II	.	.	IV	V	V	V	IV	III	IV
Melilotus alba Medicus	.	.	.	II	II	III	III	IV	II	I
Medicago lupulina L.	.	I	.	I	III	II	II	II	.	I
Medicago sativa L.	I	.	.	I	.	I	.	.	.	.
Cichorium intybus L.	.	.	.	.	II	II	I	I	.	I
Echium vulgare L.	II	.	.	I	II	II	III	I	IV	I
Onopordetalia acanthii and Artemisietea vulgaris										
Daucus carota L.	.	.	.	III	IV	IV	V	V	II	II
Artemisia vulgaris L.	.	.	.	II	I	I	II	I	II	.
Poa compressa L.	.	.	I	I	.	III	II	II	.	I
Silene alba (Miller) Krause	.	I	.	I	I	.	.	I	.	.
Cirsium vulgare (Savi) Ten.	.	I	.	I	I	.	I	.	II	.
Stellarietea mediae										
Sonchus oleraceus L.	.	I	.	IV	IV	II	IV	III	II	III
Cirsium arvense (L.) Scop.	.	I	.	II	II	I	II	II	.	.
Polygonum lapathifolium L.	.	.	.	II	II	.	II	III	V	.
Solanum nigrum L.	.	I	.	I	I	.	.	.	V	.
Chenopodium album L.	.	.	.	I	I	.	.	I	.	.

Convolvulus arvensis L.	.	.	.	I	I	.	.	I	.	.
Molinio-Arrhenatheretea										
Lotus corniculatus L. s.s.	III	I	.	IV	III	IV	III	II	III	I
Dactylis glomerata L.	IV	II	.	III	I	V	V	II	.	III
Plantago lanceolata L.	I	.	.	I	.	II	I	I	.	.
Arrhenatherum elatius (L.) Presl	I	.	.	I	.	.	.	.	.	.
Prunella vulgaris L.	I	.	.	.	.	.	.	I	.	.
Achillea millefolium L.	I	.	.	.	.	.	.	.	.	.
Trifolium hybridum L.	.	.	.	.	I	.	.	.	.	.
Leontodon hispidus L.	I	.	.	.	.	.	.	.	.	.
Other species										
Dorycnium pentaphyllum Scop.	III	I	.	II	I	II	IV	I	.	II
Bromus hordeaceus L.	.	I	.	II	I	III	IV	II	.	I
Bromus sterilis L.	.	.	.	III	II	III	III	II	.	I
Tragopogon pratensis L.	.	.	.	I	I	I	II	I	.	I
Arenaria serpyllifolia L.	.	.	.	I	I	.	III	II	.	I
Crepis vesicaria L.	.	.	.	III	II	II	III	I	.	.
Geranium purpureum Vill.	.	.	.	II	II	II	.	I	.	I
Lembotropis nigricans (L.) Griseb.	II	I	.	I	.	.	I	.	.	I
Poa trivialis L.	.	.	I	I	.	.	I	II	.	I
Torilis arvensis (Hudson) Link	.	.	.	III	II	III	.	II	.	I
Xanthium italicum Moretti	.	.	.	I	I	I	.	I	II	.
Acinos arvensis (Lam.) Dandy	.	.	.	.	I	.	I	I	.	I
Bidens frondosa L.	.	.	.	I	I	I	.	I	.	.
Calamintha nepeta (L.) Savi	.	.	.	I	.	II	.	I	.	II
Epilobium dodonaei Vill.	.	.	.	.	II	.	I	I	.	I
Plantago major L.	.	.	.	.	I	I	I	I	.	.
Rubus caesius L.	.	I	I	.	I	.	I	.	.	.
Salix alba L.	.	.	.	I	.	I	.	I	.	I
Trifolium pratense L.	.	.	.	I	.	II	I	I	.	.
Tussilago farfara L.	.	.	.	.	III	.	I	II	.	I

Artemisia verlotiorum Lamotte	.	.	.	I	I	.	.	I	.	.
Carex hallerana Asso	III	I	I	.	.	.	.	.	.	.
Catapodium rigidum (L.) Hubbard	.	.	.	.	.	II	II	I	.	.
Cerastium dubium (Bastard) Guepin	.	.	.	I	.	.	II	II	.	.
Genista germanica L.	I	II	I	.	.	.	.	.	.	.
Geranium molle L.	I	.	.	I	.	II	.	.	.	.
Geum urbanum L.	.	I	I	I	.	.	.	.	.	.
Helleborus foetidus L.	.	.	I	.	.	.	.	I	.	I
Lathyrus latifolius L.	.	I	.	I	.	.	.	I	.	.
Lathyrus venetus (Miller) Wohlf.	.	.	I	I	.	II	.	.	.	.
Lolium multiflorum Lam.	.	.	.	I	I	.	I	.	.	.
Petrorhagia prolifera (L.) P. W. Ball et Heywood	.	.	.	.	I	I	.	I	.	.
Poa pratensis L.	.	.	.	I	.	.	I	.	.	I
Rhamnus saxatilis Jacq.	I	.	.	I	.	.	I	.	.	.
Sorghum halepense (L.) Pers.	.	.	.	I	.	.	.	I	II	.
Taraxacum officinale Weber	.	.	.	I	II	.	.	I	.	.
Trifolium rubens L.	I	I	.	I	.	.	.	.	.	.
Vicia sativa L.	.	.	.	I	.	II	.	I	.	.
Viola hirta L.	I	I	II	.	.	.	.	.	.	.
Viola riviniana Rchb.	.	III	I	I	.	.	.	.	.	.
Acer pseudoplatanus L.	.	I	I	.	.	.	.	.	.	.
Agropyron repens (L.) Beauv.	.	.	.	.	.	.	I	I	.	.
Ailanthus altissima (Miller) Swingle	.	I	.	I	.	.	.	.	.	.
Amaranthus retroflexus L.	.	.	.	.	I	.	.	I	.	.
Avena barbata Potter	.	.	.	I	.	I	.	.	.	.
Bothriochloa ischaemon (L.) Keng	I	.	.	.	.	.	.	I	.	.
Buddleja davidii Franchet	.	.	.	.	I	.	.	.	.	I
Buphthalmum salicifolium L.	I	.	.	.	.	.	.	.	.	I
Bupleurum baldense Turra	I	.	.	.	.	.	.	.	.	I
Calystegia sepium (L.) R. Br.	.	.	.	I	.	.	.	I	.	.
Centaurea jacea L.	II	.	.	.	.	.	.	.	.	I

Centaurium erythraea Rafn	I	I	.	.	.	.	.	.	.	.
Cruciata glabra (L.) Ehrend.	I	II	.	.	.	.	.	.	.	.
Diplotaxis muralis (L.) DC.	.	.	.	I	.	I	.	.	.	.
Erica arborea L.	.	II	I	.	.	.	.	.	.	.
Ferulago campestris (Besser) Grec.	II	II	.	.	.	.	.	.	.	.
Fragaria vesca L.	I	.	I	.	.	.	.	.	.	.
Fraxinus excelsior L.	.	I	II	.	.	.	.	.	.	.
Fumana procumbens (Dunal) G. et G.	II	.	.	.	.	I	.	.	.	.
Geranium robertianum L.	.	.	I	I	.	.	.	.	.	.
Humulus lupulus L.	.	.	.	I	.	.	.	I	.	.
Hypochoeris maculata L.	I	I	.	.	.	.	.	.	.	.
Hypochoeris radicata L.	.	I	.	.	.	.	.	.	.	I
Juglans nigra L.	.	.	I	.	I	.	.	.	.	.
Lolium perenne L.	.	.	.	.	.	I	.	I	.	.
Mercurialis perennis L.	.	I	I	.	.	.	.	.	.	.
Molinia arundinacea Schrank	.	III	II	.	.	.	.	.	.	.
Orlaya grandiflora (L.) Hoff.	I	.	.	I	.	.	.	.	.	.
Phytolacca americana L.	.	.	.	I	I	.	.	.	.	.
Pinus sylvestris L.	.	II	I	.	.	.	.	.	.	.
Pistacia terebinthus L.	.	.	.	I	.	I	.	.	.	.
Polygala chamaebuxus L.	I	I	.	.	.	.	.	.	.	.
Polygonatum odoratum (Miller) Druce	.	I	I	.	.	.	.	.	.	.
Polygonum arenastrum Boreau	.	.	.	.	I	.	.	I	.	.
Potentilla reptans L.	.	.	.	.	.	.	.	I	.	I
Primula vulgaris Hudson	.	I	I	.	.	.	.	.	.	.
Pteridium aquilinum (L.) Kuhn	.	I	II	.	.	.	.	.	.	.
Sambucus nigra L.	.	.	II	I	.	.	.	.	.	.
Sedum album L.	.	.	.	.	.	.	.	I	.	I
Silene vulgaris (Moench) Garcke	I	.	.	.	.	.	.	I	.	.
Spartium junceum L.	.	.	.	I	.	I	.	.	.	.
Stachys officinalis (L.) Trevisan	II	II	.	.	.	.	.	.	.	.

Succisa pratensis Moench	.	I	.	.	I	.	.	.	.	.
Verbascum chaixii Vill.	I	.	.	.	I	.	.	.	.	.
Verbena officinalis L.	.	.	.	.	I	.	.	I	.	.
Vitis vinifera L.	.	.	.	I	I	.	.	.	.	.
Achillea collina Becker	I	.	.	.	.	.	.	.	.	.
Agrimonia eupatoria L.	.	I	.	.	.	.	.	.	.	.
Agropyron caninum (L.) Beauv.	.	.	.	I	.	.	.	.	.	.
Agrostis tenuis Sibth.	.	I	.	.	.	.	.	.	.	.
Alliaria petiolata (Bieb.) Cavara et Grande	.	.	I	.	.	.	.	.	.	.
Allium cirrhosum Vandelli	II	.	.	.	.	.	.	.	.	.
Allium sphaerocephalon L.	I	.	.	.	.	.	.	.	.	.
Amaranthus bouchonii Thell.	.	.	.	.	I	.	.	.	.	.
Amelanchier ovalis Medicus	I	.	.	.	.	.	.	.	.	.
Anagallis arvensis L.	.	.	.	.	.	.	.	I	.	.
Anemone nemorosa L.	.	.	I	.	.	.	.	.	.	.
Argyrolobium zanonii (Turra) P. W. Ball	I	.	.	.	.	.	.	.	.	.
Asperula cynanchica L.	I	.	.	.	.	.	.	.	.	.
Asperula purpurea (L.) Ehrend.	III	.	.	.	.	.	.	.	.	.
Asplenium adiantum-nigrum L.	.	.	I	.	.	.	.	.	.	.
Asplenium ruta-muraria L.	I	.	.	.	.	.	.	.	.	.
Astragalus monspessulanus L.	I	.	.	.	.	.	.	.	.	.
Barbarea vulgaris R. Br.	.	.	.	I	.	.	.	.	.	.
Betula pendula Roth	.	.	I	.	.	.	.	.	.	.
Biscutella cichoriifolia Loisel.	I	.	.	.	.	.	.	.	.	.
Biscutella laevigata L.	I	.	.	.	.	.	.	.	.	.
Blackstonia perfoliata (L.) Hudson	I	.	.	.	.	.	.	.	.	.
Bougainvillea spectabilis Willd.	.	.	.	.	I	.	.	.	.	.
Campanula trachelium L.	.	.	I	.	.	.	.	.	.	.
Carduus defloratus L.	.	I	.	.	.	.	.	.	.	.
Carduus nutans L.	I	.	.	.	.	.	.	.	.	.
Carex liparocarpos Gaudin	I	.	.	.	.	.	.	.	.	.

Carex michelii Host	I	.	.	.	.	.	.	.	.	.
Carex montana L.	.	II	.	.	.	.	.	.	.	.
Carex pallescens L.	.	I	.	.	.	.	.	.	.	.
Carex pendula Hudson	.	.	.	I	.	.	.	.	.	.
Carex pilosa Scop.	.	.	I	.	.	.	.	.	.	.
*Carex sylva*tica Hudson	.	.	I	.	.	.	.	.	.	.
Carthamus lanatus L.	I	.	.	.	.	.	.	.	.	.
Centaurea bracteata Scop.	II	.	.	.	.	.	.	.	.	.
Cephalanthera damasonium (Miller) Druce	.	I	.	.	.	.	.	.	.	.
Cercis siliquastrum L.	.	.	I	.	.	.	.	.	.	.
Chaenorhinum minus (L.) Lange	.	.	.	.	I	.	.	.	.	.
Chamaecytisus purpureus (Scop.) Link	I	.	.	.	.	.	.	.	.	.
Circaea lutetiana L.	.	.	I	.	.	.	.	.	.	.
Clematis recta L.	I	.	.	.	.	.	.	.	.	.
Colchicum lusitanum Brot.	I	.	.	.	.	.	.	.	.	.
Convolvulus cantabrica L.	I	.	.	.	.	.	.	.	.	.
Coronilla vaginalis Lam.	I	.	.	.	.	.	.	.	.	.
Coronilla varia L.	.	.	.	.	.	.	.	I	.	.
Cuscuta planiflora Ten.	I	.	.	.	.	.	.	.	.	.
Cynodon dactylon (L.) Pers.	.	.	.	.	.	.	.	I	.	.
Cytisus pseudoprocumbens Markgraf.	I	.	.	.	.	.	.	.	.	.
Danthonia decumbens (L.) DC.	.	I	.	.	.	.	.	.	.	.
Dianthus carthusianorum L.	II	.	.	.	.	.	.	.	.	.
Dryopteris filix-mas (L.) Schott	.	.	I	.	.	.	.	.	.	.
Duchesnea indica (Andrews) Focke	.	.	I	.	.	.	.	.	.	.
Equisetum telmateja Ehrh.	.	.	.	.	.	.	.	I	.	.
Euphorbia flavicoma DC.	I	.	.	.	.	.	.	.	.	.
Euphorbia nicaeensis All.	I	.	.	.	.	.	.	.	.	.
Festuca tenuifolia Sibth.	.	I	.	.	.	.	.	.	.	.
Ficus carica L.	.	.	.	.	.	I	.	.	.	.
Fragaria moschata Duchesne	I	.	.	.	.	.	.	.	.	.

Galinsoga parviflora Cav.	.	.	.	.	I	.	.	.	.	.
Galium album Miller	I	.	.	.	.	.	.	.	.	.
Galium aparine L.	.	.	.	I	.	.	.	.	.	.
Galium aristatum L.	.	.	I	.	.	.	.	.	.	.
Galium rubrum L.	I	.	.	.	.	.	.	.	.	.
Genista tinctoria L	I	.	.	.	.	.	.	.	.	.
Geranium columbinum L.	I	.	.	.	.	.	.	.	.	.
Globularia cordifolia L.	I	.	.	.	.	.	.	.	.	.
Helianthemum canum (L.) Baumg.	I	.	.	.	.	.	.	.	.	.
Hieracium gr. *murorum* Auct.	.	I	.	.	.	.	.	.	.	.
Hieracium pilosella L.	I	.	.	.	.	.	.	.	.	.
Hieracium piloselloides Vill.	I	.	.	.	.	.	.	.	.	.
Hieracium sylvaticum (L.) L.	.	I	.	.	.	.	.	.	.	.
Hieracium umbellatum L.	.	I	.	.	.	.	.	.	.	.
Inula ensifolia L.	I	.	.	.	.	.	.	.	.	.
Inula salicina L.	I	.	.	.	.	.	.	.	.	.
Inula spiraeifolia L.	III	.	.	.	.	.	.	.	.	.
Knautia arvensis (L.) Coulter	I	.	.	.	.	.	.	.	.	.
Koeleria splendens Presl	III	.	.	.	.	.	.	.	.	.
Lamium orvala L.	.	.	I	.	.	.	.	.	.	.
Lathyrus vernus (L.) Bernh.	.	.	I	.	.	.	.	.	.	.
Leontodon crispus Vill.	I	.	.	.	.	.	.	.	.	.
Leucanthemum vulgare Lam.	.	I	.	.	.	.	.	.	.	.
Linum tenuifolium L.	II	.	.	.	.	.	.	.	.	.
Linum trigynum L.	I	.	.	.	.	.	.	.	.	.
Odontites lutea (L.) Clairv.	II	.	.	.	.	.	.	.	.	.
Ononis natrix L.	I	.	.	.	.	.	.	.	.	.
Ononis pusilla L.	I	.	.	.	.	.	.	.	.	.
Ophrys apifera Hudson	I	.	.	.	.	.	.	.	.	.
Ophrys insectifera L.	I	.	.	.	.	.	.	.	.	.
Orchis coriophora L.	I	.	.	.	.	.	.	.	.	.

Orchis morio L.	I	.	.	.	.	.	.	.	.	.
Origanum vulgare L.	I	.	.	.	.	.	.	.	.	.
Orobanche alba Stephan	I	.	.	.	.	.	.	.	.	.
Petrorhagia saxifraga (L.) Link	I	.	.	.	.	.	.	.	.	.
Petunia x *hybrida* Hort.	.	.	.	.	I	.	.	.	.	.
Phleum phleoides (L.) Karsten	I	.	.	.	.	.	.	.	.	.
Phyteuma scheuchzeri All.	I	.	.	.	.	.	.	.	.	.
Pimpinella major (L.) Hudson	.	.	.	.	.	I	.	.	.	.
Pinus gr. *nigra*	.	I	.	.	.	.	.	.	.	.
Plantago argentea Chaix	I	.	.	.	.	.	.	.	.	.
Plantago holosteum Scop.	I	.	.	.	.	.	.	.	.	.
Polygala nicaeensis Risso	I	.	.	.	.	.	.	.	.	.
Polygala pedemontana Per. et Verl.	II	.	.	.	.	.	.	.	.	.
Polygonatum multiflorum (L.) All.	.	I	.	.	.	.	.	.	.	.
Populus alba L.	.	.	.	.	I	.	.	.	.	.
Populus tremula L.	.	.	I	.	.	.	.	.	.	.
Potentilla heptaphylla L.	I	.	.	.	.	.	.	.	.	.
Potentilla recta L.	.	I	.	.	.	.	.	.	.	.
Potentilla tabernaemontani Asch.	I	.	.	.	.	.	.	.	.	.
Primula veris L. (cfr)	.	I	.	.	.	.	.	.	.	.
Prunella laciniata (L.) L.	I	.	.	.	.	.	.	.	.	.
Prunus persica (L.) Batsch	.	.	.	.	.	.	I	.	.	.
Pseudolysimachion spicatum (L.) Opiz	II	.	.	.	.	.	.	.	.	.
Pulsatilla montana (Hoppe) Rchb.	I	.	.	.	.	.	.	.	.	.
Quercus ilex L.	.	I	.	.	.	.	.	.	.	.
Quercus robur L.	.	.	I	.	.	.	.	.	.	.
Rubia peregrina L.	I	.	.	.	.	.	.	.	.	.
Rumex crispus L.	.	.	.	I	.	.	.	.	.	.
Ruta graveolens L.	I	.	.	.	.	.	.	.	.	.
Salix purpurea L.	.	.	.	.	I	.	.	.	.	.
Saponaria ocymoides L.	.	.	.	.	.	.	.	I	.	.

Scorzonera austriaca Willd.	II	.	.	.	.	.	.	.	.	.
Scorzonera hispanica L.	I	.	.	.	.	.	.	.	.	.
Scrophularia canina L.	.	.	.	.	I	.	.	.	.	.
Sedum dasyphyllum L.	.	.	.	.	.	.	.	.	.	I
Sedum reflexum L.	I	.	.	.	.	.	.	.	.	.
Sedum sexangulare L.	I	.	.	.	.	.	.	.	.	.
Senecio jacobaea L.	I	.	.	.	.	.	.	.	.	.
Senecio vulgaris L.	.	.	.	.	I	.	.	.	.	.
Serapias vomeracea (Burm.) Briq.	I	.	.	.	.	.	.	.	.	.
Silene italica (L.) Pers.	I	.	.	.	.	.	.	.	.	.
Silene otites (L.) Wibel	I	.	.	.	.	.	.	.	.	.
Solanum dulcamara L.	.	.	.	.	I	.	.	.	.	.
Solidago virga-aurea L.	.	I	.	.	.	.	.	.	.	.
Stipa pennata L. s. s. emend. Steven	II	.	.	.	.	.	.	.	.	.
Taxus baccata L.	.	I	.	.	.	.	.	.	.	.
Thalictrum minus L.	I	.	.	.	.	.	.	.	.	.
Thesium divaricatum Jan	I	.	.	.	.	.	.	.	.	.
Trifolium alpestre L.	I	.	.	.	.	.	.	.	.	.
Trifolium montanum L.	I	.	.	.	.	.	.	.	.	.
Trifolium repens L.	.	.	.	.	.	.	.	I	.	.
Trifolium scabrum L.	.	.	.	.	.	.	.	.	.	I
Trisetum flavescens (L.) Beauv.	I	.	.	.	.	.	.	.	.	.
Typhoides arundinacea (L.) Moench	.	.	.	I	.	.	.	.	.	.
Ulmus glabra Hudson	.	.	I	.	.	.	.	.	.	.
Veronica prostrata L.	I	.	.	.	.	.	.	.	.	.
Vincetoxicum hirundinaria (L.) Moench	I	.	.	.	.	.	.	.	.	.
Viola alba Besser	.	I	.	.	.	.	.	.	.	.
Viola canina L.	.	.	I	.	.	.	.	.	.	.
Vulpia ciliata (Danth.) Link	.	.	.	.	.	.	II	.	.	.

Supplementary material 2

Regression parameters between mean age for class and mean of species abundance of the 50 most frequent species across the study area. In bold specie with significant regression values.

Species	Slope	Error	Intercept	Error	r	p
Picris hieracioides	-0.0481	0.017535	4.4418	0.87668	-0.84555	0.071
Lactuca serriola	**-0.0461**	**0.011075**	**3.9734**	**0.55371**	**-0.92327**	**0.025**
Senecio inaequidens	**-0.06521**	**0.014605**	**6.265**	**0.73021**	**-0.93231**	**0.02**
Stachys recta	0.020349	0.010013	2.7192	0.5006	0.76109	0.14
Fraxinus ornus	**0.14569**	**0.038436**	**2.0844**	**1.9217**	**0.90954**	**0.03**
Populus nigra	-0.02324	0.093023	15.693	4.6508	-0.14275	0.82
Robinia pseudoacacia	0.16452	0.15344	8.7082	7.6715	0.52634	0.36
Ostrya carpinifolia	**0.24675**	**0.062669**	**5.287**	**3.1332**	**0.91535**	**0.03**
Clematis vitalba	-0.08744	0.06243	11.874	3.1213	-0.62878	0.26
Centranthus ruber	-0.04836	0.034255	6.7726	1.7126	-0.63182	0.25
Dactylis glomerata	**-0.04426**	**0.001592**	**6.372**	**0.079604**	**-0.99806**	**0.00**
Sonchus oleraceus	-0.0217	0.012552	2.5816	0.62754	-0.70636	0.18
Daucus carota	-0.03531	0.012414	3.0945	0.62064	-0.85412	0.07
Lotus corniculatus	-0.03305	0.019368	3.1594	0.96831	-0.70187	0.19
Euphorbia cyparissias	-0.02226	0.030488	3.6903	1.5243	-0.38841	0.52
Brachypodium rupestre	0.048302	0.03232	1.6735	1.6159	0.65328	0.23
Rubus ulmifolius	-0.08618	0.086426	12.962	4.321	-0.49894	0.39
Dorycnium pentaphyllum	-0.031	0.037881	7.101	1.8939	-0.42718	0.47
Melica ciliata	0.00927	0.047179	5.6057	2.3588	0.11272	0.86
Geranium sanguineum	-0.00566	0.029366	2.9084	1.4682	-0.11069	0.86
Erigeron annuus	-0.01807	0.016248	2.6351	0.81233	-0.54036	0.35
Crataegus monogyna	0.02434	0.054895	5.6504	2.7445	0.248	0.69
Euphorbia dulcis	-0.00635	0.01932	2.0652	0.96591	-0.18646	0.76
Carex flacca	0.081099	0.039966	1.0826	1.9981	0.7606	0.14
Melilotus alba	**-0.04013**	**0.011885**	**3.4947**	**0.59419**	**-0.88977**	**0.04**
Sanguisorba minor	-0.00933	0.018897	2.6463	0.94478	-0.27409	0.66
Hedera helix	**0.20336**	**0.057865**	**-2.2837**	**2.8931**	**0.89698**	**0.04**
Teucrium chamaedrys	0.070172	0.069707	3.4861	3.4851	0.50249	0.39
Tamus communis	**0.11258**	**0.032225**	**0.4155**	**1.6111**	**0.89594**	**0.04**
Bromus sterilis	-0.02991	0.019684	2.5348	0.98415	-0.65948	0.23
Bromus hordeaceus	-0.05111	0.02113	6.1499	1.0564	-0.81304	0.09
Echium vulgare	-0.00599	0.018393	2.0334	0.91958	-0.18491	0.77
Ligustrum vulgare	0.030278	0.0375	1.4929	1.8749	0.42251	0.48
Artemisia alba	0.084578	0.074759	4.927	3.7377	0.54686	0.34
Helianthemum nummularium	0.055425	0.018521	-0.40343	0.92599	0.86548	0.06
Quercus pubescens	0.25779	0.11183	3.6661	5.5909	0.79948	0.10
Cotinus coggygria	0.082162	0.043679	0.5473	2.1838	0.73564	0.16
Globularia punctata	0.021611	0.033558	1.1412	1.6778	0.34849	0.57

Medicago lupulina	-0.03683	0.009594	3.2848	0.47964	-0.9115	0.03
Bromus condensatus	**0.43075**	**0.069443**	**-2.4868**	**3.4719**	**0.96316**	**0.01**
Setaria viridis	-0.12864	0.1389	9.9586	6.9445	-0.47153	0.42
Cornus sanguinea	0.071014	0.041528	1.9381	2.0762	0.70257	0.19
Bromus erectus	0.17725	0.20978	6.4198	10.488	0.43843	0.46
Polygonum lapathifolium	-0.05219	0.03586	4.2692	1.7929	-0.64333	0.24
Torilis arvensis	**-0.05138**	**0.015855**	**4.2371**	**0.79271**	**-0.88193**	**0.05**
Prunus avium	0.037238	0.062404	2.3448	3.12	0.32573	0.59
Ruscus aculeatus	0.023308	0.008028	-0.15301	0.40137	0.8588	0.06
Thymus pulegioides	0.090034	0.040983	0.416	2.049	0.78529	0.12
Galium lucidum	-0.00181	0.058977	4.2791	2.9486	-0.01776	0.98
Crepis vesicaria	-0.00745	0.005282	0.82038	0.26409	-0.63123	0.25

3.2 Manuscript to be submitted: Geomorphological heterogeneity affects plant traits and natural revegetation patterns on limestone quarries

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Abstract

Revegetation patterns after quarry abandonment have been widely studied from several ecological point of view, but a trait-based approach is still lacking. The aim of this study is to investigate plant species patterns and successful plant strategies limestone quarries according to geomorphological heterogeneity. In particular, we carried out 113 vegetation plots on artificial cliffs, embankments and platforms and we collected 25 morphological, ecological and dispersal traits to detect species adaption across environments. As a case study we selected the extractive basin of Botticino (Lombardy, Italy). The results obtained by SIMPER and CCA analyses showed that species distribution and abundance were clearly differentiated according to the main topographic gradient of the three geomorphological surfaces we studied. The frequency of the distribution of species traits on the different geomorphological surfaces showed that artificial cliffs had the most limiting environmental conditions for plant establishment, selecting dispersal mechanism depending mostly by wind and life forms characteristic of slow vegetation dynamics. Embankments and platforms, which showed similar characteristics each others, seems to be correlated with a higher moisture availability and zoochorous/hydrochorous dispersal agents, respectively. Results may be useful to give general indications about the species selection for quarry restoration, according to different type of geomorphological surface. Spontaneous succession should be prefer on artificial cliffs where adverse environmental conditions select peculiar morphological and reproductive species traits.

Key words: artificial cliffs, embankments, platforms, morphology, ecological needs, dispersal, plant strategies, quarry restoration

Introduction

Spontaneous revegetation dynamics after the abandonment of quarries are widely studied all over the world, especially in order to use such a basic knowledge for the planning of future restoration projects (e.g. Tischew & Kirmer 2007). During the first years after the quarry abandonment, environmental conditions are very adverse for plant establishment, so that only some vegetation patches of few ruderal species are able to colonize the bare substrate, which generally shows relevant chemical and physical limitations (e.g. water and nutrients deficiency). With the amelioration of the site environmental conditions (i.e. soil cover, thickness and chemical characteristics), biotic filters due to competition and facilitation become more and more important (e.g. Mota et al. 2004; Martínez-Ruiz et al. 2007), and perennial and more exigent species progressively replace the annual ruderal ones (e.g. Martínez-Ruiz et al. 2007; Frouz et al. 2008). Nevertheless, abiotic filters strongly affect plant communities composition during the whole recolonization process (e.g. Dana & Mota 2006; Tishew & Kirmer 2007). Among abiotic filters, quarry geomorphological heterogeneity is predicted to have a great relevance due to differences in the disturbance regime, soil properties and micro-climatic conditions (e.g. Novák & Konvička 2006; Duan et al. 2008). In particular, different plant species patterns characterizing a precise phase of the vegetation succession (e.g. pioneer species, late colonizer species) could be identified according to three geomorphological features (i.e. artificial cliffs, platforms and embankments) at different time from quarry abandonment, in response to the mentioned abiotic factors (e.g. Novák & Konvička 2006; Duan et al. 2008). However, such differences could be also the result of a shifting in the importance of different biotic interactions due to dissimilar adaptation strategies (i.e. traits) of plants (e.g. Garreth & Leishman 2009).

In the study of quarry restoration, such ecological evidences are at present scarcely supported by a traits-based approach (Řehounková & Prach 2010), although it is widely recognised that particular combinations and values of species traits could be an useful instrument to predict plant strategy (Wilson et al. 1999), species presence and abundance, plant fitness and vegetation communities (e.g. Cingolani et al. 2007; Sonnier et al. 2010). It is recognized that phenology and life forms are useful to predict the possible success of species establishment, since phenology is implicated in water "economy" and resources acquisition through the leaves production, longevity and shedding (e.g. Castro-Díez et al. 2003; Navas et al. 2003), while life forms are distributed according to environmental gradients: annual herbs (i.e. therophytes and some hemicryptophytes) are dominant on high disturbed sites, where they take advantages by investing more in reproduction by producing small but numerous seeds (Díaz et al. 2007). Anyway, most efforts regarding the study of species traits since now focused only on specific fields (Sonnier et al. 2010), such as the study of the invasion process by alien species (Jauni & Hyvönen 2012), species patterns as affected by landscape-level processes such as changes in land use and fire (e.g. Lomba et al. 2011), the primary succession of alpine species (Caccianiga et al. 2006), possible future plant assemblages according to climate changes (Dobrowski et al. 2011). Moreover, Pywell et al. (2003) used species traits as a tool to evaluate the success of a restoration. Until now no studies specifically treated the adaptation of species (i.e. species traits) in relation to the quarry geomorpological heterogeneity and to the different disturbance regime to which each quarry landform (artificial cliffs, platforms and embankments) is subjected.

Thus, the aim of our study was the characterization of the plant functional traits growing on the different geomorphological surfaces on a quarry area. As a case study we considered the limestone quarries located in the extractive basin of Botticino (Lombardy, Italy). In particular, we try to answer the following questions: a) What are the main environmental factors affecting species according to type of geomorphological surface? b) Does geomorphological heterogeneity select species traits in abandoned quarry areas and which traits are selected? c) Which are the implications for future restoration project?

Material and methods

Study area. The study area is located on the Botticino extractive basin, the second most important Italian extractive area. About 135 quarries are still working for the extraction of limestone, included the commercially known “Botticino Marble”, which is exported all over the world as facing and structural elements for buildings (Clerici & Meda 2005). The basin is located on the hill area of the Brescia Province (Lombardy, Italy), at north-east of the city of Brescia, and cover 5 Municipalities: Botticino, Nuvolento, Nuvolera, Paitone and Serle (coordinates in the centre of the basin: 1605608 504557; Fig. 1a). Altitude ranges from about 180 to 650 m a.s.l. The climate is continental, with mean annual temperature of 13.5°C and annual rainfall of 1026.13 mm. The most extended local lythology is the limestone of the “Corna” formation, connected of karst phenomena (Servizio Geologico d’Italia 2008). Vegetation on the quarries surroundings is mainly composed by woodlands, usually managed as copse and dominated by *Quercus pubescens*, with a high presence of *Ostrya carpinifolia* and *Fraxinus ornus*. Such vegetation communities have been locally replaced by copse woodlands of *Castanea sativa* because of the past economic value.

Due to the extraction techniques, a quarry basin is generally characterized by a high geomorphological heterogeneity, that is attributable to the presence of three main man-made geomorphological structures: artificial cliffs, embankments and platforms (Fig. 1b).

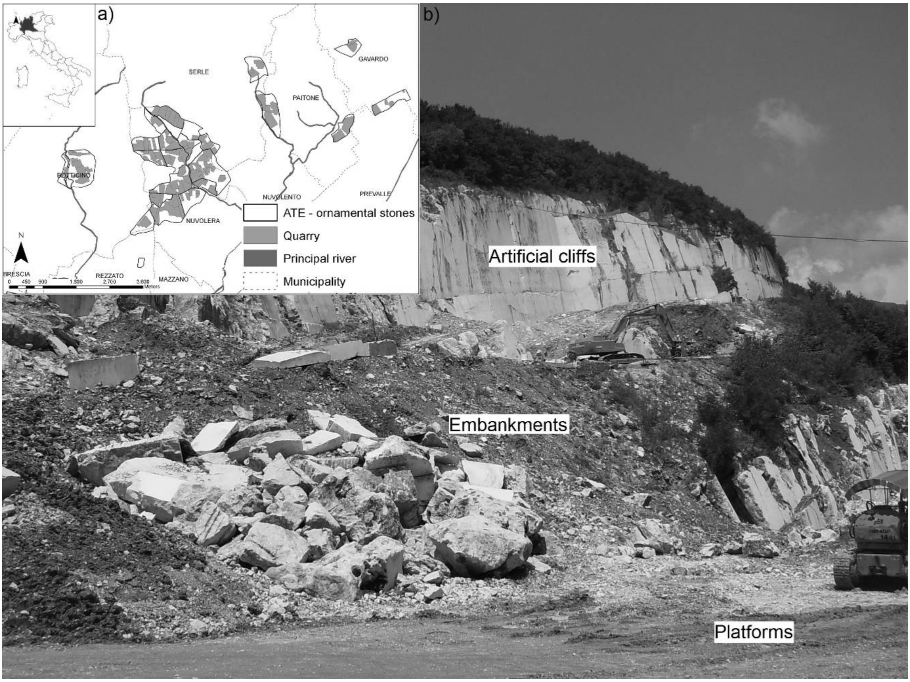

Fig. 1 a) Location of the study area and b) geomorphological features in quarries: artificial cliffs, embankments and platforms

Sampling and data collection. During spring and summer 2010, we carried out 113 vegetation plots of 25 mq in 52 working quarries all over the extractive basin, of which 68 plots on embankments, 14 on platforms and 31 on artificial cliffs. The disparity of the number of the plots, recorded through a random stratified sampling, is due to the extraction techniques: every quarry has in general one platform for the manoeuvring of the vehicles (which is almost entirely covered by bare ground), few artificial cliffs that are temporarily abandoned and many embankments that are often moved.

To characterize the types of plant communities growing on the three artificial landforms, we made a complete list of vascular plant species and we estimated plant species cover according to Braun-Blanquet (1928) modified by Pignatti (1953). We carried out a SIMPER analysis on species present in almost three plots, by means of the software PAST, in order to recognize differences in plant community composition.

We also recorded the following abiotic factors (stational/ecological data): coordinates, elevation (m a.s.l.), aspect (°) and slope (°), stoniness and rockiness (estimated %), average stones dimension (cm). For investigating the recolonization trend, the surface age of quarry abandonment (on which we surveyed our plots) was collected interviewing quarrymen and then it was considered in the following data analysis. At this aim we grouped plot according to five class of age: a) 0-2 years (t=0); b) 3-10 years (t=1); c) 11-22 years (t=2); b) 23-44 years (t=3); e) >44 years (t=4).

Species traits. A large number of species traits is needed in order to understand which are connected to fundamental aspects of plant life cycle and are responsible in determining plant strategies (Navas et al. 2010). Thus, we selected 25 species traits regarding plant history and morphology, ecology and dispersal (Table 1), according to Cornelissen et al. (2003) and McIntyre et al. (1999), in order to understand which are the most suitable plant traits that are selected by each geomorphological features. Data, which were all grouped into categorical classes, were mostly taken from Pignatti (1982).

Morphological traits were: 1) Raunkiaer life forms (Raunkiær 1934); 2) plant height (PH); 3) type of stem; 4) presence of thorns; 5) presence of stolons; 6) type of leaf; 7) type of root; 8) family.

Traits related to species requirements according to Ellenberg indicator values and CSR strategies according to Grime (1974, 1977): 1) CSR strategy (only for herbaceous species): we collected data from Cerabolini et al. (2010) and integrated them with Hodgson et al. (1999), according to canopy height, leaf dry matter content, flowering period, flowering start, leaf dry weight, lateral spread and specific leaf area; 2) light (L); 3) temperature (T); 4) continentality (C); 5) moisture (U); 6) reaction (R); 7) nutrient (N) (Ellenberg et al 1991). We extracted data from Pignatti et al. (2005) and we assigned values to each species on a 9° scale for continentality, reaction and nutrient, and 12° for light, temperature and moisture; data with no preference (X) were also considered.

Traits linked to plant reproduction and dispersal were: 1) corological form; 2) start of the flowering period; 3) duration of the flowering period; 4) sex of the flowers; 5) type of corolla; 6) type of inflorescence; 7) type of fruit; 8) seed mass (SM); 9) main type main of seed dispersal; 10) seed dispersal distance. We extracted data on seed mass from the Seed Information Database of the Kew Royal Botanic Gardens (Kew Royal Botanic Gardens 2011) and compared with Cerabolini et al. (2003). Data about seed dispersal (type and distance) were extracted from Müller-Schneider (1986) and Bouman et al. (2000), compared with the Seed Information Database of the Kew Royal Botanic Gardens (Kew Royal Botanic Gardens 2011) and classified according to Vittoz & Engler (2007). About mixed strategist, the main one was used for the classification.

Morphological traits	
Life form	P (phanaerophytes), Ch (chamaephytes), H (hemicryptophytes), G (geeophytes), T (terophytes)
Plant height (PH)	a) ≤20cm, b) 20-40cm, c) 40-80cm, d) 80-160cm, e) 160-320cm, f) 320cm
Type of stem	Mainly ascending, Mainly erect, Erect-ascending, Climbing-voluble, Prostrate-creeping (almost in part)
Presence of thorns	Species with thorns, Species without thorns
Presence of stolons	Species with stolons, Species without stolons
Type of leaf	Composite, Lanceolate-elliptic, Linear-spatulate, Ovate, Deeply lobate, Round, Needle-shaped, Others
Type of root	Fascicled root, Tap root, Rhizome
Family	Apiaceae, Asteraceae, Fabaceae, Lamiaceae, Poaceae, Rosaceae, Salicaceae, Valerianaceae, Others
Traits related to species requirements	
CSR strategy	C (competitive), S (stress tolerant), R (ruderal), CS (mixed competitive, stress tolerant), CR (mixed competitive, ruderal), SR (mixed stress tolerant, ruderal), CSR (mixed competitive, stress tolerant, ruderal)
Light (L)	1-12
Temperature (T)	1-12
Continentality (C)	1-9
Moisture (U)	1-12
Reaction (R)	1-9
Nutrient (N)	1-9
Traits related to reproduction and dispersal	
Corological form	Endemic, Stenomediterranean, Eurimediterranean, Paleotemperate, Eurasiatic, European, Subatlantic, Circumboreal, Cosmopolitan, Alien
Start of the flowering period	January, February, March, April, May, June, July, August, September, October, November, December
Duration of the flowering period	1-12
Sex of the flowers	Only hermaphrodite, Mixed (hermaphrodite and/or male/female/polygamous), Only male and female
Type of corolla	Absent, Perianth reduced, Attinomorphic (tubulous, funnel-shaped, caryophyllaceae, rotate), Zygomorphic

	(labiated, ligulated, spurred, papilionaceous), Attinomorphic and zygomorphic (ligulated,tubulose), Free elements (petals/tepals)
Type of inflorescenze	Ament, Head, Inflorescence with clearly peduncolate flowers (cyme, corymb, umbel, raceme, verticil, fascicule, glomerule), Panicle, Spike, Solitary flower, cynthianum, cone
Type of fruit	Not dehiscent fruit (achene, diachene, pentachene, polyachene, tetrachene, rosehip, acorn), Not dehiscent fruit with fly structures (cypsela, ash-key), Not dehiscent fruit - graminoids (caryopsis, achene-like), Dehiscent fruit (capsule, legume, follicle), Fleshy fruit (berry, drupe, polydrupe, apple)
Seed mass (SM)	a) ≤0.1mg, b) 0.1-0.5mg, c) 0.5-1mg, d) 1-5mg, e) 5-10mg, f) 10-50mg, g) 50mg
Type of seed dispersal	Autochory, Zoochory, Anemochory, Hemerochory, Mixed – autochory, Mixed – zoochory, Mixed – anemochory, Mixed – hydrochory, Mixed – hemerochory, unknown
Seed dispersal distance	1m, 5m, 15m, 150m, 500m, 1500m, 5000m, unknown

Table 1 List of categorical species traits

Data analysis. For the analyses, we considered only species present in almost 3 plots all around the study area. Such cut was made to reduce the noise that resulted from unexplained or residual variance in the species composition across the dataset.
Since abiotic factors often explain a great amount of ecosystem variability (Díaz et al. 2007), we calculated mean stational data for each geomorphological surface and we assessed *Canonical Correspondence Analysis* (CCA; ter Braak 1986) between and within different geomorphological surfaces after converting species frequency according to Van der Maarel (1979). We considered as environmental variables those that better describe the landscape heterogeneity of quarry areas, i.e.: 1) stoniness, 2) rockiness, 3) slope, 4) elevation, 5) age, 6) aspect and 7) maximum stone dimension. We made CCA analyses by CANOCO software using default setting and considering both the marginal and conditional effect of each variable. In order to investigate ecological gradients within each geomophological feature, we performed a multiple CCA analysis (Gilardelli et al. in press): one for the whole quarry area and three on the geomorpfological surfaces we investigated within quarries: artificial cliffs, embankments and platforms.
We then elaborated data about species traits in order to identify the per cent frequency of distribution of each plant trait (subdivided in classes) according to the three main quarry geomorphological surfaces over the extractive basin. Then, because of the disparity in the number of plots on embankments, platforms and cliffs, we normalized sums by dividing for the total number of plots recorded on the three geomorphological surfaces. We examined significance of the frequency distributions of all species traits using χ^2 statistics (contingency table) and tested for significance using the Monte Carlo permutation test. We performed these last analyses by using the PAST software version 2.14 (Hammer et al. 2001).

Results

Biotic and abiotic factors. Artificial cliffs showed the highest values of slope and rockiness (53.29° and 70.42%, respectively), while we recorded the lowest values on platforms (7.36° and 0%, respectively; Table 2a). Artificial cliffs showed the highest age (21.06 years from abandonment), but the lowest vegetation and soil cover (13.19% and 4.68%, respectively). The per cent vegetation cover along with tree, shrubs, herbs percent covers showed the following tendency: a) as expected, vegetation, tree and herb layers percent cover were higher on both embankments and platforms and lower on artificial cliffs; b) shrub cover showed the highest value on embankments and the lowest on artificial cliffs.

a)	Embankments		Platforms		Artificial cliffs	
	Mean	*St. Dev.*	*Mean*	*St. Dev.*	*Mean*	*St. Dev.*
Main aspect	SW; S		none; S		S; E	
Elevation (m a.s.l.)	339.9	110.9	354.1	107.1	309.5	74.2
Age (years from abandonment)	9.29	12.92	6.43	4.69	21.06	20.61
Vegetation cover (%)	64.87	33.80	64.43	34.44	13.19	11.23
Soil cover (%)	17.51	21.60	16.00	18.47	4.68	9.19
Stoniness (%)	14.79	15.26	19.57	20.14	11.71	21.39
Rockiness (%)	2.85	14.34	0.00	0.00	70.42	29.87
Maximum stone dimension (cm)	60.15	50.93	48.36	67.05	35.84	57.88

b)

Species	Study area	Cumulative %	Species	Embankments	Species	Platforms	Species	Artficial cliffs
Populus nigra	3.024	3.936	*Populus nigra*	2.09	*Populus nigra*	2.71	*Centranthus ruber*	2.1
Centranthus ruber	2.343	6.984	*Lactuca serriola*	1.79	*Picris hieracioides*	1.79	*Melica ciliata*	1.52
Rubus ulmifolius	2.217	9.87	*Senecio inaequidens*	1.69	*Daucus carota*	1.71	*Senecio inaequidens*	1.26
Melica ciliata	2.043	12.53	*Rubus ulmifolius*	1.68	*Lactuca serriola*	1.5	*Populus nigra*	1.19
Senecio inaequidens	2.003	15.14	*Picris hieracioides*	1.66	*Senecio inaequidens*	1.43	*Picris hieracioides*	1.19
Clematis vitalba	1.881	17.58	*Clematis vitalba*	1.22	*Sonchus oleraceus*	1.43	*Lactuca serriola*	1.16
Picris hieracioides	1.864	20.01	*Daucus carota*	1.13	*Medicago lupulina*	1.43	*Dactylis glomerata*	0.968
Dactylis glomerata	1.841	22.41	*Sonchus oleraceus*	1.09	*Dactylis glomerata*	1.21	*Sonchus oleraceus*	0.935
Lactuca serriola	1.819	24.77	*Ostrya carpinifolia*	1.07	*Lotus corniculatus*	1.21	*Stachys recta*	0.935
Daucus carota	1.741	27.04	*Dactylis glomerata*	1.06	*Torilis arvensis*	1.07	*Daucus carota*	0.71

Table 2 a) Stational data and of embankments, platforms and artificial cliffs; b) SIMPER analysis to determine the ten most contributing species to the observed dissimilarity in terms of percentage abundance for each geomorphological surface. The overall average dissimilarity according to the Bray–Curtis index is 76.85.

Based on SIMPER analysis (Table 2b) the overall average dissimilarity due to the abundance of species across the study area according to the Bray-Curtis index is 76.85. *Populus nigra* is the species that mostly contributes to the dissimilarity among habitats, and contributes to the characterization of embankments and platforms surfaces. The lasts differ for *Lactuca serriola* and *Senecio inaequidens*, which characterize embankments, and *Picris hieracioides* and *Daucus carota*, which characterize platforms. *Centranthus ruber*, *Melica ciliata* and *Senecio inaequidens* specifically contribute to characterize artificial cliffs.

The trend of the abiotic factors considered in the CCA analyses (Fig. 2, Table 3a) showed evident differences among geomorphological surfaces, that were mainly detected for the stoniness, rockiness, elevation, age and slope factors. The four ordinations resulted in medium-high eigenvalues with cumulative percent variance values of species-environment relation always over 60% (Table 3b). In all the analyses, the four reported eigenvalues are canonical, corresponding to axes that are constrained by environmental variables. The environmental factor explaining most of the variability among morphological surfaces is rockiness (LambdaA=0.13; F-ratio=2.43; p=0.001). Plots carried out on embankments and platforms have a degree of overlapping and their distribution seems mostly affected by lower values of stoniness and age of abandonment. Cliffs plots are clearly differentiated and are mostly influenced by positive values of rockiness and slope.

As regards the CCA analyses of the single geomorphological surfaces, few environmental variables are significant for artificial cliffs and platforms, i.e.: a) positive values of elevation (LambdaA=0.16; F-ratio=0.11; p=0.001) and slope (LambdaA=0.12; F-ratio=1.51; p=0.033) for the first surface; b) positive values of stoniness (LambdaA=0.25; F-ratio=0.11; p=0.002) and aspect (LambdaA=0.19; F-ratio=0.09; p=0.045) for the second one. In the CCA of embankments the most significant variable is age of abandonment (LambdaA=0.20; F-ratio=3.02; p=0.001); secondarily stoniness and elevation show good levels of variance contributing to explain the spatial distribution of plots.

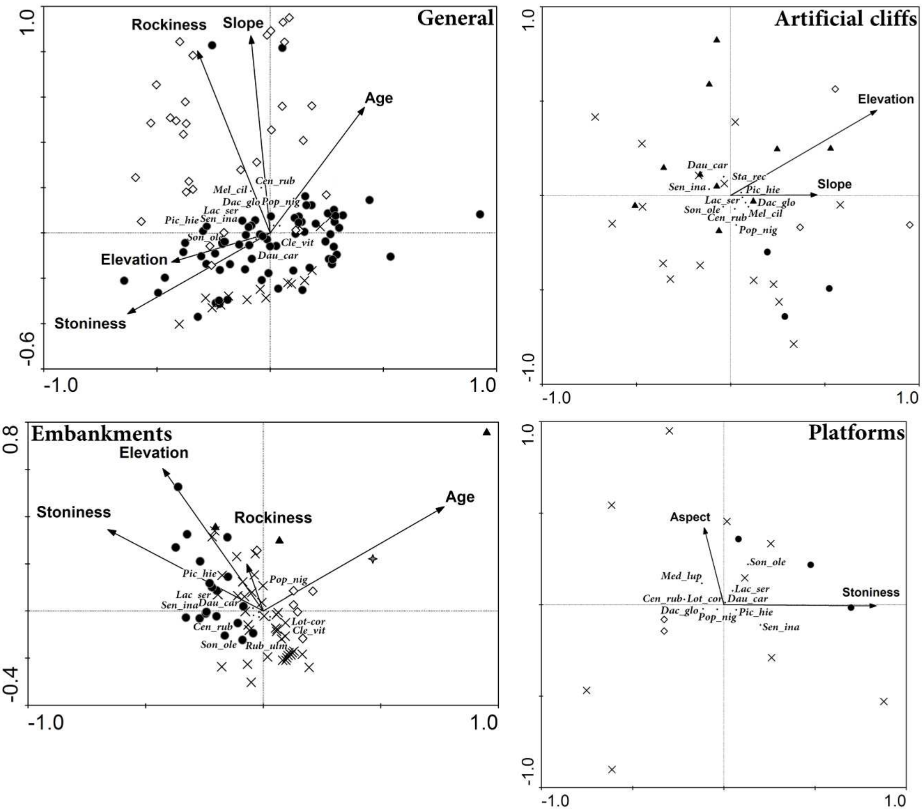

Fig. 2 CCA diagrams. General CCA: legend: black circle: embankments; cross: platforms; white diamond: artificial cliffs. Cliffs, embankments and platforms legend: black circle: plots abandoned from 0-2 years; cross: plots abandoned from 3-10 years; white diamond: plots abandoned from 11-22 years; gray star: plots abandoned from 23-44 years; black triangle: plots abandoned from more than 44 years.

a)	**Marginal Effects**	**Conditional Effects**		
	Lambda1	**LambdaA**	**P**	**F**
GENERAL				
Stoniness	**0.12**	**0.12**	**0.001**	**0.11**
Rockiness	**0.12**	**0.13**	**0.001**	**2.43**
Slope	**0.11**	**0.08**	**0.011**	**1.46**
Elevation	**0.11**	**0.11**	**0.001**	**2.16**
Age	**0.11**	**0.08**	**0.003**	**2.16**
Aspect	0.06	0.05	0.320	0.04
Maximum stone dimension	0.05	0.04	0.360	0.07
ARTIFICIAL CLIFFS				
Elevation	**0.16**	**0.16**	**0.001**	**0.11**
Slope	**0.12**	**0.12**	**0.033**	**1.51**
Aspect	0.11	0.08	0.233	1.08
Rockiness	0.10	0.10	0.076	1.29
Age	0.10	0.11	0.073	1.31
Maximum stone dimension	0.08	0.09	0.245	1.07
Stoniness	0.08	0.06	0.514	0.06
EMBANKMENTS				
Age	**0.20**	**0.20**	**0.001**	**3.02**
Stoniness	**0.17**	**0.12**	**0.001**	**0.11**
Elevation	**0.13**	**0.11**	**0.001**	**0.09**
Aspect	0.08	0.07	0.242	1.06
Slope	0.08	0.08	0.081	1.25
Rockiness	**0.07**	**0.09**	**0.040**	**1.49**
Maximum stone dimension	0.06	0.05	0.458	0.06
PLATFORMS				
Stonines	**0.25**	**0.25**	**0.002**	**0.11**
Age	0.22	0.14	0.129	1.31
Slope	0.21	0.18	0.058	1.49
Aspect	**0.15**	**0.19**	**0.045**	**0.09**
Elevation	0.12	0.11	0.373	0.06
Maximum stone dimension	0.12	0.06	0.577	0.04

b) Axes	1	2	3	4	Total inertia
GENERAL					
Eigenvalues	0.192	0.128	0.092	0.066	5.835
Species-environment correlations	0.788	0.735	0.792	0.711	
Cumulative percentage variance of species data	3.3	5.5	7.0	8.2	
Cumulative percentage variance of species-environment relation	31.2	52.0	66.9	77.6	
Sum of all eigenvalues					5.835
Sum of all canonical eigenvalues					0.615
ARTIFICIAL CLIFFS					
Eigenvalues	0.197	0.146	0.130	0.087	2.532
Species-environment correlations	0.869	0.906	0.842	0.819	
Cumulative percentage variance of species data	7.8	13.5	18.6	22.1	
Cumulative percentage variance of species-environment relation	27.3	47.5	65.4	77.5	
Sum of all eigenvalues					2.532
Sum of all canonical eigenvalues					0.721
EMBANKMENTS					
Eigenvalues	0.270	0.110	0.094	0.079	4.477
Species-environment correlations	0.869	0.864	0.775	0.701	
Cumulative percentage variance of species data	6.0	8.5	10.6	12.4	
Cumulative percentage variance of species-environment relation	37.4	52.6	65.6	76.4	
Sum of all eigenvalues					4.477
Sum of all canonical eigenvalues					0.724
PLATFORMS					
Eigenvalues	0.293	0.211	0.145	0.137	1.758
Species-environment correlations	0.977	0.939	0.892	0.928	
Cumulative percentage variance of species data	16.7	28.7	36.9	44.7	
Cumulative percentage variance of species-environment relation	31.4	54.0	69.5	84.2	
Sum of all eigenvalues					1.758
Sum of all canonical eigenvalues					0.934

Table 3 a) Parameters of CCA analyses. In bold are reported significant environmental variables, b) Eingenvalues, species- environment correlation and cumulative percentage of variance.

Species traits. The results of contingency tables of the percent frequencies of the 25 morphological, ecological and reproductive species traits distributed on the three geomorphological surfaces (Table 4, see Supplementary material 2) show that eight traits resulted no significant. Out of a total, 13 traits resulted highly significant at 0.01 level and 4 traits at the 0.05 level based on both Fisher's exact p-value and Monte Carlo permutation test.

	M;N	Degrees freedom	Chi^2	p (Fishers' extact test)	Monte Carlo p
Morphological traits					
Life form	5;3	8	43.994	5.705E-07	0.0001
Plant height (PH)	6;3	10	45.906	1.492E-06	0.0001
Type of stem	5;3	8	32.262	0.0001	0.0001
Presence of thorns	2;3	2	16.423	0.0003	0.0004
Type of leaf	8;3	14	58.352	2.278E-07	0.0001
Family	9;3	16	60.261	4.730E-07	0.0001
Traits related to species requirements					
Moisture (U)	9;3	16	47.635	0.0001	0.0001
Traits related to reproduction and dispersal					
Corological form	10;3	18	45.787	0.0003	0.0006
Start of the flowering period	9;3	16	39.559	0.0009	0.0001
Type of corolla	6;3	10	40.315	1.491E-05	0.0001
Type of fruit	5;3	8	36.005	1.753E-05	0.0002
Main seed dispersal type	10;3	18	66.598	1.686E-07	0.0001
Seed dispersal distance	8;3	14	51.706	3.154E-06	0.0001

Table 4 Contingency tables of percent frequencies of the traits distributed on the three geomorphological surfaces, with 99% of significance

The 13 highly significant traits (Fig. 3, Supplementary material 1, Supplementary material 2, Supplementary material 3), showing a strong relation with type of geomorphological surfaces are here described.

Morphological traits:

a) life forms: main differences are in the percent frequency of geophytes and chamaephytes; the first ones were mainly found on embankments and secondly on platforms, the second ones have their main distribution on artificial cliffs;
b) plant height: tall herbs and/or shrubs are mainly distributed on embankments while short herbs were mainly found on platforms;
c) type of stem: species with a mainly ascending stem were mainly observed on artificial cliffs, while species with a climbing-voluble and prostrate-creeping stem were mostly found on platforms;
d) presence of thorns: the species with thorns showed a increasing frequency trend from

embankments to artificial cliffs;

e) leaf type: the main differences are due to composite, lanceolate-elliptic, deeply lobate and rounded leaves, that showed lower frequency on artificial cliffs; rounded leaves had the lowest percent frequency on platforms;

f) family: higher differences were found on the *other* families, that showed lower frequency on artificial cliffs and a correspondent higher frequency on embankments.

Traits related to species requirements:

a) Ellenberg indicator values of moisture (U): we observed a decreasing trend in moisture availability from platforms, where most species indicators of stagnant conditions were found, to artificial cliffs, where species indicators of low water availability were observed.

Traits related to reproduction and dispersal:

a) corological form: the main differences are due to endemic species that are mainly found on artificial cliffs along with stenomediterranean species; circumboreal and subatlantic showed a decreasing trend from embankments to artificial cliffs; paleotemperates and aliens had the highest values on platforms.

b) start of the flowering period: early flowering species were mainly found on platforms; species which flowering on September were only observed on platforms and embankments;

c) type of corolla: main differences were due to the percent frequency of species with a corolla attinomorphic, zygomorphic and with free elements, that are less abundant on artificial cliffs;

d) type of fruit: we observed main differences for fleshy fruits, that were more abundant on embankments, and secondly on platforms; not dehiscent and dehiscent fruits (not graminoids, and without fly structures) were mostly observed on platforms;

e) type of seed dispersal: we observed species with an autochory, mixed-autochory and mixed-hydrochory seed dispersal on platforms, and secondly on embankments; species with an anemochory and mixed-anemochory dispersal prevailed on artificial cliffs; species with a zoochory and mixed-hemerochory seed dispersal were mostly observed on embankments;

f) seed dispersal distance: species with a low dispersal distance were mainly associated to artificial cliffs; plant species with medium dispersal distances were mainly found on platforms and secondly on embankments.

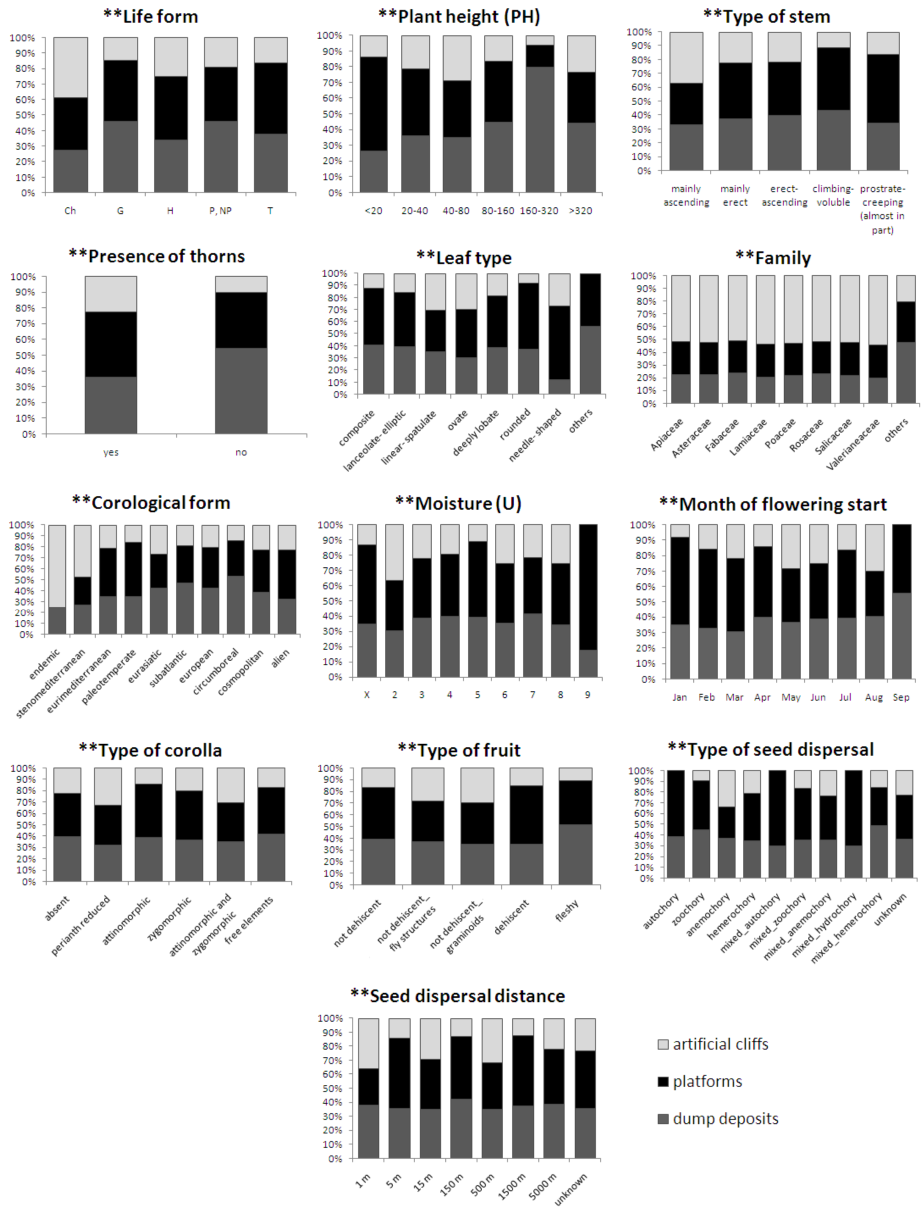

Fig. 3 Distribution of species traits according to geomorphological surfaces. Legend: ** highly significant differences

Discussion

Our results revealed that geomorphological heterogeneity affects plant species distribution and abundance within quarry areas inducing meso-environmental heterogeneity in the vegetation patterns. Within quarries, landforms and topographic characteristics, such as rockiness, slope and stoniness, are the main abiotic factors that determine plant diversity and favour differences in the colonization patters on the three main geomorphological surfaces: embankments, platforms, and artificial cliffs. Within each geomorphological surface, different abiotic factors mainly affect vegetation dynamics, such as elevation and slope on artificial cliffs, and stoniness on platforms. Even if stoniness and elevation strongly affect vegetation pattern also on embankments, time after quarry abandonment is here the most environmental factor driving vegetation dynamics, so that the course of the vegetation succession can be more easily identified than in the other geomorphological surfaces (e.g. Martínez-Ruiz et al. 2007; Frouz et al. 2008).

However, as stressed by previous authors (e.g. Richerson & Lum 1980; Duan et al. 2008), the relationship between plant communities and environmental heterogeneity may go deeper, consequently vegetation patterns and plant diversity at the micro scale are often reshaped by resources availability (Pausas & Austin 2001). In the study area, the main direct variable is the human disturbance, as demonstrated by the fact that Grime's ruderal strategists are equally distributed independently by type of geomorphological surface showing that modern extraction techniques (including the continue moving of the dump embankments and the vehicles manoeuvres) induced generalized stress and disturbance for plants, limiting their growth and the vegetation development (Booker & Callaghan 1998). Ruderal species, that are good colonists, are here favoured by the creation of many niches associated with open and disturbed conditions, thanks to a rapid germination, a short life cycle, an early flowering and a heavy allocation of resources (McIntyre et al. 1995, 1999).

Despite the presence of such a generalized disturbance, differences in functional species traits regarding morphological, ecological and reproductive characteristics can be identified across geomorphological features, as already stressed in previous studies (e.g. Nichols et al. 1998; Jauni & Hyvönen 2012). In particular, the good predictability of Ellenberg values of moisture (and secondarily nutrients) for detecting plant distribution and abundance within communities (e.g. Nichols et al. 1998) is confirmed by our study. A high level of disturbance is also reflected on reproduction strategies that can be observed analysing the following traits: size, shape, dispersal mechanisms and dormancy of seeds, time and space of germination (Grime 2006).

The prevalence on platforms of hemicryptophytes and terophytes with limited plant height and a mainly climbing-voluble or prostrate creeping stem could indicate a nutrient deficiency (Grime 1977); nevertheless, on the studied working quarries they could be connected to a very high disturbance due to the trampling by workers and machineries. This is also revealed by ecological traits: the higher presence of species adapted to live in very humid conditions in comparison to the other geomorphological surfaces, is here connected to the compaction of soil, that also presents a clayey texture (data not showed). In addition, the majority of species with an authochory and hydrochory seed dispersal strategy are more abundant in this surface.

The high presence of chamaephytes on artificial cliffs, belonging to a restricted number of families (e.g. *Valerianaceae*, *Lamiaceae*, *Poaceae*), with linear-spatulate leaves are indexes of very adverse limiting abiotic factors for plant establishment and survival (Pausas & Austin 2001; Pywell et al. 2003). On such a geomorphological surface, the ability of the species to establish and persist is mostly limited not by human disturbance, but by resources (water and secondarily nutrient) availability, as demonstrated by the fact that most species typical of dry and steno-mediteranean environments, besides endemic species, were mostly found on such geomorphological surface. Moreover, even if wind can be generally identified as one of the most important dispersal agent all over the extractive basin, anemochory dispersal on cliffs has a even greater relevance, as demonstrated by the dominance of species with small seeds with flight structures such as *Centranthus ruber* and *Melica ciliata*, that are typical of the initial phases of quarry recolonization (Hensen & Müller 1997; Řehounková & Prach 2010).

On embankments, morphological and ecological traits reflected lower levels of anthropic disturbance and less limiting environmental factors. In fact, tall herbs, shrubs and trees (geophytes and phanaerophytes), with meristematic tissue brought to more than 80 cm aboveground were mostly found. The role of the animal communities is here revealed by species traits related to reproduction and dispersal: most of species with fleshy fruits and a mainly zoochory seed dispersal were found on embankments, where, however, also man is one of the most important dispersal agent.

Implications for practice

The comparison of the trait-based analysis and of environmental variables has revealed a very high level of human disturbance affecting vegetation patterns all over the extractive basin, independently by type of geomorphological surface. This fact underline the importance of applying some measures even before the end of the exploitation, such as the planning of quarry activity in order to limit the removal of ecosystem over large areas and their progressive restoration where the exploitable ore body is locally exhausted.

Once the quarry is completely exploited, different restoration strategies and techniques should be foreseen according to type of geomorphological surface, and considering species traits that are selected on embankments, artificial cliffs and platforms, respectively.

Spontaneous succession should be preferred on artificial cliffs because of the very adverse environmental conditions especially connected to slope, rockiness and moisture availability, that could be hardly mitigated. In such a case, the success of the restoration by artificial interventions is not guaranteed also by use of costly techniques of naturalistic engineering.

Nevertheless, some devices can be made in order to improve dispersal limitations and the ability of the species to establish and persist, that is fundamental during the early phases of recolonization (Pywell et al. 2003). For example, considering that wind is here the most important dispersal agent, species with small flattening seed could be seeded on the artificial cliffs and/or their surroundings. In fact, small flattening seeds can be dispersed for long distances, can be produced in large number during one reproductive event and tend to be buried deeper into the soil (Cornelissen et al. 2003).

On platforms, the improvement of soil physical conditions (e.g. by scarification) is recommended before proceeding with the vegetation establishment, in order to avoid problems connected with the excessive stamping. Moreover, the selection of suitable plant species should take into account possible problems of asphyxia connected to the clayey texture. Since platforms present very low slopes (so that slope stability is generally ensured), and grasses (hemicryptofytes and terophytes) seems to be favoured on such a geomorphological surface, the artificial recreation of grassland could be a successful restoration strategy, especially if also species able to spread rapidly (e.g. by wind dispersal or clonal growth) are used (Pywell et al. 2003).

As regards the embankments, where time is the main factor affecting vegetation dynamics, human efforts should be focused in directing the spontaneous succession towards an earlier establishment of natural woodlands (oak woodlands in the study area). Trees, thanks to their subaerial height and their deep root system (Schenk & Jackson 2002) have access to a larger pool of resources such as light, water and nutrients (Moles & Westoby 2004), avoiding superficial water stress. In the selection of the most suitable plant species, traits that are here positively selected should be taken into account, such as, for example: life form (phanerophytes), plant height (tall herbs), seed dispersal (long distance) and type of fruit (fleshy fruit).

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References

1. Bertness M.D., Callaway R. 1994. Positive interactions in communities. Tree 9(5): 191-193.
2. Bouman F., Boesewinkel D., Bregman R., Devente N., Oostermeijer G. 2000. Verspreiding van zaden. KNNV Uitgeverij. 240 pages.
3. Braun-Blaunquet J. 1928. Pflanzensoziologie. Sprinter, Verl. Wien; II ed. nel 1951, III ed. nel

1964. Schippmann U., 1991- Revisionder europaischen Arten der Gattung Brachypodium Palisot de Beauvois. Boissiera, Genève, 45.1-249

4. Brooker R.W., Callaghan T.V. 1998. The balance between positive and negative plant interactions and its relationship to environmental gradients: a model. Oikos 81(1): 196-207.
5. Castro-Díez P., Montserrat-Martí G., Cornellissen J.H.C. 2003. Trade-offs between phonology, relative growth rate, life form and seed mass among 22 Mediterranean woody species. Plant Ecology 166: 117-129.
6. Cerabolini B.E.L., Brusa G., Ceriani R.M., De Andreis R., Luzzaro A., Pierce S. 2010. Can CSR classification be generally applied outside Britain? Plant Ecology 210: 253-261.
7. Cerabolini B.E.L., Ceriani R.M., Caccianiga M., De Andreis R., Raimondi B. 2003. Seed size, shape and persistence in soil: a test on Italian flora from Alps to Mediterranean coasts. Seed Science Research 13: 75-85.
8. Cingolani A.M., Cabido M., Gurvich D.E., Renison D., Díaz S. 2007. Filtering processes in the assempbly of plant communities: are species presence and abundance driven by the same traits? Journal of Vegetation Science 18: 911-920.
9. Cleland E.E., Clark C.M., Collins S.L., Fargione J.E., Gough L., Gross K.L., Pennings S.C., Suding K.N. 2011. Pattern of trait convergence and divergence among native and exotic species in herbaceous plant communities are not modified by nitrogen enrichment. Journal of Ecology 99: 1327-1338.
10. Cornelissen J.H.C., Lavorel S., Garnier E., Díaz S., Buchmann N., Gurvich D.E., Reich P.B., ter Steege H., Morgan H.D., van der Heijden M.G.A., Pausas J.G., Poorter H. 2003. A handbook of protocols for standardised and easy measurement of plant functional traits worldwide. Australian Journal of Botany 51: 335-380.
11. Dana E.D., Mota J.F. 2006. Vegetation and soil recovery on gypsum outcrops in semi-arid Spain. Journal of Arid Environments 65: 444-459.
12. Deléglise C., Loucougaray G., Alard D. 2011. Spatial patterns of species and plant traits in response to 20 years of grazing exclusion in subalpine grassland communities. Journal of Vegetation Science 22: 402-413.
13. Díaz S., Cabido M. 1997. Plant functional types and ecosystem function in relation to global change. Journal of Vegetation Science 8: 463-474.
14. Díaz S., Lavorel S., de Bello F., Quétier F., Grigulis K., Robson M. 2007. Incorporating plant functional diversity effects in ecosystem service assessments. PNAS 104(52): 20684-20689.
15. Dobrowski S.Z., Thorne J.H., Greenberg J.A., Safford H.D., Mynsberge A.R., Crimmins S.M., Swanson A.K. 2011. Modeling plant distributions over 75 years of measured climate change in California, USA: Relating temporal transferability to species traitsEcological Monographs 81 (2): 241-257.
16. Duan W., Ren H., Fu S., Wang J., Yang L., Zhang J. 2008. Natural recovery of different areas of a deserted quarry in South China. Journal of Environmental Sciences 20: 476-481.
17. Ellenberg H., Weber H.E., Düll R., Wirth V., Werner W., Paulissen D. 1991. Zeigerwerte von pflanzen in Mitteleuropa. Erich Goltze, Göttingen.
18. Frouz J., Prach K., Pižl V., Háněl L., Starý J., Tajovský K., Materna J., Balík V., Kalčík J., Řehounková K. 2008. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology 44: 109-121.

19. Garreth K., Leishman M.R. 2009. Plant functional trait variation in relation to riparian geomorphology: The importance of disturbance. Austral Ecology 34(7): 793-804
20. Gilardelli F., Gentili R., Prosser F., Bonomi C., Varotto C., Sgorbati S., in press. Ecological and biodiversity gradients across alpine dry grassland habitats: implications for an endangered species. Nordic Journal of Botany. 10.1111/j.1756-1051.2012.01388.x
21. Grime J.P. 2006. Trait convergence and trait divergence in herbaceous plant communities: mechanisms and consequences. Journal of Vegetation Science 17: 255-260.
22. Grime J.P. 1974. Vegetation classification by reference to strategies. Nature 250: 26-31.
23. Grime J.P. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. The American Naturalist 111 (982): 1169-1194.
24. Hammer Ø., Harper D.A.T., Ryan P.D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica 4 (1): 9 pages. http://palaeo-electronica.org/2001_1/past/issue1_01.htm [accessed on 20 february 2011]
25. Hensen I., Müller C. 1997. Experimental and structural investigations of anemochourus dispersal. Plant Ecology 133: 169-180.
26. Hladun K.R., Parker D.R., Trumble J.T. 2011. Selenium accumulation in the floral tissue of two Brassicaceae species and its impact on floral traits and plant performance. Environmental and Experimental Botany 74: 90-97.
27. Hodgson J.G., Wilson P.J., Hunt R., Grime J.P., Thompson K. 1999. Allocating C-S-R plant functional types: a soft approach to a hard problem. Oikos 85: 282-294.
28. Jauni M., Hyvönen T. 2012. Interactions between alien plant species traits and habitat characteristics in agricultural landscapes in Finland. Biological Invasions 14: 47-63.
29. Kew Royal Botanic Gardens. 2011. Seed Information Database. http://data.kew.org/sid/sidsearch.html [accessed on 20 february 2011]
30. Lloret F., Montserrat V. 2003. Diversity patterns of plant functional types in relation to fire regime and previous land use in Mediterranea woodlands. Journal of Vegetation Science 14: 387-398.
31. Lomba A., Bunce R.G.H., Jongman R.H.G., Moreira F., Honrado J. 2011. Interactions between abiotic filters, landscape structure and species traits as determinants of dairy farmland plant diversity. Landscape and Urban Planning 99: 248-258.
32. Martínez-Ruiz C., Fernández-Santos B., Putwain P.D., Fernández-Gómez M.J. 2007. Natural and man-induced revegetation on mining wastes: changes in the floristic composition during early succession. Ecological Engineering 30: 286-294.
33. McIntyre S., Lavorel S., Tremont R.M.. 1995. Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. Journal of Ecology 83(1): 31-44.
34. McIntyre S., Lavorel S., Landsberg J., Forbes T.D.A. 1999. Disturbance response in vegetation – towards a global perspective on functional traits. Journal of Vegetation science 10: 621-630.
35. Moles A.T., Westboy M. 2004. Seed mass and seedling establishment after fire in Ku-ring-gai Chase National Park, Sydney, Australia. Austral Ecology 29: 383-390.
36. Mota J.F., Sola A.J., Jiménez-Sánchez M.L., Pérez-garcía F.J., Merlo M.E. 2004. Gypsicolous flora, conservation and restoration of quarries in the southeast of the Iberian Peninsula. Biodiversity and Conservation 13: 1797-1808.

37. Müller-Schneider P. 1986. Verbreitungsbiologie der Blütenpflanzen Graubündens. Veröff. Geobot. Institute ETH, Stiftung Rübel, Zurigh, 85. 268 pages.
38. Navas M.-L., Ducout B., Roumet C., Richarte J., Garnier J., Garnier E. 2003. Leaf life span, dynamics and construction cost of species from Mediterranean old-fields differing in successional status. New Phytologist 159: 213-228.
39. Navas M.-L., Roumet C., Bellmann A., Laurent G., Garnier E. 2010. Suites of plant traits in species from different stages of a Mediterranean secondary succession. Plant Biology 12: 183-196.
40. Novák J., Konvička M. 2006. Proximity of valuable habitats affects succession patterns in abandoned quarries. Ecological Engineering 26: 113-122.
41. Pignatti S. 1953. Introduzione allo studio della pianura veneta orientale. Archivio botanico 29: 131-158
42. Pignatti S. 1982. Flora d'Italia. 3 volumes. Edagricolae, Bologna.
43. Pignatti S. 2005. Bioindicazione attraverso le piante vascolari. Valori di indicazione secondo Ellenberg (Zeigerwerte) per le specie della flora d'Italia.
44. Piqueray J., Bisteau E., Cristofoli S., Palm R., Poschold P., Mahy G. 2011. Plant species extinction debt in a temperate biodiversity hotspot: community, species and functional traits approaches. Biological Conservation 144: 1619-1629.
45. Pywell R.F., Bullock J.M., Roy D.B., Warman L., Walker K.J., Rothery P. 2003. Plant traits as predictors of performance in ecological restoration. Journal of Applied Ecology 40: 65-77.
46. Raunkiær C. 1934. The life forms of plants and statistical plant geography. Oxford university Press. 632 pages.
47. Řehounková K., Prach K. 2010. Life-history and habitat preferences of colonizing plant species in long-term spontaneous succession in abandoned gravel-sand pits. Basic and Applied Ecology 11: 45-53.
48. Richerson P.J., Lum K.-L. 1980. Patterns of plant species diversity in California: relation to weather and topography. The American Naturalist 116(4): 504-536.
49. Schenk H.J., Jackson R.B. 2002. The global biogeography of roots. Ecological Monographs 72(3): 311-328.
50. Sonnier, G., Shipley, B., Navas, M.-L. 2010. Quantifying relationships between traits and explicitly measured gradients of stress and disturbance in early successional plant communities. Journal of Vegetation Science 21: 1014-1024.
51. Ter Braak C.J.F. 1986. Canonical Correspondence Analysis: a new eingenvector technique for multivariate direct gradient analysis. Ecology 67(5): 1167-1179.
52. Tischew S., Kirmer A. 2007. Implementation of basic studies in the ecological restoration of surface-mined land. Restoration Ecology 15 (2): 321-325.
53. Van der Maarel E. 1979. Trasformation of cover-abundance values in phytosociology and is effect on community similarity. Vegetatio, Den Haag, vol. 39 no. 2: 97-154
54. Van Kleunen M., Schlaepfer D.R., Glaettli M., Fisher M. 2011. Preadapted for invasiveness: do species traits or their plastic response to shading differ between invasive and non invasive plant species in their native range? Journal of Biogeography 38: 1294-1304.
55. Verheyen K., Honnay O., Motzkin G., Hermy M., Foster D.R. 2003. Response of forest plant species to land-use change: a life-history trait-based approach. Journal of Ecology 91: 563-577.

56. Vittoz P., Engler R. 2007. Seed dispersal distances: a typology based on dispersal modes and plant traits. Botanica Helvetica 117: 109-124.
57. Wilson P.J., Thompson K., Hodgson J.G. 1999. Specific leaf area and leaf dry matter content as alternative predictors of plant strategies. New Phytologist 143: 155-162.
58. Zheng S., Lan Z., Li W., Shao R., Shan Y., Wan H., Taube F., Bai Y. 2011. Differential responses of plant functional trait to grazing between two contrasting dominant C3 and C4 species in a typical steppe of Inner Mongolia, China. Plant Soil 340: 141-155.

Supplementary material 1

Trait comparison between embankments, platforms and artificial cliffs. Legend: significant P values in bold (* P < 0,05; ** P< 0,001); species traits for which more over than 50% of the species were found on only one morphological surface in dark gray; species traits for which more less than 20% of the species were found on only one morphological surface in pale gray. E=embankments, P=platforms, C=artificial cliffs

Life form	Ch	G	H	P	T	
E	26.95	45.89	33.46	45.55	37.36	
P	34.03	39.15	40.90	34.98	45.88	
C	39.02	14.96	25.64	19.47	16.76	
PH	a	b	c	D	e	f
E	26.38	36.28	35.32	44.93	79.88	44.14
P	60.06	42.69	36.06	38.87	13.86	32.57
C	13.56	21.03	28.62	16.20	6.26	23.29
Type of stem	Mainly ascending	Mainly erect	Erect-ascending	Climbing -voluble	Prostrate-creeping (almost in part)	
E	32.93	37.27	39.63	43.55	34.27	
P	30.33	40.15	38.63	44.87	49.70	
C	36.74	22.59	21.73	11.58	16.03	
Presence of thorns	no	yes				
E	35.89	54.16				
P	41.15	35.23				
C	22.96	10.61				
Presence of stolons	yes	no				

E	27.84	37.51											
P	43.02	40.66											
C	29.14	21.82											
Type of leaf	Composite	Lanceolate-elliptic	Linear-spatulate	Ovate	Deeply lobate	Round	Needle-shaped	Others					
E	40.99	39.23	35.01	30.52	39.17	37.36	12.42	56.60					
P	46.85	45.32	34.50	39.98	42.35	54.44	60.33	43.40					
C	12.16	15.45	30.49	29.51	18.48	8.20	27.25	0.00					
Type of root	Tap-root	Fascicled	Rhizome										
E	37.88	34.85	35.47										
P	40.19	35.64	48.28										
C	21.94	29.51	16.25										
Family	Apiaceae	Asteraceae	Fabaceae	Lamiaceae	Poaceae	Rosaceae	Salicaceae	Valerianaceae	Others				
E	22.45	21.93	23.61	20.19	21.28	22.63	21.75	19.55	47.06				
P	25.48	25.48	25.25	26.04	25.62	25.55	25.59	25.93	32.01				
C	52.07	52.59	51.14	53.77	53.11	51.82	52.67	54.53	20.93				
CSR strategy	Mainly C	Mainly CR	Mainly CS	CSR	Mainly R	Mainly S	Mainly SR						
E	38.20	36.83	27.44	28.57	38.00	37.12	34.00						
P	37.11	45.25	48.81	45.19	36.27	40.41	46.86						
C	24.70	17.92	23.74	26.24	25.74	22.46	19.15						
L	X	1	2	3	4	5	6	7	8	9	10	11	12
E	0.00	0.00	0.00	0.00	30.66	36.49	29.04	29.16	25.31	28.75	0.00	10.44	0.00
P	0.00	0.00	0.00	0.00	48.94	39.97	35.87	49.20	50.15	40.82	0.00	73.06	0.00
C	0.00	0.00	0.00	0.00	20.40	23.54	35.10	21.64	24.54	30.44	0.00	16.50	0.00
T	X	1	2	3	4	5	6	7	8	9	10	11	12
E	32.45	0.00	24.50	0.00	43.09	36.83	37.92	38.72	37.48	0.00	0.00	0.00	0.00

P	47.80	0.00	39.67	0.00	29.90	44.46	42.56	34.50	40.55	0.00	0.00	0.00	0.00
C	19.75	0.00	35.83	0.00	27.01	18.71	19.52	26.78	21.98	0.00	0.00	0.00	0.00
C	X	1	2	3	4	5	6	7	8	9			
E	32.57	0.00	0.00	32.81	37.32	37.94	36.76	37.76	49.82	0.00			
P	52.29	0.00	0.00	56.91	34.36	40.10	46.07	28.41	34.57	0.00			
C	15.14	0.00	0.00	10.28	28.32	21.97	17.17	33.83	15.61	0.00			
U	X	1	2	3	4	5	6	7	8	9	10	11	12
E	34.35	0.00	30.16	38.14	39.16	38.66	34.92	41.16	34.09	17.07	0.00	0.00	0.00
P	52.35	0.00	33.04	39.32	40.98	49.75	39.15	36.72	40.38	82.93	0.00	0.00	0.00
C	13.30	0.00	36.80	22.54	19.86	11.60	25.93	22.11	25.53	0.00	0.00	0.00	0.00
R	X	1	2	3	4	5	6	7	8	9			
E	36.52	0.00	24.50	29.17	42.32	36.73	41.81	36.88	37.81	32.66			
P	44.51	0.00	39.67	70.83	20.55	37.34	36.73	42.82	39.80	39.66			
C	18.97	0.00	35.83	0.00	37.13	25.92	21.46	20.30	22.39	27.68			
N	X	1	2	3	4	5	6	7	8	9			
E	38.68	31.28	33.12	47.00	36.85	37.07	36.91	35.43	42.24	29.17			
P	41.75	36.11	37.36	28.30	38.42	48.02	46.89	48.78	40.33	70.83			
C	19.58	32.61	29.53	24.71	24.73	14.91	16.19	15.79	17.42	0.00			
Corologic al form	Endemic	Stenomed iterranean	Eurimedit erranean	Paleotem perate	Eurasiatic	Subatlant ic	European	Circumbo real	Cosmopo litan	Alien			
E	24.56	26.96	35.19	34.90	42.39	46.84	42.43	53.15	38.75	32.20			
P	0.00	25.35	43.24	48.90	30.70	34.47	37.47	32.27	38.75	45.06			
C	75.44	47.69	21.57	16.20	26.91	18.68	20.10	14.57	22.50	22.74			
Start of the flowering period	January	February	March	April	May	June	July	August	Septembe r				
E	34.93	32.66	30.38	39.81	36.31	38.35	39.10	39.90	55.26				
P	56.56	51.17	47.59	45.73	34.99	36.35	44.32	29.81	44.74				

C	8.51	16.18	22.03	14.46	28.70	25.30	16.58	30.29	0.00			
Duration of the flowering period	1	2	3	4	5	6	7	8	9	10	11	12
E	62.22	41.40	38.69	33.66	36.16	41.49	31.77	28.81	41.88	0.00	0.00	32.81
P	37.78	33.93	37.00	45.70	43.63	40.31	45.00	50.47	58.12	0.00	0.00	56.91
C	0.00	24.67	24.31	20.64	20.21	18.20	23.23	20.72	0.00	0.00	0.00	10.28
Sex of the flowers	Only hermaphrodite	Mixed	Only male and female									
E	36.82	33.25	39.90									
P	41.21	41.31	37.51									
C	21.97	25.44	22.59									
Type of corolla	Absent	Perianth reduced	Attinomorphic	Zygomorphic	Attinomorphic and zygomorphic	Free elements						
E	38.86	31.52	38.57	36.21	34.83	41.58						
P	38.52	35.20	47.09	43.46	34.24	40.65						
C	22.62	33.28	14.33	20.32	30.93	17.77						
Type of inflorescence	Ament	Head	cyanthium	with clearly peduncolate flowers	Cone	Panicle	Solitary flower	Spike				
E	38.24	35.39	38.49	37.91	12.42	38.96	37.90	32.90				
P	37.15	42.15	37.39	41.25	60.33	32.78	52.60	57.63				
C	24.61	22.46	24.12	20.84	27.25	28.26	9.50	9.46				

Type of fruit	Non dehiscent fruit	Non dehiscent fruit with fly structures	Non dehiscent fruit - graminoids	Dehiscent fruit	Fleshy fruit					
E	39.00	36.73	34.32	34.61	50.91					
P	43.72	34.96	35.93	50.02	38.04					
C	17.28	28.31	29.75	15.37	11.04					
Seed mass	a	b	c	D	e	f	g			
E	28.40	31.92	34.72	38.52	33.09	50.00	45.76			
P	37.62	42.97	38.55	42.22	51.43	33.79	32.33			
C	33.98	25.11	26.73	19.26	15.48	16.21	21.90			
Type of seed dispersal	autochory	zoochory	anemochory	Hemerochory	mixed - Autochory	mixed - Zoochory	mixed - Anemochory	mixed - Hydrochory	mixed - Hemerochory	unknown
E	38.18	44.59	36.91	34.28	29.17	35.22	34.94	29.17	48.35	35.87
P	61.82	45.20	29.21	44.41	70.83	48.12	40.83	70.83	35.58	40.99
C	0.00	10.21	33.88	21.31	0.00	16.66	24.22	0.00	16.07	23.14
Seed dispersal distance	1	5	15	150	500	1500	5000	Unknown		
E	37.97	35.80	35.17	42.60	35.21	37.41	38.96	35.87		
P	26.34	50.24	35.62	44.69	33.13	50.10	39.27	40.99		
C	35.69	13.96	29.22	12.71	31.66	12.49	21.77	23.14		

Supplementary material 2

Contingency tables of percent frequencies of the 25 morphological, ecological and reproductive species traits distributed on the three geomorphological surfaces. Legend significance level: ** 99% significant, * 95% significant

	M;N	Degrees freedom	Chi^2	p (Fishers' extact test)	Monte Carlo p	Significance
Morphological traits						
Life form	5;3	8	43.994	5.705E-07	0.0001	**
Plant height (PH)	6;3	10	45.906	1.492E-06	0.0001	**
Type of stem	5;3	8	32.262	0.0001	0.0001	**
Presence of thorns	2;3	2	16.423	0.0003	0.0004	**
Presence of stolons	2;3	2	5.055	0.0799	0.0801	
Type of leaf	8;3	14	58.352	2.278E-07	0.0001	**
Type of root	3;3	4	12.106	0.0166	0.0163	*
Family	9;3	16	60.261	4.730E-07	0.0001	**
Traits related to species requirements						
CSR strategy	7;3	12	16.295	0.1781	0.1783	
Light (L)	7;3	12	20.550	0.0574	0.0561	
Temperature (T)	7;3	12	12.947	0.3729	0.3686	
Continentality (C)	7;3	12	23.870	0.0212	0.0234	*
Moisture (U)	9;3	16	47.635	0.0001	0.0001	**
Reaction (R)	9;3	16	11.171	0.7988	0.8001	
Nutrient (N)	10;3	18	40.565	0.0017	0.0023	*
Traits related to re production and dispersal						
Corological form	10;3	18	45.787	0.0003	0.0006	**
Start of the flowering period	9;3	16	39.559	0.0009	0.0001	**
Duration of the flowering period	10;3	18	19.877	0.3398	0.3465	
Sex of the flowers	3;3	4	1.424	0.8401	0.8419	
Type of corolla	6;3	10	40.315	1.491E-05	0.0001	**
Type of inflorescence	8;3	14	22.574	0.0676	0.0689	
Type of fruit	5;3	8	36.005	1.753E-05	0.0002	**
Seed mass	7;3	12	30.646	0.0022	0.0020	*
Main seed dispersal type	10;3	18	66.598	1.686E-07	0.0001	**
Seed dispersal distance	8;3	14	51.706	3.154E-06	0.0001	**

Supplementary material 3

P values among different morphological surfaces

Life forms	Enbankments	Platforms	Cliffs
Enbankments		0.01219	0.01219
Platforms	0.03656		0.53090
Cliffs	0.03656	1.00000	
Plant height			
Enbankments		0.00508	0.00508
Platforms	0.01522		0.63040
Cliffs	0.01522	1.00000	
Type of stem			
Enbankments		0.01219	0.01219
Platforms	0.03656		0.67610
Cliffs	0.03656	1.00000	
Presence of thorns			
Enbankments		0.24530	0.24530
Platforms	0.73580		0.69850
Cliffs	0.73580	1.00000	
Presence of stolons			
Enbankments		0.24530	0.24530
Platforms	0.73580		0.24530
Cliffs	0.73580	0.73580	
Type of leaf			
Enbankments		0.00112	0.00112
Platforms	0.00337		0.40050
Cliffs	0.00337	1.00000	
Type of root			
Enbankments		0.08086	0.08086
Platforms	0.24260		0.66250
Cliffs	0.24260	1.00000	
Family			
Enbankments		0.00041	0.00041
Platforms	0.00124		0.00041
Cliffs	0.00124	0.00124	
CSR strategy			
Enbankments		0.00217	0.00217
Platforms	0.00650		0.15990
Cliffs	0.00650	0.47960	

Light (L)			
Enbankments		0.00265	0.00217
Platforms	0.00794		0.25020
Cliffs	0.00650	0.75050	
Temperature (T)			
Enbankments		0.00217	0.00217
Platforms	0.00650		0.05528
Cliffs	0.00650	0.16590	
Continentality (C)			
Enbankments		0.00217	0.00217
Platforms	0.00650		0.94900
Cliffs	0.00650	1.00000	
Moisture (U)			
Enbankments		0.00048	0.00041
Platforms	0.00145		0.92960
Cliffs	0.00124	1.00000	
Reaction (R)			
Enbankments		0.00041	0.00041
Platforms	0.00123		0.12210
Cliffs	0.00123	0.36630	
Nutrients (N)			
Enbankments		0.00018	0.00018
Platforms	0.00055		0.62320
Cliffs	0.00055	1.00000	
Corological form			
Enbankments		0.00018	0.00033
Platforms	0.00055		0.13030
Cliffs	0.00098	0.39080	
Start of the flowering period			
Enbankments		0.00041	0.00041
Platforms	0.00124		0.96480
Cliffs	0.00124	1.00000	
Duration of the flowering period			
Enbankments		0.00018	0.00018
Platforms	0.00055		0.57030
Cliffs	0.00055	1.00000	
Sex of the flowers			
Enbankments		0.08086	0.08086
Platforms	0.24260		0.08086
Cliffs	0.24260	0.24260	

Type of corolla			
Enbankments		0.00508	0.00508
Platforms	0.01522		0.22980
Cliffs	0.01522	0.68930	
Type of inflorescence			
Enbankments		0.00001	0.00001
Platforms	0.00002		0.83610
Cliffs	0.00003	1.00000	
Type of fruit			
Enbankments		0.01219	0.01219
Platforms	0.03656		0.40340
Cliffs	0.03656	1.00000	
Seed mass			
Enbankments		0.00217	0.00217
Platforms	0.00650		0.20130
Cliffs	0.00650	0.60400	
Type of seed dispersal			
Enbankments		0.05887	0.00055
Platforms	3.39900		0.00013
Cliffs	6.20700	9.60600	
Seed dispersal distance			
Enbankments		0.00018	0.00018
Platforms	0.00054		0.17260
Cliffs	0.00053	0.51790	

4 Experimental analysis

Wisdom is the daughter of experience - Leonardo da Vinci -

Since the Botticino extractive basin is located on a semi-natural hill landscape, restoration efforts should be directed to the re-establishment of a semi-natural, site-specific and long-term self-sustaining plant communities and ecosystems. Calcareous extractive basins are generally characterized by many limiting abiotic factors (especially regarding water and nutrient availability) and a high human disturbance that insists on the area since historical times. In such conditions, a very slow spontaneous vegetation dynamics is not enough to ensure the establishment and development of a valuable vegetation in acceptable times. Moreover, taking into account that the quarry areas show different types of geomorphological surfaces, different techniques should be planned according to the geomorphological heterogeneity within quarry. In particular, human interventions are recommended on dump deposits and platforms, that represent a good opportunity to increase the natural, ecological, productive and aesthetic value of the whole extractive area, also by decreasing environmental risks (e.g. erosion and underground water contamination). In any case, a successful near-natural restoration, based on a careful planning and on a rational plant species selection, requires preliminary and site-specific analyses relevant from the scientific point of view. Such preliminary analyses are fundamental in order to define the target ecosystem and its level of complexity, along with the successional phase of spontaneous vegetation at which it is best to plan the intervention.

4.1 Experimental site

The fully exploited quarry "*ex Sgotti - Cava Alta*" (ATE 13/12; property of the Municipality of Nuvolento) was selected for the in situ restoration experiment (Fig. 4.1). The Provincial Quarry Plan (regional law D.G.R. 21.12.2000 n. VI/120) has provided a target for the quarry restoration after its abandonment on the basis of site conditions and characteristics of the surrounding area (semi-natural woodlands not very close to urban centres).

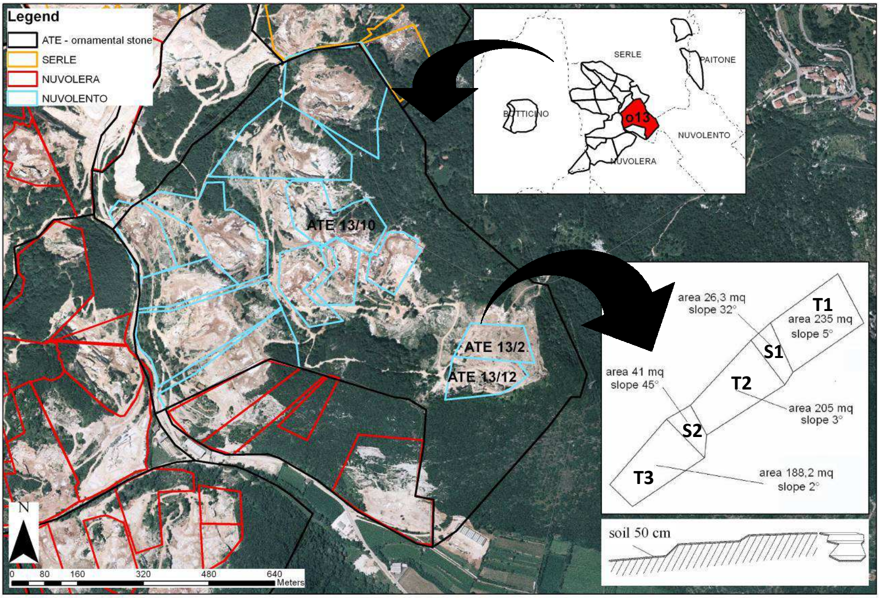

Fig. 4.1 Location of the experimental site. ATE are represented in black; each quarry is represented in different colors, according to the Municipality in which they are (data from: Geoportale della Lombardia, database Ufficio Autorizzazioni Cave, Provincia di Brescia; GoogleMaps)

In particular, an area of about 600 m^2 (coordinates: 1606633 5044874, altitude: 394 m a.s.l., aspect: 225°) was selected and remodeled: the final abandonment profile was constituted by three terraces of about 200 m^2 almost horizontal (slope between 2-5°) and connected by two small areas of 45° and 32° slope, respectively. According to law D.G.R. 21.12.2000 n. VI/120, the area was covered by an homogeneous soil layer[3] deep 50 cm, made by quarry debris and topsoil that were previously dumped in the quarry "*Marmi Spinetti S.r.l.*" (ATE 13/10; Municipality of Nuvolento), close to the experimental site.

4.1.1 Site characterization

Soil physical and chemical characteristics and surrounding vegetation play a crucial role in determining the success of any restoration, by affecting plant growth, abundance, quality, disease resistance and by diverting the direction of succession.

[3] For simplicity, such a layer is named "soil" in the present paragraph, unless in a improper way, since no soil horizons and phenomena of pedogenesis were observed

Soil analysis. In order to evaluate physical and chemical characteristics of the soil, we carried out analyses using standard protocols (Università di Milano-Bicocca, 2011) in accordance with the Italian legislation (DM 13/09/1999; DM 25/03/2002).

Soil sampling and preparation. We collected soil samples in the experimental site, following a zig-zag path and avoiding the marginal areas. We transferred them into a plastic pail and then mixed in order to obtain homogeneous *global samples*, which were put into clean and dry plastic bags. At the end of such a phase, we collected 2 samples for each terraces: 1 "superficial" (0-20 cm of depth) and 1 "mixed" (0-50 cm of depth) (Table 4.1). We also evaluated rocky outcrops and the skeleton.

Sample code	Terrace	Type of sampling	Explored depth (cm)
11/0075	T1	Mixed	0-50
11/0076	T1	Superficial	0-20
11/0077	T2	Mixed	0-50
11/0078	T2	Superficial	0-20
11/0079	T3	Mixed	0-50
11/0080	T3	Superficial	0-20

Table 4.1 Collected soil samples

The day after the sampling, we homogenized samples, we spread representative samples on a paper tray and dried them at environmental temperature in a protected room for 2 weeks. Then, we broke the aggregates by hands and rubber stoppers, and we sieved samples with a sieve of 2 mm in order to separate the *fine soil*, that was transferred into a 200 mL plastic pail, impermeable to dust and water and not interacting with the soil.

Apparent texture (5 fractions). In order to estimate apparent texture on the basis of the ratio between granulometric fractions of sand, silt and clay, we put 10 g of soil in a plastic bottle with 25 ml of a dispersant solution (0.825 g sodium hexametaphosphate $[(NaPO_3)_6]$ + 0.175 g sodium carbonate anhydrous $[Na_2CO_3]$). Bottles were agitated on a rotating agitator for 8 hours (50-60 rotations/minute); then, we transferred samples into a sedimentation cylinder by means of a sieve of 0.1 mm.
We sampled 10 ml of solution in a Petri dish on the basis of the sedimentation times of the Esenwein's Pipette at 18.5°C (the environmental temperature) after: a) 1 minute and 54 seconds (Petri A), b) 11 minutes and 38 seconds (Petri B) and c) 18 hours, 55 minutes and 46 seconds (Petri C). We dried the sieve of 0.1 mm and the Petri dishes at 105°C for 4 hours and then weighted them, so that results were calculated as:

A (clay) = (net_w Petri C - W) * 500 * (100/m)

Lg (coarse silt) = (net_w Petri A - net_w Petri B) * 500 * (100/m)

Lf (fine silt) = (net_w Petri B - net_w Petri C) * 500 * (100/m)

Smg (coarse sand) = (net_w sieve 0.1 mm) * 10 * (100/m)

Smf (fine sand) = 1000 - Smg - Lg - Lf - A

where: net_w = net weight; W = reference solution corresponding to added salts (0.02 g); m = mass of the sample (g).

pH in water and KCl. We added 10 g of samples to 25 mL of demineralized water; into another glass, we added 10 g of samples to 25 mL of KCl 1 M. We then agitated the two solutions with a glass stick. The day after, we measured pH with a previously calibrated pH meter by moving the electrode in the circular sense.

Total carbonates. We added 10 mL of HCl 1:2 solution to 1 g of soil in a test-tube and put in the calcimeter. We equilibrated the calcimeter and, according to the developed CO_2, we expressed results as follows:

$$CO_3^{2-}(g/Kg) = \frac{CO_2 * (P - vapor\_pressure) * 273}{270 * (273 + °C)} * 0.0044655 * \frac{1000}{m}$$

where: CO_2 = ml of CO_2 developed by the reaction; P = atmospheric pressure (mm Hg); vapor_pressure = 5.29551*2.718281828549*(0.0595317*°C); °C = environmental temperature (°C); m = mass of the sample (g).

Organic carbon (Walkley & Black method). We added 10 mL of potassium dichromate ($K_2Cr_2O_7$ 1/6 M [49.032 g/l]) to 1g of sample in a flask; thus, we added 20 ml of sulfidric acid (H2SO4 96% ρ = 1.84), we firstly agitated the flask and then left to rest for 30 minutes, so that the following reaction took place:

$$2K_2Cr_2O_7 + 3C + 8H_2SO_4 \rightarrow 2K_2SO_4 + 2Cr_2(SO_4)_3 + 3CO_2 + 8H_2O$$

(organic carbon oxidation: $4Cr^{6+} + 3C^0 \rightarrow 4Cr^{3+} + 3C^{4+}$)

We added 200 mL of water in order to stop the reaction, together with 1 ml of the indicator ferroin (for 1000 ml: 14.85 g o-phenanthroline monohydrate + 6.95 g $FeSO_4*7H_2O$). We titrated the exceeding dichromate with the Mohr salt 0.5 M (for 1000 mL: 196.06 g $Fe(NH_4)_2(SO_4)_2*6H_2O$ + 15 ml H_2SO_4) until the color changed from green to red while the following reaction took place:

$$K_2Cr_2O_7 + 6FeSO_4 + 7H_2SO_4 \rightarrow K_2SO_4 + Cr_2(SO_4)_3 + 3Fe_2(SO_4)_3 + 7H_2O$$

(dichromate reduction: $Cr^{6+} + 3Fe^{2+} \rightarrow Cr^{3+} + 3Fe^{3+}$)

Results were expressed as follows:

$$C(g/Kg) = 38.961 * \frac{B - A}{B * m}$$

where B = titrant used for the reference solution (ml); A = titrant used for the sample (ml); m = mass of the sample (g).

Cation Exchange Capacity (CEC). We added 25 mL of extraction solution with pH of 8.1±0.1 (2.5 g $BaCl_2*2H_2O$ + 0.5625 ml triethanolamine) to 2 g of soil into a centrifuge tube and agitated on a rotating agitator for 3 minutes, let settle for 5 minutes and agitate for 3 minutes again. We centrifuged samples for 5 minutes to 3000 rpm; we collected the supernatant through fast filter and used it for the analysis of the exchangeable cations.
As for the precipitate, we added 25 mL of water and we manually agitated the tube till its complete suspension; then we centrifuged it for 5 minutes to 3000 rpm and we through away the supernatant (passage repeated 2 times). We added 25 mL of magnesium sulfate solution ($MgSO_4*7H_2O$ 0.05 M [12.324 g/l]), we agitated samples and centrifuged them for 5 minutes at 3000 rpm. We sampled 10 mL and put into a Erlenmeyer flask, together with 100 mL of water, 10 mL of the buffer solution at pH 10 (0.54 g of NH_4Cl + 3.5 ml NH_4OH [ρ=0.89]) and a spatula of the indicator (20 g of NaCl + 0.2 g of Nero Eriocromo T [sodium salt of the acid 1-1-hydroxy-2-naphthylazo-6-nitro-2-naphtol-4-sulfonic]). We made the titration with the disodium salt of the EDTA (ethylenenediaminetetetraacetic acid) 0.025 M (9.305 g/l) until the color changed from pink to blue. Results were expressed as follows:

$$CEC(\text{meq/100 g [cmol(+)/Kg]}) = \frac{1}{m} * \left[250 - (10 * \frac{A}{B} * (25 + C - D) \right]$$

where: A = EDTA used for the tritation of the sample (ml); B = EDTA used for the tritation of the reference solution (ml); m = mass of the sample (g); C = weight of the tube after the centrifugation (g); D = weight of the tube before the centrifugation and of the sample (before the extraction).

Exchangeable cations. We added 0.3 mL of the supernatant collected for the analysis of the CEC to 1 mL of lanthanum, and bring to the final volume of 10 mL with HNO_3 1% (dilution factor: 33.3). We analyzed the solution by the spectrophotometer, with different wavelength according to the analyzed cation (Table 4.2).

Exchangeable cation	Wavelenght (nm)	Type of analysis
Ca	422.7	absorption
Mg	285.2	absorption
K	766.5	emission
Na	589.0	emission

Table 4.2 Wavelength and type of analysis regarding exchangeable cations

The concentration of the exchangeable cations was expressed as cmol(+)/kg. Considering the great importance of the interactions between potassium and the other exchangeable cations for the dynamics of potassium in soils (besides the passages among its different forms), we also calculated the ratio Mg/K.

Assimilable phosphorous (Olsen method). We added 0.5 g of active carbon free from phosphates and 40 ml of $NaHCO_3$ extraction solution 0.5 M pH 8.5±0.1 to 1.25 g of sample into a 50 ml cap tube; we agitated samples by an agitator for 30 minutes and filtered them. We added to 10 ml of the filtered supernatant: about 5 drops of the p-nitrophenol solution ($NO_2C_6H_4OH$ 0.25%), 15 ml of the solution of ammonium molybdate [40 g/l $(NH_4)_6Mo_7O_2$*$4H_2O$], about 5 drops of the sulfuric acid 2.5 M (until the disappearing of the yellow color), 8 ml of the sulfomolybdic reagent (4 ml H_2SO_4 solution 2.5 M [0.56 ml H_2SO_4 96% ρ=1.84], 2.4 ml of the solution of ascorbic acid 0.1M [$C_6H_8O_6$ 17.6 g/l], 0.4 ml of the solution of antimony potassium tartrate [$K(SbO)C_4H_4O_6$*½H_2O 0.2728 g/l].
We made the calibration line by 6 solutions of 50 ml with concentration of 0.0-0.2-0.4-0.6-0.8-1.0 mg/l of phosphorous made by dilution of 0-5-10-15-20-25 ml of the standard solution of 2 mg/l phosphorous (1000 ml: 2 ml of the mother solution of 1000 mg/l of P [4.3938 g KH_2PO_4 dried to 40°C), water and 8 ml of the sulfopmolybdic reagent.
We read the samples and the reference solutions at the spectrophotometer after 10 minutes at 720 nm. Results were expressed as follows:

$$C(mg/Kg) = A * \frac{V_1}{V_2} * \frac{50}{m}$$

where: A = concentration of phosphorous in the sample from the calibration line (mg/l); V_1 = volume of the extraction solution (40 ml); V_2 = volume of the solution containing the sample; m = mass of the sample (g).

Vegetation analysis. We monitored the vegetation that spontaneously developed on the experimental site for four months after the landform modeling and soil addiction (June 2011), till the plantation and seeding phase (October 2011). We carried out 5 vegetation plots (3 on terraces and 2 on slopes), in which we estimated: a) plant species cover according to Braun-Blanquet scale (Braun Blanquet 1928) modified by Pignatti (1953) and b) ecological data, such as cover of tree, shrub, herbs and moss layers (%).
We checked the flora growing on the surroundings of the experimental site and we represented graphically the distribution of life forms, corology and ecological forms, according to Ellenberg indicators (Ellenberg 1974) modified for the Italian vascular flora (Pignatti 2005). Because of the geographical position of the study area, we do not considered salinity.

4.1.2 Results

Soil physical characteristics. Rocky outcrops were present only on the lower boundary of the highest terrace (T1) and on the centre of the lowest slope (S2), where they showed low surface cover (3% and 5%, respectively). Calcareous rocky debris, mainly angular, were numerous and homogeneously distributed along all the morphological surfaces, where they covered 25% of each area. Dimensions were very heterogeneous, so that, according to FAO (2006), can be identified: fine gravels (2-6 mm), medium gravels (6-20 cm), coarse gravels (20-60 cm) and stones (60-200 cm).

As for the *fine soil*, all the samples were very similar and showed a high percent of clay, being made by 43.68(±0.90)% of clay, 30.70(±1.01)% of silt and 25.62(±0.77)% of sand (Table 4.3).

Sample	Smg	Smf	Total S	Lg	Lf	Total L	A
11/0075	161	99	260	95	210	305	435
11/0076	162	107	269	104	189	293	438
11/0077	157	100	257	105	204	309	434
11/0078	167	85	252	100	219	319	429
11/0079	146	101	247	60	239	299	454
11/0080	148	104	252	94	223	317	431
Mean	**156.83**	**99.33**	**256.17**	**93.00**	**214.00**	**307.00**	**436.83**
St.dev	**8.28**	**7.61**	**7.73**	**16.78**	**17.16**	**10.12**	**8.98**

Tab. 4.3 Clay, silt and sand content (g/Kg) in the samples. Legend: Smg: coarse sand (2-0.1 mm), Smf: fine sand (0.1-.0.05 mm), S: sand (2-0.05 mm), Lg: coarse silt (0.05-0.02 mm), Lf: fine silt (0.02-0.002 mm), L: silt (0.05-0.002 mm), A: clay (<0.002 mm)

According to the USDA classification (USDA 2003), all the sample showed a clay texture (Fig. 4.2).

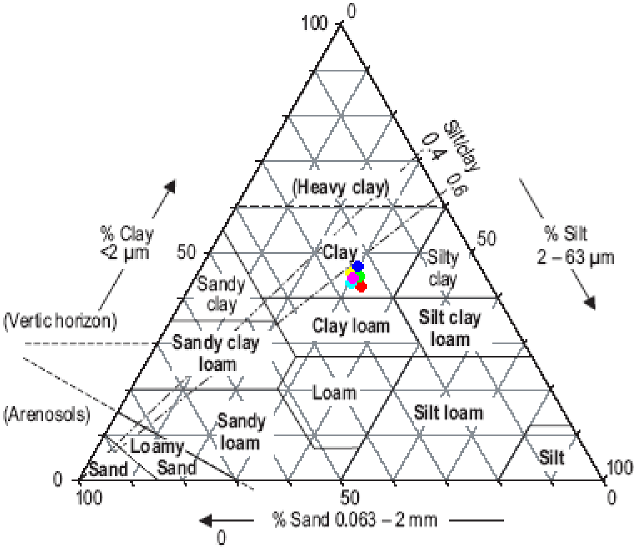

Fig. 4.2 USDA classification of the samples (from: FAO 2006, modified). Legend: red 11/0075; yellow 11/0076; green 11/0077; sky-blue11/0078; dark blue 11/0079; pink 11/0080

The plasticity index (PI), calculated according to Perelli (1987)[4], was 54.11.

Soil chemical characteristics. All the samples showed almost the same chemical characteristics: a) pH of 8.6 in water and 7.5 in KCl, b) 21.27 (±2.66)% of carbonates (Table 4.4).

Sample	Total CO_3^{2-}	Organic C*	Organic matter	Assimilable P
	g/Kg	g/Kg	mg/Kg	mg/Kg
11/0075	162	6.1	10.5	2.26
11/0076	228	5.8	10.0	2.45
11/0077	210	6.0	10.3	1.52
11/0078	236	6.1	10.5	1.89
11/0079	226	6.6	11.4	2.08
11/0080	214	6.5	11.2	1.89
Mean	**212.67**	**6.18**	**10.65**	**2.01**
St.dev	**26.58**	**0.31**	**0.54**	**0.33**

Table 4.4 Total carbonates, organic carbon, organic matter and assimilable phosphorous content in the samples. Legend: * corrected value

[4] $IP = 50 * \ln(A/10) - 10 * \ln(SO/0.15)$, where: A = content of clay (%), SO = content of organic matter (%)

In order to calculate the organic matter content, we used the following correction factors: a) 1.3, since the semiquantitative method used for the determination of the organic carbon can oxidize 77% of the total organic carbon (as demonstrated experimentally), b) 1.724, since it is assumed that organic matter contains 58% of carbon on average. Thus, on average organic matter represents 1.06(±0.05)% of the samples. The content of assimilable phosphorous is 2.01 mg/Kg.
The Cation Exchange Capacity (CEC) is 18.78±1.05 cmol(+)/Kg. Because of limestone, the exchangeable calcium saturates the CEC (with the Basic Saturation Ratio of 100%) and the sum of the values read to the spectrophotometer exceeded the CEC (20.57±0.79 cmol(+)/Kg), as expected. Thus, we calculated calcium by the difference between the CEC and the other cations, and thus resulting 16.18±0.93 cmol(+)/Kg (Table 4.5).

Sample	CEC	Ca(c)	Ca (r)	Mg	K	Na	BSR
11/0075	17.23	15.03	20.02	2.10	0.07	0.03	100
11/0076	19.11	16.72	20.22	2.27	0.09	0.03	100
11/0077	18.44	15.66	20.29	2.65	0.09	0.04	100
11/0078	18.32	15.63	19.81	2.56	0.09	0.04	100
11/0079	19.23	16.45	21.33	2.64	0.09	0.05	100
11/0080	20.34	17.61	21.77	2.56	0.11	0.06	100
Mean	**18.78**	**16.19**	**20.57**	**2.46**	**0.09**	**0.04**	**100.00**
St.dev	**1.05**	**0.93**	**0.79**	**0.23**	**0.01**	**0.01**	**0.00**

Table 4.5 CEC (cmol(+)/Kg), exchangeable cations (cmol(+)/Kg) and BSR (%) in the samples. Legend: Ca(c) calcium calculated, Ca(r) calcium read

The ratio between magnesium and potassium is 27.33.

Vegetation on the experimental site. A very scattered vegetation cover developed on the experimental sites (10% on the whole area) in four months; it consisted exclusively of an herb layer. Stated that the floristic richness was higher (but anyway low) on the three terraces than on the two slopes, the herb layer mostly consisted of few and sparse individuals (Table 4.6).

	T1	**T2**	**T3**	**S1**	**S2**	
Slope (°)	2	3	5	32	45	
Vegetation (herbs) cover (%)	10	10	10	10	10	
Soil cover (%)	62	65	65	65	60	
Stoniness (%)	25	25	25	25	25	
Rockness (%)	3	0	0	0	5	
Species						***Non-native flora***
Setaria viridis (L.) Beauv.	3	3	3	3	3	
Ambrosia artemisiifolia L.	2	1	1			Neo Inv (Canada & USA)
Solanum nigrum L.	2	1	1	+		
Rubus ulmifolius Schott	2		1		2	
Polygonum lapathifolium L.	1	1	2		1	
Populus nigra L.	1	R	R			
Lactuca serriola L.	+	1	1		1	
Echium vulgare L.	+	+	+			
Xanthium italicum Moretti	+					Neo Inv (N America)
Clematis vitalba L.	R	+	R	1		
Senecio inaequidens DC.	R	R	R		R	Neo Inv (S Africa)
Echinochloa crus-galli (L.) Beauv.	R		R			
Lotus corniculatus L. s.s.	R		R			
Geranium sanguineum L.	R				R	
Picris hieracioides L.		R	R			
Sorghum halepense (L.) Pers.		R				Arc Inv (Tropics - Africa, Asia)
Stachys recta L.		R				
Daucus carota L.			+			
Sonchus asper (L.) Hill			+			
Melilotus alba Medicus			R			
Robinia pseudoacacia L.			R		+	Neo Inv (USA)
Artemisia vulgaris L.					+	
Cirsium vulgare (Savi) Ten.					+	
Cornus sanguinea L.*					(+)	
Prunus avium L.*					(+)	

Table 4.6 Vegetation growing on added soil. Legend: *: plants high more than 1 m, survived to landform modelling and soil addiction; Neo: neophyte; Arc: archaeophyte; Inv: invasive

25 species were found; the most abundant species were: *Setaria viridis*, and secondly *Ambrosia artemisiifolia*, *Solanum nigrum*, *Polygonum lapathifolium* and *Lactuca serriola*. Two species, i.e. *Rubus ulmifolius* and *Clematis vitalba*, clearly came from the closest surrounding areas; *Cornus sanguinea* and *Prunus avium* were already present before site

modelling. 20% of the recorded species (5 species) were non-native, coming from North America and Tropical Africa and Asia, and even considered invasive on the Italian territory according to Celesti-Grapow et al. (2009).

Flora on the surroundings of the experimental site. We found 93 species on the surroundings of the experimental site (Appendix 4.1). Most species were perennial and annual herbs (44% and 17% of the total, respectively); tree species also represented a relevant part of the flora, consisting in 16% of the total recorded species (Fig. 4.3).

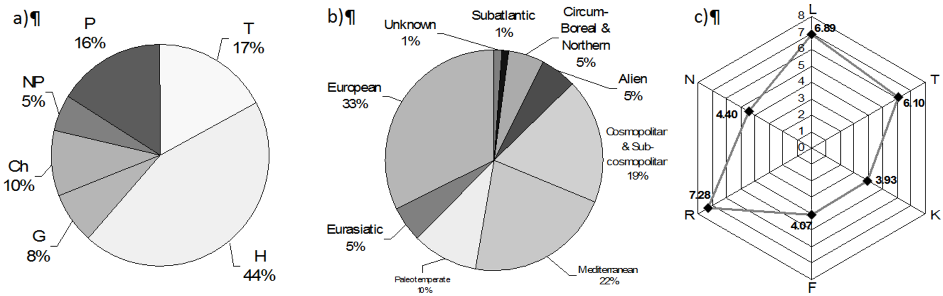

Fig. 4.3 a) biological forms, b) corology and c) Ellenberg indicator for the flora of the quarry "*Ex Sgotti – Cava Alta*. Legend: L: light (1-12); T: temperature (1-12); K: continentality (1-9); F: moisture (1-12); R: reaction (1-9); N: nutrients (1-9)

Most species were European (33%), Mediterranean (22%) or with a wide-range distribution (19%). Alien species represented 5% of the total, and included very invasive species such as *Robinia pseudoacacia* (USA), *Ambrosia artemisiifolia* (Canada & USA), *Erigeron annuus* (Canada & USA), *Conyza canadensis* (Canada & USA) and *Senecio inaequidens* (S Africa). Ellenberg indicators showed medium values for light (L=6.89), temperature (T=6.10), and nutrients (N=4.40), low-medium values for continentality (K=3.93) and moisture (F=4.07) and medium-high value for pH (R=7.28).

4.1.3 Useful remarks for the planning of restoration experiment

Soil chemical and physical characteristics. The soil used for the restoration experiment showed some physical limitations due to a) the limited soil depth, b) the high presence of skeleton and limestone fragments deriving from the physical break-up of the substrate, c) the clayey texture. In particular, the soil can be identified as a high plastic "heavy soil": in such conditions, microporosity prevails on macroporosity, so that water retention is high and the risk of asphyxia is not absent (Perelli 1987). A marked presence of carbonates improves the soil structure, by forming stable aggregates, increasing cohesion and adhesion forces and providing calcium and magnesium (Perelli 1987). Moreover, on "heavy soil", a content of 1% of organic matter, as in this case, is considered sufficient to ensure good

physical, chemical and hydrogeological characteristics, besides a good biological activity, mostly thanks to the association of organic matter and clay particles (Perelli 1987).
The strongly alkaline soil pH is optimal for the assimilability of calcium and magnesium (here present in widely sufficient content for plant nutrition), which are mostly available between pH 7.0-9.0 and 6.0-8.5, respectively. Nevertheless, pH exceeds the optimal range for the highest assimilability of the other elements, such as phosphorous (optimal pH: 6.5-7.5) and potassium (optimal pH: 6.0-8.0; Perelli 1987). In particular, the content of assimilable phosphorous is very low, according to Landi (1988), also because it is usually fixed to calcium (forming soluble bi- and tri-calcium phosphate) and/or to clay particles in alkaline "heavy soils" (Muzzi & Rossi 2003). According to Perelli (1987), the high Mg/K ratio (up to 5) could be a symptom of problems in the assimilation of the potassium. The CEC can be considered satisfactory, so that soil is characterized by a good capacity to retain cations, to avoid their loss because of leaching, to allow the exchanges with the solutions and thus to allow the plant nutrition (Perelli 1987).
Stated all this, some considerations should be taken into account in order to plan the experimental restoration: a) some efforts are required in order to limit the presence of skeleton and to ameliorate the content of nutrients in the soil; b) the selection of suitable plant species should be aimed to privilege the low exigent ones in terms of nutrients; c) the use of species able to tolerate more or less prolonged period of asphyxia should be planned wherever situations of waterlogging can be hypothesized (thus, especially on platforms).

Vegetation on the experimental site and its surroundings. The vegetation growing on the experimental site is typical of the *pioneer phase* of the vegetation succession on the quarries of the Botticino extractive basin, where abiotic factors (mainly soil characteristics) limit plant establishment and growth in a relevant way. In fact, the area was almost bare, with some vegetation patches characterized by low structural complexity and species richness: the few dominant species (e.g. *Setaria viridis*) were ruderal, light-requiring, fast-growing and with a herbaceous habit, a very effective anemochorous dispersal and a developed ipogeous biomass, as found in similar conditions (e.g. Martínez-Ruiz et al. 2007). In such conditions, the invasive alien species (e.g. *Ambrosia artemisiifolia*) are favored.
The analysis of the flora on the abandoned quarry areas on the surroundings of the experimental site showed that the whole area is generally interested by a) conditions of whole light, but also some conditions of reduced light; b) intermediate conditions among aridity and soil well supplied with water; c) basic or neutral-basic soils; d) intermediate conditions among soils poor of nutrients and with a suitable level of them. The distribution of the corological forms also revealed the great influence by the near Garda lake (which has a sub-Mediterranean climate) and of the high anthropic disturbance.
Stated all this, some considerations should be taken into account in order to plan the experimental restoration: a) it is necessary to contrast the spread of alien invasive species,

already in place on the experimental site and its surroundings, that could be favored by spontaneous vegetation dynamics; b) selected plant species should be able to establish, survive and grow on basic substrate with whole light conditions; c) as for species requirements regarding water need, the selection of the most suitable species should take into account the geomorphological heterogeneity of the quarry site; d) the influence of the Garda lake on local climate should be considered.

4.2 Plant species selection: germination tests

The selection of suitable plant species is a key aspect affecting the success of any restoration project. As for the herbaceous layer, sowing is one the most used technique and it also allows to add seeds of trees and shrubs species to the herb seed mixture. In order to achieve a successful and economical restoration, the selection of seeds that germinate without requiring pre-treatments is a fundamental prerequisite (Chosa & Shetron 1976; Parrotta & Knowles 2001). Many efforts have been made in the study of seed germination connected with the recovery of tropical rain forests (e.g. Garcia et al. 2005; Sánchez-Coronado et al. 2007), wet areas (e.g. Patzelt et al. 2001) costal environments (e.g. Reed et al. 1998; Orth et al. 2000), heatlands (e.g. van der Berg et al. 2003), lakes and rivers (e.g. Ke & Li 2006). Nevertheless, data about the germination of species that are suitable for the restoration of quarries are few (Windsor & Clements 2001; Bischoff et al. 2005; Wagner et al. 2011). Thus, the principal aim of the present section is to obtain preliminary information about the germination of some common species growing on the Botticino extractive basin (including the pioneer and alloctonous ones) that have a key role in the recolonization of quarry sites. This information is also important to assess the possibility to conserve the studied species as seed, for their future use in restoration projects.

4.2.1 Material and methods

We selected a limited number of not protected species that are common on the Botticino extractive basin and/or in the grasslands present on the quarries surroundings: a) *Anthyllis vulneraria*, *Cotinus coggygria*, *Lotus corniculatus* and *Rosa canina*, that are also included in many restoration projects of local quarries; b) *Populus nigra* and the invasive *Senecio inaequidens*, that are able to colonize all the morphological surfaces present on the extractive basin; c) *Carex flacca*, *Geranium molle*, *Sanguisorba minor*, *Stachys recta* and *Tragopogon pratensis*, that can be easily found on dump deposits and grasslands in the quarry surroundings.

Seeds collection. We identified populations of the selected species in the Botticino extractive basin according to geographical and ecological bonds (e.g. presence of quarry roads, change of vegetation type). For each population, we recorded stational data such as coordinates (grid: UTM; datum: WGS84), elevation (m a.s.l.), aspect (°) and slope (°), and we estimated ecological data such as stoniness and rockiness (%), average stones dimension

(cm), surfaces age (years), cover of tree, shrub, herbs and moss layers (%). Moreover, we also evaluated: the extension of the population, the total number of individuals and of the mature ones, the phenology of the sampled individuals (Appendix 4.2). In order to limit the impact of the sampling on the reproductive potential of the selected populations, we collected not over 20% of the mature seeds (ESCONET 2009). We separated seeds from debris the day after the sampling, dried with silica gel with a 3:1 ratio and conserved to 4°C with no direct exposure to sun light. We did not make any pre-treatments (e.g. mechanical or chemical scarification of the seed coat, addiction of hormones) in order to test germination at the most economical conditions.
We monitored all the germination tests daily for 45 days; seeds were considered germinated if the radicle or the cotyledons emerged from the teguments.

Germination tests in Petri dishes at standard conditions. The day after the sampling, we sowed 100 randomly selected seeds of all the sampled species in Petri dishes on filter paper. We made the germination tests in a growing chamber with constant environmental conditions (continuos light, water supplied when necessary, temperature of 25°C).
According to seeds availability, germination tests were replicated after seed conservation for one year at 4°C with silica gel; specifically 100 seeds of *A. vulneraria*, *C. coggygria*, *R. canina*, *S. minor* and *S. inaequidens* were used for these tests.

Germination tests for *Populus nigra*. *P. nigra* represents a very interesting species in the Botticino extractive basin, because of its capability to colonize any morphological surfaces from the early phases of recolonization till the creation of almost monospecific formations at later stages. Thus, we deepened germination tests on such a species by testing different substrates, water availability and a conservation method (Table 4.7).

N° of replicates	Conservation method	Water (ml)	Substrate
150 seeds	None – sowed the day after sampling	substrate always wet	feathery hair contained in capsules filter paper
100 seeds	4°C, with silica gel one year	1 2	cotton wool
		1 2 5 7	feathery hair contained in capsules
		substrate always wet	filter paper

Table 4.7 Experimental design on *Populus nigra*

Germination tests in Petri dishes at near-natural conditions. We randomly selected and sowed 150 seeds of *A. vulneraria*, 100 of *C. coggygria*, 100 of *G. molle*, 100 of *R. canina*,

44 of *T. pratensis*, 100 of *S. minor*, and 100 of *S. recta* in Petri dishes with filter paper (always wet) after their conservation for one year at 4°C with silica gel.
In order to simulate near-natural conditions, we made the germination test in the laboratory of BIOVEG of the University of Milano-Bicocca from 13.04.2012 to 13.05.2012 (in the period during which seeds are supposed to germinate on the extractive basin). The environmental conditions of light and temperature where comparable with the external ones and with those present in Brescia, i.e.: 14 hours of light per day on mean (station of Milan, E009°11'31" N45°27'59", 122 m a.s.l.; data from: AOPA 2012) and 15°C of temperature (station 869, Milan - via Feltre, sensor 8162, 5037617 1519463; data from: Servizio Meteorologico Regionale 2012).

Germination tests in pots. We sowed 100 randomly selected seeds of *A. vulneraria*, *C. coggygria*, *G. molle*, *L. corniculatus*, *R. canina* and *S. minor* in pots filled with the "soil" used for the restoration experiment, as substrate. We made the germination test in a growing chamber with constant environmental conditions of light (always day) and temperature (25°C); we ensured a constant supply of distilled water by a home-made irrigation system.

4.2.2 Results

Germination tests in Petri dishes at standard conditions. Except for *S. inaequidens*, species showed low percentage of germination on filter paper in Petri dishes at standard environmental conditions (Table 4.8).

Conservation method	Species	Geminated seeds n°/tot	%
none – sowed the day after sampling	*A. vulneraria*	9/100	9.0
	C. flacca	9/100	9.0
	C. coggygria	0/100	0.0
	G. molle	38/100	38.0
	L. corniculatus	11/100	11.0
	P. nigra	0/150	0.0
	R. canina	0/100	0.0
	S. minor	53/100	53.0
	S. inaequidens	89/100	89.0
	S. recta	4/100	4.0
	T. pratensis	57/100	57.0
4°C, with silica gel for one year	*A. vulneraria*	5/100	5.0
	C. coggygria	0/100	0.0
	P. nigra	66/100	66.0
	R. canina	0/100	0.0
	S. minor	0/100	0.0
	S. inaequidens	69/100	69.0

Table 4.8 Germination in Petri dishes at standard environmental conditions

As regards seeds sowed immediately after sampling, only *S. minor* and *T. pratensis* reached almost 50% of germinated seeds, while none seed of *C. coggygria*, *P. nigra* and *R. canina* germinated. After the conservation at 4°C for one year, the percentage of germination decreased in *A. vulneraria* (from 9% to 5%), *S. minor* (from 53% to 0%) and *S. inaequidens* (from 89% to 69%), while it increased in *P. nigra* (from 0% to 66%). *C. coggygria*; *R. canina* did not germinate.

Germination tests onfor *Populus nigra*. As regards the immediate sowing after sampling, 49.3% of seeds germinated on feathery hair contained in the capsules, while, as above reported, none germinated on filter paper at the same standard environmental conditions (Table 4.9). Concerning seeds conserved at 4°C for one year, the percentage of germination greatly increased when seeds were placed on filter paper while remained constant when seeds were placed on feathery hair. The characteristics of the substrate were determinant for germination independently from seed conservation.

Conservation method	Water (ml)	Substrate	Germinated seeds	
			n°/tot	%
none – sowed the day after sampling	substrate always wet	feathery hair contained in the capsules	74/150	49.3
		filter paper	0/150	0.0
4°C, with silica gel for one year	1	cotton wool	11/100	11.0
	2		23/100	23.0
	1	feathery hair contained in the capsules	0/150	0.0
	2		2/100	2.0
	5		15/100	15.0
	7		42/100	42.0
	substrate always wet	filter paper	66/100	66.0

Table 4.9 Germination of *Populus nigra* in Petri dishes at standard environmental conditions

Germination tests in Petri dishes at near-natural conditions. Germination of tested species at near-natural conditions after their conservation at 4°C for one year is generally low (Table 4.10). Species with higher percentage of germination are *S. minor* and *T. pratensis* (44% and 40%, respectively), while *C. coggygria* and *R. canina* did not germinate.

Species	Germinated seeds	
	n°/tot	%
A. vulneraria	33/150	22.0
C. coggygria	0/100	0.0
G. molle	11/100	11.0
R. canina	0/100	0.0
S. minor	44/100	44.0
S. recta	8/100	8.0
T. pratensis	40/100	40.0

Table 4.10 Germination in Petri dishes at near-natural environmental conditions

Germination tests in pots. The percentages of germination in pots are very low: only *A. vulneraria* reached 20% of germinated seeds, while *C. coggygria*, *L. corniculatus* and *R. canina* did not germinate (Table 4.11). One individual of *Setaria viridis* also germinated in the pot where *A. vulneraria* was sown.

Species	Germinated seeds	
	n°/tot	%
A. vulneraria	11/100	22.0
C. coggygria	0/100	0.0
G. molle	2/100	4.0
L. corniculatus	0/100	0.0
R.canina	0/100	0.0
S. minor	2/100	4.0

Table 4.11 Germination in vases at standard conditions

4.2.3 Useful remarks for the planning of restoration experiment

The obtained results are preliminary and should be much deepened and improved, e.g. by setting different replica at different temperature and light conditions (and eventually pre-treatments), and also by using material with different origin (e.g. see Bischoff et al. 2005; Aud & Ferraz 2011). In general, *P. nigra* and *S. inaequidens* show a high plasticity (especially for nutrient availability) and regeneration capacity across a wide range of climatic and hydrological gradients: for example, *S. inaequidens* can produce 10000 seeds per plant during prolonged flowering (Barsoum 2002; López-García & Maillet 2005). Thus, such species are very competitive, especially on disturbed sites, where the creation of microsites free from competition represents an important colonization chance. Our germination tests suggested that the spread of *P. nigra* and *S. inaequidens* (and secondly of *S. minor* and *T. pratensis*) over the Botticino extractive basin could be connected with their high seed germination, at least in proper environmental conditions: López-García & Maillet (2005) also found that most seeds of *S. inaequidens* rapidly germinate over 14-30°C,

especially at higher temperatures (within 2 days at 20°C). *S. minor* and *T. pratensis* could need lower temperatures (e.g. 15°C) to reach 100% of germinated seeds (data from: Seed Information Database).
The tests on *P. nigra* and *A. vulneraria* underlined the importance of testing different environmental conditions and of making in situ trials. In particular, we observed higher germination of *P. nigra* when we used feathery hair contained in the capsules (and secondly cotton wool) as substrate with increasing water supply. This fact could be connected with the availability of microsites suitable for the germination, that, according to Barsoum (2002), are fundamental in regulating species germination besides the type of local substrate and climatic conditions. *A. vulneraria* showed generally low germination in the tested conditions, according to previous studies (Reyes & Trabaud 2009). Nevertheless, the germination was higher on field (personal observation during the restoration experiment), showing that laboratory experiments may be not always predictive of seeds germination during restoration. Moreover, it should be taken into account that the "soil" used for the restoration usually shows a proper seed bank, as showed by the germination of the not sowed *S. viridis* during the experiments in pots.
Species-specific laboratory tests could be an useful tool to understand if seeds remain viable if conserved ex situ and/or are characterized by seed dormancy, in order to verify if and how they can be used for future restoration projects. For example, our results showed that the germination of *S. inaequidens* (obviously not recommended for local restorations) is lower after conserving seeds at 4°C for one year, according to López-García & Maillet (2005). Freshly mature seeds of *G. molle* are characterized by the presence of impermeable seed coats and physiological dormancy of the embryo: seeds lose their dormancy after 3 months of dry storage (Van Assche & Vandelook 2006). *C. flacca* and *S. recta* are characterized by a physiological dormancy (data from: Seed Information Database), so that 4-5 months at 0°C could be sufficient to promote their germination (Mondoni A., personal communication). Guner & Tilki (2009) demonstrated that *C. coggygria* is characterized by a hard seed coat and an internal dormancy (with a degree depending on climate of origin and individuals) which can be broken by pre-treatments such as cold stratification or scarification followed by cold stratification. Rowley (1956) showed that seed germination in *R. canina* is delayed, so that, in general, more than a third of the seeds produce seedlings over 2-6 years; in such a case, seed dormancy can be broken by storage in a moist medium at changing temperature and sowing in a substrate with good light, aeration and moisture retention. Our tests are preliminary and less in depth than species-specific analysis, so that the low germination that we obtained should not be considered as an impediment to the use of the species for restoration purpose.
Even if we can not deduce species-specific information about seed dormancy by our tests, we can say that: a) laboratory tests are an useful tool in order to obtain preliminary information about species-specific suitability to be conserved ex situ and to be used for

future restoration projects; b) field trials testing species-specific germination are required, since laboratory tests could be not able to reproduce local environmental conditions (e.g. availability of microsites suitable for germination, water availability, local substrate, climatic conditions, biotic interactions); c) the knowledge of the vegetation growing on the quarry surroundings can be an useful indicator of the composition of the "soil" seed bank used for the restoration, and thus to predict possible distortion of the planned vegetation dynamics; d) the spread of ruderal and invasive species on the extractive basin (e.g. *P. nigra* and *S. inaequidens*) could be connected with a high germination capacity in appropriate environmental conditions.

4.3 Redesign of the shrub and tree layers

In order to recreate a self-sustaining valuable vegetation community, the selection of suitable tree and shrub species is fundamental, especially where initial site conditions are so adverse (such as on quarries) that could affect, directly or not, plant life and distribution, and thus vegetation establishment and growth. Species to be selected for restoration purpose generally share some characteristics. First of all, they are autochtonous, since they are supposed to be already adapted to local environmental conditions and they are genetically compatible with local populations (Bradshaw 2004). Species-specific ecological needs are selected according to local climate (temperature, precipitations, light radiation, wind and freeze), microclimate (as affected by slopes aspect and morphology), edaphic conditions and topographic features (aspect, slope and altitude) (Bernini et al. 2003; Muzzi & Rossi 2003). The use of both pioneer and more exigent species is usually recommended in order to accelerate vegetation dynamics and the progressive improvement of site characteristics (Muzzi & Rossi 2003), e.g. by reducing runoff, erosion, water and soil pollution (Sharma & Sunderraj 2005). Moreover, the use of species belonging to the *Fabaceae* family could enhance soil fertility (Sharma & Sunderraj 2005).

In general, species potentially suitable for quarry-specific restoration projects are identified on the basis of such general characteristics and on the study of spontaneous recolonization of abandoned quarries. Nevertheless, such a selection usually implies a high degree of subjectivity and personal experience and low attention is paid to the redesign of the complexity of the natural vegetation, although the importance of the use of phytosociological associations as models is recognized (Muzzi & Rossi 2003). Only few authors focused their attention on the elaboration of more objective methods for species selection, although in context different from quarry restoration (e.g. Ramírez 2006) or based on few species traits, such as relative density, relative frequency, relative dominance and regeneration potential of tree species growing in forests surrounding the quarry areas (Sharma & Sunderraj 2005). Thus, the principal aim of the present section is to define a procedure, as objective as possible, which allows to select the most suitable specific composition and density of plantation of trees and shrubs in the experimental site.

4.3.1 Material and methods

Selection of the "vegetation model" and of the plant species density. We graphically represented the type and distribution of local woodlands by means of ArcGIS (version 9.1) according to Del Favero (2002); we overlapped data to the graphical representation of the local geomorphology (represented as polygons with the same aspect). Considering that the aspect of the experimental site was 225°, we considered as "reference woodland" for the restoration the dominant plant community growing on south-west, south and west aspect.
We carried out vegetation plots in the "reference woodland" on the semi-natural area of the P.L.I.S. ("*Local Park of Supra-Municipal Interest*") "Parco delle Colline di Brescia" (Fig. 4.4). The park is the nearest protected area to the extractive basin, being located on 4308 ha, from 190 to 960 m a.s.l., on the surroundings of the city of Brescia (Municipalities of Brescia, Bovezzo, Cellatica, Collebeato, Rodengo Saiano, Nuvolera and Rezzato). Dominant vegetation are termophilous woodlands dominated by *Ostrya carpinifolia*, *Fraxinus ornus* and *Quercus pubescens* (especially on sunny south slopes), that are interrupted by semi-natural woodlands dominated by *Betula pendula*, *Fagus sylvatica* or *Castanea sativa*, and by xerophilous grasslands, where endemic and Mediterranean species also grows (Suardi 2005).

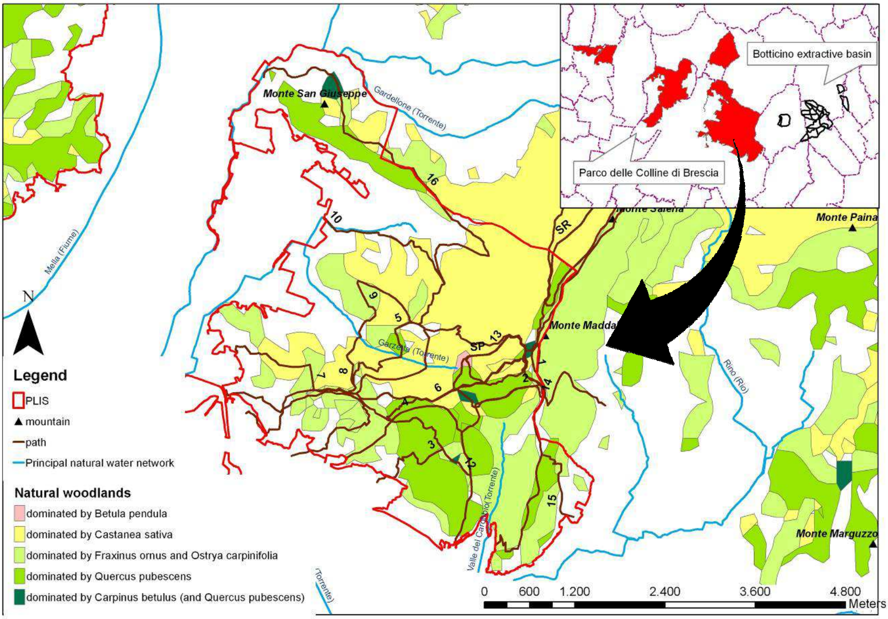

Fig. 4.4 Woodlands on the P.L.I.S. "Parco delle Colline di Brescia" (data from: Geoportale della Regione Lombardia; Del Favero 2002)

We identified the "vegetation model" as the dominant species in the main vegetation types of the selected area, and their relative abundance. At this aim we performed 7 vegetation plots of 50 mq from April to May 2011 on homogeneous woodlands and high shrublands. We recorded stational data, such as coordinates (grid: UTM; datum: WGS84), elevation (m a.s.l.), aspect (°) and slope (°), and we estimated ecological data such as vegetation cover, soil cover, stoniness and rockiness (%), cover of tree, shrub, herbs and moss layers (%). In order to identify plant species density, we recorded the total number of trees and high shrubs, the tree diameter at 1.5 meter above ground and the distance between trees. We also made the floristic list of the herbaceous layer.

Selection of plant species. In accordance with the Provincial Quarry Plan (Zanotti 1996), we firstly selected tree and shrub species among the autochthonous ones growing on the plain and/or on the hill (0-1000 m a.s.l.) and whose presence is documented on the surroundings of the Botticino extractive basin, according to De Carli et al. (1999).

Definition of criteria and variables. We considered the following criteria for species selection: a) successful establishment of the vegetation; b) recreation of a vegetation compatible with the surrounding (semi)natural one; c) improvement of environmental site conditions (especially of chemical and physical characteristics of the soil); d) creation of a self-sustaining plant community (requiring none or very low human efforts). We did not considered social or economical criteria (because of the naturalistic nature of the restoration) and aesthetic value of the species (that is subjective).
On the basis of such criteria, we selected 11 variables that are directly or indirectly linked to species ecological characteristics or traits (Table 4.12). Among the ecological characteristics, we used Landolt indexes (Landolt 1977), since they consider the type of humus in soil and the soil texture (not considered by Ellenberg indicators), that are key factors in determining vegetation dynamics at the beginning of the succession on just abandoned quarries.

Criteria	Variable	Data source
a) successful establishment of the vegetation	1) Landolt indicator of soil humidity (F) 2) Landolt indicator of soil chemical reaction (R) 3) Landolt indicator of soil content of nitrogen and nitrogen compounds (N) 4) Landolt indicator of content of humus (H) 5) Landolt indicator of soil texture, i.e. dispersion (aeration) of the substrate (D) 6) Landolt indicator of light (L) 7) Landolt indicator of temperature (T) 8) Landolt indicator of continentality (C)	Zanotti 1996 (according to Landolt 1977, as modified by Andreis & Levy 1988)
b) introduction of a vegetation compatible with the surrounding (semi)natural one	9) Species growing on large scale and on similar environmental conditions of the experimental site	Bernini et al. 2003; Del Favero 2002
c) improvement of environmental characteristics	10) Species producting organic matter and secondary products (e.g. flowers, fruits)	Groppali et al. 2008; Pignatti et al. 1982
d) creation of a self-sustaining plant community	11) Seed dispersal strategy	Groppali et al. 2008; Müller-Schneider 1986

Table 4.12 Criteria, variables and data source used for the species selection

Attribution of weights and scores. We attributed a weight between 1 and 5 to those variables that are supposed to be linked to the plant survival after the transplantation (Table 4.13). We attributed lower weights to those variables that can affect long-term vegetation dynamic, as for example the progressive higher contribution of the species coming from the areas surrounding quarries.

Variables	Weight
1) Landolt indicator of soil humidity (F)	5
2) Landolt indicator of soil chemical reaction (R)	4
3) Landolt indicator of soil content of nitrogen and nitrogen compounds (N)	5
4) Landolt indicator of content of humus (H)	4
5) Landolt indicator of soil texture, i.e. dispersion (aeration) of the substrate (D)	1
6) Landolt indicator of light (L)	4
7) Landolt indicator of temperature (T)	2
8) Landolt indicator of continentality (C)	1
9) Species growing on large scale and on similar environmental conditions of the experimental site	4
10) Species producting organic matter and secondary products (e.g. flowers, fruits)	3
11) Seed dispersal strategy	1

Table 4.13 Weights (1-5) attributed to the variables

According to experimental site conditions, the biogeographic classification of the study area (see previous chapters) and the selection of the "vegetation model", we assigned a score between 1 and 9 to each value of the variables (Table 4.14). We attributed higher scores to less exigent species in term of water and nutrient availability, able to survive on full light stations, with a high production of biomass and secondary products attracting animals (e.g. flowers, fruits), able to reproduce in a disturbed environment where wind and man are the most important dispersal agents.

Variables	Value	Score
Landolt indicator of F, N, H	1 (soils very arid, with very low nutrient availability and without humus)	9
	2	7
	3 (average values)	5
	4	3
	5 (soils very rich of water, with excess of nutrient content and with very rich humus)	1
Landolt indicator of R, D, L, T, C	1 (soils pH < 4,5, rocky environments, shady stations of the alpine zone, with oceanic climate)	1
	2	3
	3 (average values)	5
	4	7
	5 (soil pH >6,5, clayey, stations with full light, with the hottest conditions and continental climate)	9
Suitable vegetation type (final destination)	Characteristic species of woodland dominated by *Quercus pubescens*	9
	Characteristic species of woodland dominated by *Fraxinus ornus* and *Ostrya carpinifolia*	5
	Infrequent species of woodland dominated by *Quercus pubescens*	7
	Infrequent species of woodland dominated by *Fraxinus ornus* and *Ostrya carpinifolia*	3
	Sporadic species of woodland dominated by *Quercus pubescens*	5
	Sporadic species of woodland dominated by *Fraxinus ornus* and *Ostrya carpinifolia*	1
Improvement of environmental condition	Deciduous species (producing organic matter)	1
	Deciduous species (producing organic matter) dispersed by animals or man	4
	Deciduous species (producing organic matter) with N-fixation mechanisms	6
	Deciduous (producing organic matter), with N-fixation mechanisms and dispersed by animals or man	9
Dispersal	Mixed strategy (Anemochory, Zoochory, Hemerochory)	9
	Mainly Anemochory (Anemochory; Anemochory and Zoochory; Anemochory and Hemerochory)	7
	Hemerochory and Zoochory (Hemerochory and Zoochory; Zoochory, Nautochory and Hemerochory)	5
	Mainly Hemerochory (Hemerochory; Autochory, Zoochory and Hemerochory)	3
	Mainly Zoochory (Zoochory; Hydrocory and Zoochory)	1

Table 4.14 Scores (1-9) of the values of the variables

Calculation of the final score. The final score for each species was calculated as:

$$score_x = \sum_i v_{ix} * w_i$$

where: v_{ix}= value of the variable i for the species x; w_i= weight of the variable i

4.3.2 Results

Selection of the "vegetation model" and of the plant species density. Woodlands dominated by *Quercus pubescens* (both in the variant typical of limestone substrate and in that one primitive with a relevant presence of *Cotinus coggygria*) represented the "reference woodland" (Fig. 4.5). Secondarily, woodlands dominated by *Fraxinus ornus* and *Ostrya carpinifolia* (typical, or primitive and characteristic of rocks and detrital slopes) could be used as vegetation model. On the other hand, secondary woodlands dominated by *Castanea sativa* cannot be considered suitable because of their past spread connected to their human exploitation for fruits, timber and resins (Gallinaro 2004; Conedera et al. 2004).

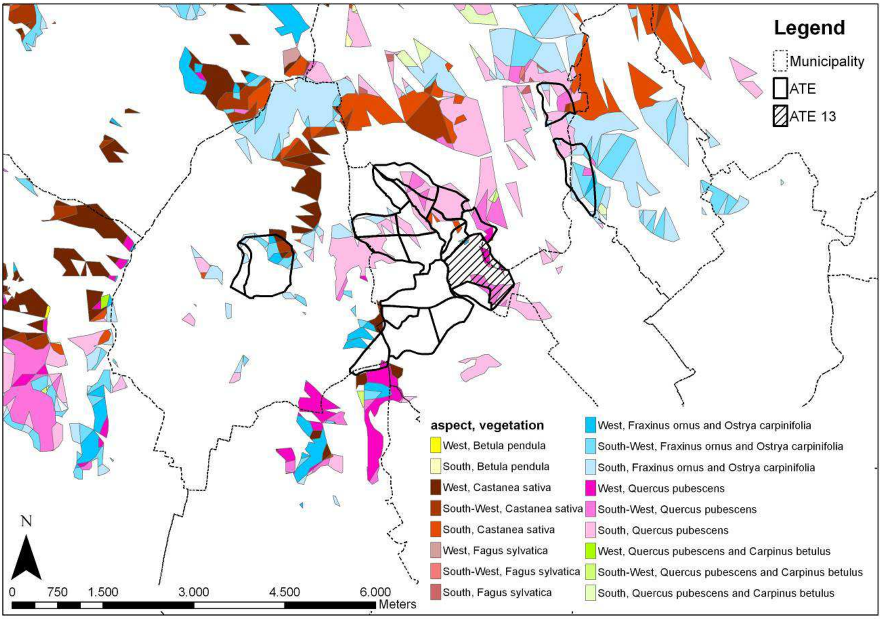

Fig. 4.5 Semi-natural and natural woodlands on south-west, south and west slopes on the surroundings of the ATE 13 (data from: Del Favero 2002; Geoportale della Provincia di Brescia)

The plots recorded in the P.L.I.S. "Colline di Brescia" showed that more than 50% of trees and high shrubs belongs to the species *Quercus pubescens*, while *Fraxinus ornus* and *Ostrya carpinifolia* were less abundant; other species showed much lower presence (Table

4.15). Trees presented a scattered distribution with a mean distance among individuals of 2.47 (±0.50) m; the mean trees density was 0.31 (±0.07) trees/m^2.

Trees (%)	**Mean**	**St.dev**
Cotinus coggygria Scop.	1.79	4.72
Crataegus monogyna Jacq.	5.36	9.83
Erica arborea L.	1.10	2.91
Fraxinus ornus L.	15.39	12.02
Ostrya carpinifolia Scop.	13.58	19.86
Pinus sylvestris L.	2.64	3.42
Quercus ilex L.	1.95	5.15
Quercus pubescens Willd.	58.20	26.46
Distance (m)	**2.47**	**0.50**

Table 4.15 Mean presence of trees and high shrubs on the woodlands dominated by *Quercus pubescens* on the P.L.I.S. “Parco delle Colline di Brescia”

Five species were constantly present on the herbaceous layer: young individuals of *Cytisus sessilifolius* and *Clematis vitalba*, *Cotinus coggygria* and the herbaceous *Carex flacca* and *Peucedanum cervaria* (Appendix 4.3).

Selection of plant species. On the basis of the calculated score ranging from 220 to 64 (Appendix 4.4), we divided species into five groups according to their suitability for the use in local restoration projects: A) very suitable (ranging from 220 to 209), B) suitable (ranging from 201 to 183), C) low suitable (ranging from 180 to 157), D) not very suitable (ranging from 155 to 127), and E) not suitable (ranging from 123 to 64). We identified groups taking into account the presence of discontinuities in the attribution of the scores (Fig. 4.6).

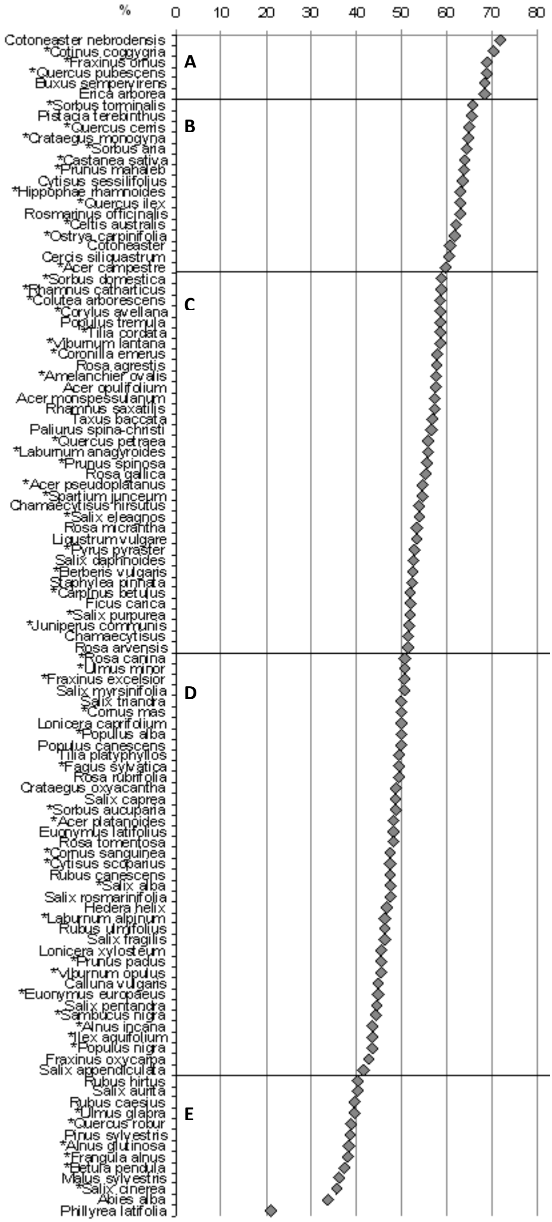

Fig. 4.6 Species groups and scores (represented as percentage in relation to the obtainable maximum score). Legend: * species available for the restoration experiment

Considered that the area of the three terraces on the experimental site is 209.4 m^2 on average, the total number of trees/high shrubs that should be planted on each terrace is 98. We selected the number of individuals of each species by mimic their relative presence as recorded on the plots carried out on the P.L.I.S. "Parco delle Colline di Brescia" (Table 4.16).

Species	plants/terrace n°	plants/terrace % vs total	Age (years)**	Height (cm)**	Provenience** (Region, Locality)
Group A					
*Cotinus coggygria**	15	15.31	1	60	Apennines (Menconico-PV)
*Fraxinus ornus**	15	15.31	1	50	low plain (Magenta-MI)
*Quercus pubescens**	35	35.71	1	30	*avanalpica* (Roncarro-BG)
Group B					
Acer campestre	1	1.02	1	50	*esalpica* (Solto Collina-BG)
Celtis australis	1	1.02	1	50	*mesalpica* (Berbenno-SO)
*Crataegus monogyna**	1	1.02	1	90	*esalpica* (Esine-BS)
*Ostrya carpinifolia**	15	15.31	2	50	*esalpica* (Almenno S. B.-BG)
Prunus mahaleb	3	3.06	4	100	*esalpica* (Tignale-BS)
Sorbus torminalis	5	5.10	2	30	*esalpica* (Tignale-BS)
Group C					
Corylus avellana	3	3.06	2	80	high plain (Seriate-BG)
Spartium junceum	1	1.02	1	70	*esalpica* (Tremosine-BS)
Group D					
Cornus sanguinea	1	1.02	1	100	*esalpica* (Cividate Camuno-BS)
Rosa canina	1	1.02	1	40	high plain (Curno-BG)
Ulmus minor	1	1.02	1	60	*avanalpica* (Paladina-BG)

Table 4.16 Experimental design of the tree-high shrub layer; Legend: * species present on the plots of the P.L.I.S. "Parco delle Colline di Brescia"; ** characteristics of plant material (as close as possible to the experimental site) available in the ERSAF nursery of Curno (supplier of plant material)

4.3.3 Useful remarks for the planning of restoration experiment

Previous technical reports and studies based on the identification of the typical local flora (regional law D.C.R. 21.12.2000 n. VI/120; Pesci 2004) recommended a list of species for the restoration interventions in the Botticino extractive basin, including species of the submediterranean area (e.g. *Fraxinus ornus*, *Ostrya carpinifolia*, *Quercus pubescens*, *Q. petraea*, *Prunus avium*) and of the submountain one (e.g. *Quercus pubescens*, *Q. petraea*, *Carpinus betulus*, *Castanea sativa*, *Ostrya carpinifolia*). The method here presented tries to go beyond previous proposal by redesigning the tree and shrub layer as objectively as possible, also by the structural point of view, in order to: a) increase the possibility of plant survival and b) reproduce the complexity (in a simplified way) of local seminatural woodlands. For this reason, we selected only autochthonous species present on the quarry natural surroundings since a) they are adapted to survive on local conditions (even extreme and/or extremely variable), so that they require lower human efforts (e.g. fertilization, irrigation); b) they are the base for the creation of a vegetation compatible with the pre-existing one; c) they provide suitable habitat for local fauna; d) they are not dangerous for man health (usually); e) they contribute to maintain ecological integrity and biodiversity, also contrasting alien invasive species (Wilson 1996; Bernini et al. 2003). Nevertheless, such a condition (that is the base of the selection by D.C.R. 21.12.2000 n. VI/120 and Pesci 2004) is necessary but not sufficient: for example, species typical of late successional phases could be not able to survive during the initial phases of quarry revegetation (Muzzi & Rossi 2003), where abiotic limiting factors are relevant. Thus, we considered a high number of parameters in order to better differentiate selected species even when they show the same score for one variable (Sharma & Sunderraj 2005). We gave greater importance to parameters that could affect plant establishment and survival, according to the previous site characterization (e.g. high soil pH, low water and nutrient availability, high sun exposure because of extended bare areas, south-west aspect and high reflection due to the pale colours of the substrate). We gave less importance to the capability of species to improve site conditions, that we considered important, however, with particular reference to the fundamental role of organic matter, which is the biggest source of nitrogen and potassium on reclaimed dump deposits, reduces soil bulk density, thus increasing soil porosity and having positive effects on plant nutrition and growth (Maiti & Ghose 2005). The main input of organic matter on quarry areas come from the decomposition of aerial parts of plants (thus, being correlated also with litter accumulation and percent plant cover), besides plant roots and rhizomes (Izquierdo et al. 2005). The selection of N-fixing species, such as mycorrhizal and nodulated tree or shrubs legumes, may be successful on quarries (Claassen & Hogan 2002), even if they may require some additional efforts for the initial plant establishment, such as inoculation of rhizobial strains, arbuscolar mycorhizal fungi, slow release sources of phosphorous and other plant nutrients (Franco & De Faria 1997; Rodríguez-Echeverría & Pérez-Fernández 2005). We also selected plants able to improve the biotic community by attracting insects and animals thanks to the showy flowers, nectar and/or fleshy fruits, stated that plants themselves are at the base of the trophic network (e.g. Díaz et al. 1998).

Experimentally, the mortality of planted species in the restoration of limestone quarries could be very high: 50-70% of individuals could die during the first three years after the transplantation where soil is not well developed (Muzzi & Rossi 2003). In order to obtain the optimal plant density for the restoration experiment, we increased of 50% the reference mean plant density recorded on the plots of the P.L.I.S. “Parco delle Colline di Brescia” (thus resulting 0.47 trees/m^2). In comparison to the “vegetation model” we used a lower relative abundance of *Quercus pubescens* in order to a) test a higher number of shrubby individuals belonging to group A (i.e. *Cotinus coggygria*) for the development of a shrub layer (taking into account that the starting point for the revegetation is a bare ground, and not a "fluctuating phase" like in the P.L.I.S.) and b) test on field species belonging to different groups in order to verify the effectiveness of the selection method.

4.4 Redesign of herb layer

Autochthonous herbaceous species of local provenience (from areas ecologically similar to those that should be restored) are considered worldwide the most suitable plant material to restart natural succession (Florineth 2007; Regione Lombardia 2011). Nevertheless, the demand and the supply of seeds of native herbaceous species is inadequate both in Italy and at global scale (Waters et al. 1997; Bernini et al. 2003); in Lombardy, it is mostly connected to some experimental activities of specialised research centres (Regione Lombardia 2011). Thus, the phase of grassing in most technical restorations is made by the more economical and more available commercial seed mixtures, made by few allochthonous species (one or two species usually constitute 85-90% of the total weight), that are artificially selected mainly in order to obtain an "immediate green effect" and/or to solve imminent erosion problems (Florineth 2007; Regione Lombardia 2011). Such mixtures represent a high risk for the environment (e.g. for genetic pollution, invasion, health risks), also considering that they could potentially replace the native local flora.
Another type of material that could be used for restoration purposes is the hayseed (in the Italian language called "*fiorume*"), i.e. a heterogeneous seed mixture of local provenience which is well known by the traditional agriculture: old farmers used to collect seeds and plant residuals on the floor of the barns (the hayseed, exactly) and to spread it on areas for grazing in order to create new pastures or to improve the existing ones (CFA 2011; Regione Lombardia 2011). Today, the hayseed is directly collected on field by use of modified agricultural machineries (e.g. treshing-machines with brushes) during the harvesting of a "donor grassland" and used for environmental and engineering restoration, especially of ski tracks (Ferrario 2011). Besides the fact that the actual land-use and foraging value of the donor grassland is not compromised, the use of hayseed is predicted to have many advantages such as a) a rapid creation of an almost continuous herb layer, with a suitable equilibrium among graminoids and not graminoids, b) the contrast of the spread of not desirable species, by increasing the inter-specific plant competition, c) the soil stabilization and its protection from erosion, d) the improvement of soil chemical and physical characteristics (CFA 2011; Regione Lombardia 2011), e) the achievement of long-term aims, such as the creation of complex and stable landscape units compatible with the surroundings (Muzzi & Rossi 2003). The aim of such a section is to create the preconditions to test the characteristics of the hayseed to be used for the restoration of the limestone quarries of the study area, characterizing a "donor grassland" close to the experimental site.

4.4.1 Material and methods

<u>Study area and selection of the "donor grassland".</u> Xerotermophilous grasslands with a Mediterranean mark dominated by *Bromus erectus* and *Brachypodium rupestre* (*mesobromion*) prevails on the calcareous substrates of the Lombardy Pre-Alps; discontinuous grasslands dominated by *Bromus condensatus*, *Melica ciliata* and *Artemisia alba* are also present on primitive soils with high stoniness (Minelli 2005; Nodari 2006; Fig. 4.7). Grasslands dominated by *Bromus erectus* and *Brachypodium rupestre* are mainly located on hilly, dry and exposed slopes, on soils poor of nutrients and organic matter, and with low depth. Most of them have a secondary origin (they occupy past vineyards), and are (or have been) periodically mowed. Biodiversity is high, with some dominant species such as *Bromus erectus, B. condensatus, Brachypodium rupestre, Chrysopogon gryllus, Stachys recta, Peucedanum cervaria, Dactylis glomerata, Euphorbia cyparissias, Salvia pratensis* and *Teucrium chamaedrys* (Nodari 2006).

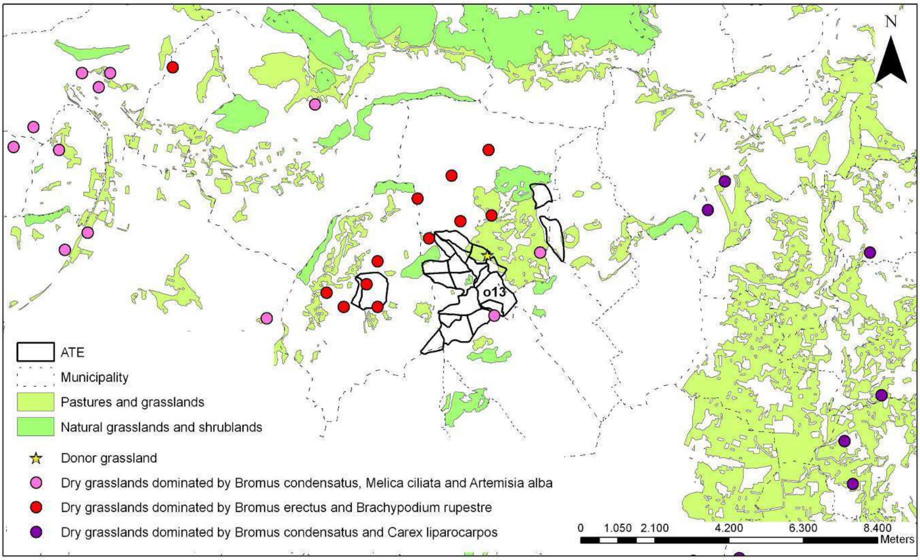

Fig. 4.7 Location and classification of the grasslands on the surroundings of the Botticino extractive basin (data from: Geoportale della Regione Lombardia; Geoportale della Provincia di Brescia; Nodari 2006)

We selected a grassland close to the experiment site as suitable source of hayseed, i.e. as "donor grassland". On April 2011, we recorded stational data such as coordinates (grid: UTM; datum: WGS84), elevation (m a.s.l.), aspect (°) and slope (°) and we estimated ecological data such as stoniness and rockiness (%), cover of tree, shrub, herbs and moss layers (%). We also estimated plant species cover according to Braun-Blanquet (1928) modified by Pignatti (1953).

Hayseed collection and characterization. We selected *B. erectus* as guide species in order to monitor seeds maturation and maximise the yield. Because of the limited dimension and the low accessibility of the donor grassland, we collected the hayseed on may 2011 by a brush harvester bring to shoulder; in order to improve the yield and collect the seeds of as many species as possible, we regulated the height of the brush according to the height of the plant infructescences. We firstly spread the collected hayseed in a dry and airy repaired room in order to avoid the begin of fermentation processes; once dried, it was conserved in a fresh and dry environment and transported to the "Laboratory for the conservation of plant biodiversity" of the CFA ("Centro Flora Autoctona"; Galbiate, LC, Lombardy) for the characterization and the germination test.

Characterization of the hayseed. Three replies of 10 g were sampled and cleaned according to the expeditious protocol (modified) for the cleaning of the hayseed collected by grasslands dominated by *Bromus erectus* developed by CFA. The procedure consisted into the alternation of sieving of different grains and passages on a blowing machine; at the end of each phase, we separated mature seeds by hand from the rest of the sample, including for example damaged seeds, leaves, flowers, soil and rest of insects (Fig. 4.8).

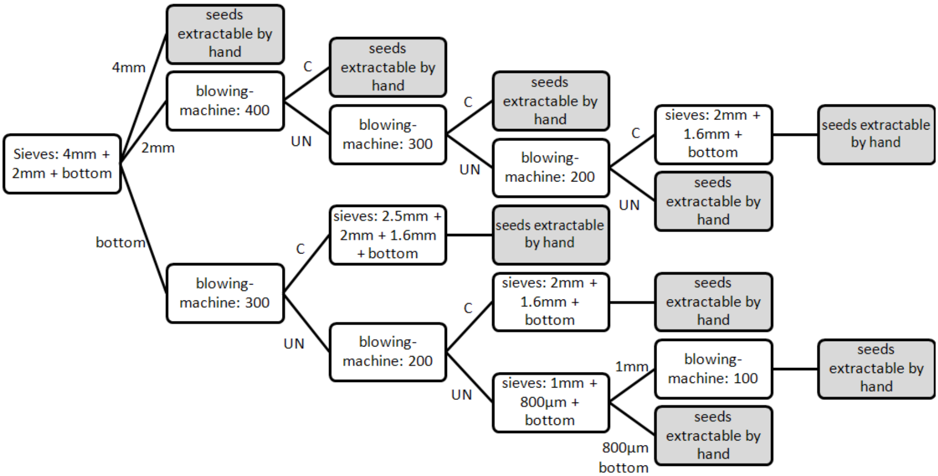

Fig. 4.8 Cleaning protocol used for the collected hayseed; Legend: C: clean; UN: unclean

After having counted the seeds, we weighted them by means of the analytical balance *Precisa Gravimetrics AG* (Dietikon, Svizzera; resolution of 0.1 mg). Thus, we calculated the theoretical optimal sowing density (considering 100% of seeds germinate) in order to obtain the establishment of 8000 plants/m^2, according to Florineth (2007).

Germination tests. We sowed three replies of 10 g of hayseed (different from those used for the characterization) on three seed trays with a density of 125 g/m^2. We distributed uniformly the hayseed on a substrate made by 50% of commercial universal soil and 50% of sand (always wet). We made the tests in a greenhouse. After having monitoring the tests for one month, we randomly carried out three plots of 5 x 5 cm (plot A, plot B, plot C) in each seed tray; we counted the seedlings of monocots and dicots on each plot and we determined the germinated species.

4.4.2 Results

Selection of the "donor grassland". The "donor grassland" was an annually mowed grassland (40 x 4 m) located in a clearing of a woodland dominated by *Quercus pubescens*, close to the experimental site (coordinates: 1606045 – 5046163; altitude: 438 m a.s.l.; Municipality of Serle), with a south-east aspect (mean aspect: 147°) and low slope (mean slope: 15°). The herb layer was continuous (it covers 99% of the area, while only 1% was covered by soil) and presented a high floristic diversity, counting 63 species, of which the most abundant were: *Bromus erectus*, *Anthyllis vulneraria*, *Dactylis glomerata*, *Salvia pratensis*, *Arrhenatherum elatius*, *Bromus sterilis*, *Filipendula vulgaris* and *Lolium multiflorum*. According to species frequency (Appendix 4.5), the donor grassland was classified as "*mesobromion*".

Characterization of the hayseed. Seeds represented 16.67% of the total weight of each sample on average; the mean number of seeds in each sample was 1026, so that seed density was 103 seeds/g (Table 4.17). The optimal seed density allowing to ensure the germination of 8000 plants/m^2 (Florineth 2007), was 77.97 g/m^2 of hayseed.

Sample	Seeds weight		Hay weight		Number of seeds		Optimal seed density
	g	%	g	%	in 10 g	n°/g	g/m²
1	1.8	18.0	8.2	82.0	1064	106.4	75.19
2	1.2	12.0	8.8	88.0	915	91.5	87.43
3	2.0	20.0	8.0	80.0	1098	109.8	72.86
Mean	**1.67**	**16.67**	**8.33**	**83.33**	**1026**	**102.6**	**77.97**

Table 4.17 Seeds weight, hay weight, number of seeds and optimal seed density for restoration purpose on the samples

Germination tests. Twenty-eight seedlings germinated on the plots on mean, so that 11067 seeds/m^2 are expected to germinate with a sowing density of 125 g/m^2 of hayseed (Table 4.18). Most germinated species were monocots (*Poa pratensis*, *Dactylis glomerata* and

Bromus erectus); the germination of dicots (mostly *Trifolium pratense* and *Sanguisorba minor*) was lower.

		1		2		3		Mean - plot	
		N°/plot	**N°/mq**	**N°/plot**	**N°/mq**	**N°/plot**	**N°/mq**	**N°/plot**	**N°/mq**
Plot A	Monocots	18	7200	32	12800	16	6400	22	8800
	Dicots	1	400	3	1200	1	400	2	667
	Total	19	7600	35	14000	17	6800	24	**9467**
Plot B	Monocots	29	11600	39	15600	28	11200	32	12800
	Dicots	2	800	1	400	1	400	1	533
	Total	31	12400	40	16000	29	11600	33	**13333**
Plot C	Monocots	28	11200	28	11200	19	7600	25	10000
	Dicots	2	800	1	400	0	0	1	400
	Total	**30**	**12000**	**29**	**11600**	**19**	**7600**	**26**	**10400**

Table 4.18 Germinated seedlings on the recorded plots

The optimal seed density allowing to ensure the germination of 8000 plants/m^2 (Florineth 2007), was 90.36 g/m^2 of hayseed.

4.4.3 Useful remarks for the planning of restoration experiment

We selected the donor grassland and the time of harvesting in order to increase the possibility of a successful replication of a grassland as similar as possible to the local ones and suitable to establish on the adverse environmental conditions of quarries. For such reasons, we selected a donor grassland very close to the experimental site, so that a) it was suitable from the ecological, phytoclimatic and phytogeographic point of view, b) plant material was already selected by local environmental conditions, also considering that species referring to the "*mesobromion*" are typical of dry environments and low fertile soils (similarly to quarries, even if in a less extreme way), c) germination problems are expected to be low, so that human efforts are minimized (CFA 2011; Regione Lombardia 2011). We ensured a high biodiversity level by collecting hayseed through a brush harvester, so that also the smallest seeds were collected thanks to the air flux created by the rotation of the brushes (Loch et al. 1996). This way, vegetation will be more robust and biologically stable to stress and environmental fluctuations than those made by only one or few species (Silcock & Johnston 1993; Garden et al. 1996); also the density of native perennial grasses is expected to increase progressively (Elseroad et al. 2003). Since we collected the hayseed from a (semi)natural grassland, the final mixture presented high percent of species belonging to the *Poaceae* and *Fabaceae* families, that have relevant roles in stabilizing and nitrifying soil, respectively (Wilson 1989). The firsts grow rapidly and create a superficial but close root system, adapted to control superficial erosion; the second ones increase N and organic-C contents and biological activity of top soil layers with a species-specific behaviour (Azcón & Barea 1997), especially during first phases of revegetation (Alegre et al. 2004).

Bernini et al. (2003) highlighted that a weak point of the use of hayseed is its scarce purity (i.e. low weight of seeds on the total) and low germination. Our qualitative and quantitative characterization and germination tests allowed to overcome these problems. In fact, the optimal sowing density can be calculated experimentally every time: for the case study, the hayseed density calculated by the characterization should be increased of 15-20% for restoration purpose. Moreover, such a knowledge also allows to plan some corrective actions, such as: increase of collection efforts (also by selection of new suitable donor grasslands), addition of autoctonous seeds to the hayseed, transplantation of turfs and seedlings, creation of "safe sites" and "recolonization areas" (CFA 2011). Finally, it is possible to recreate a grassland with high naturalistic value both for species composition and genotypes (CFA 2011; Regione Lombardia 2011) and suitable to improve environmental characteristics on short and long term, including the visual impact on landscape (Waters et al. 1997).

4.5 Manuscript to be submitted: Contribution of herbaceous species' roots to topsoil stabilization on quarry dump deposits

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Abstract

Quarry areas are very heterogeneous environments for plant life because of human-induced disturbance; among different geomorphological surfaces, dump deposits could present problems of superficial slope stability, since, at the end of the exploitation, they are usually covered with a "soil layer" of limited depth for restoration purposes. Stated the importance of the plant root systems to overcome such a problem, we investigated the contribution of three herbaceous species, *Anthyllis vulneraria*, *Bromus erectus* and *Stachys recta*, to ensure superficial slope stability of the dump deposits on limestone quarries of the Botticino extractive basin (Lombardy, Italy). We carried out 421 tensile strength tests (35 on *A. vulneraria*, 262 on *B. erectus* and 124 on *S. recta*) by means of the Stable Micro System TA Hd Plus apparatus (load cell of 500 N, noise of 0.01%, constant speed of 10 mm min^{-1}, acquisition at 200 Hz). We analyzed data according to 7 classes of root diameter and we performed the Kolmogorov-Smirnov test and the ANCOVA. We calculated the Root Volume Ratio after having acquired digital images of part of the root system of 10 individuals of each species by means of Winrhizo. We elaborated data according to the classification used for the tensile strength tests. We then calculated the root cohesion as the sum of the product of the tensile strength and the RVR of the roots of each class of diameter. We found that the root tensile strength of the three analyzed species strongly decreased with root diameter according to a potential curve, with a behavior similar to that of tree and shrub species. Our study showed that the W&W method (that can be improved by the use of more advanced models such as the RBM) can furnish some basic information about the root cohesion of herbaceous species, obtaining comparable results with literature data. On the whole, among the studied species, *B. erectus* showed the highest root tensile strength, root volume ratio and root cohesion, confirming the importance of the use of species with fasciculated root system (such as those belonging to the Poaceae family) for restoration projects.

Key words: *Bromus erectus*, *Anthyllis vulneraria*, *Stachys recta*, root tensile strength, root volume ratio, root cohesion, superficial mass movements, limestone quarries, dump deposits

Introduction

Stone quarries are very heterogeneous areas because of human-induced disturbance (Gentili et al 2011), that is revealed by the presence of three main geomorphological surfaces: dump deposits, artificial cliffs and platforms. Dump deposits are inactive areas where waste materials produced during the extractive activity (mostly made by stone fragments) are dumped. Because of their origin, they are usually characterized by undesirable chemical and physical properties so that they are very hard to colonize by vegetation and could remain bare for long time (Muzzi & Rossi 2003). For this reason, they are often covered at the end of the quarry exploitation with a "soil layer" of limited depth (e.g. a layer deep 50 cm made by the original topsoil removed during the site preparation, according to Italian law) in order to create acceptable conditions for plant establishment. Nevertheless, such an addiction creates a discontinuity surface, that could increase the superficial instability of the dump deposits (e.g. connected to debris and mud flows, mass movements and landslides), especially during intense rainfall events (Baroni et al. 2000). In addition, soil particles could be easily removed and transported (Bernini et al. 2003), so that the potential risk of superficial erosion by gravity, wind and rain is high (Sort & Alcañiz 1996). This way, slope stability is affected both on short and long term (Shu et al. 2005; Carrick & Krüger 2007), inhibiting the natural revegetation processes (Gentili et al. 2010).

In such a context, the facilitation of revegetation processes through an appropriate selection of plant species is fundamental (Bernini et al. 2003; Mafian et al. 2009). The root system of herbaceous, shrub and tree species has a key role both for slope stability (e.g. Simon & Collison 2002; Rickson et al. 2006; Tosi 2007) and erosion control (e.g. De Baets et al. 2007). In fact, roots control soil hydrological features, by forming macropores within soil, controlling the infiltration rate and the movement of water, and thus the moisture content (e.g. Ziegler & Giambelluca 1998; Bernini et al. 2003). They also affects the soil mechanical characteristics, by forming a binding network within the soil layer (e.g. Waldron 1977; Schmidt et al. 2001), increasing the organic matter content (Gyssels et al. 2005) and anchoring the superficial soil layers to the deep stable ones (or to the bedrock). This way, the aggregate stability, the soil shear strength and resistance increases (e.g. Bernini et al. 2003; Bischetti 2003; Davoudi 2011) contributing to the landscape features on long term (Istanbulluoglu & Bras 2005).

The mechanical contribution of vegetation to soil stability is characterized by a high spatial heterogeneity, since it greatly depends on root system development, and thus on plant morphogenetic features, plant competition, soil characteristics such as texture, structure and moisture (Bischetti et al. 2009), species and root size (Waldron 1977). Although the behavior of both small and large roots along the soil profile during shearing can be modeled (e.g. Gray & Laiser 1982; Morgan & Rickson 1995), the only fiber reinforcement is usually considered, and expressed as additional root cohesion. The most simple model for the calculation of root cohesion is the W&W method (Wu 1976; Waldron 1977), that is based on the assumption that roots are cylindrical, elastic and perpendicular to the shear surface: when the rooted soil is sheared, roots mobilize their tensile strength, that is made by a tangential component (that opposes the shear force) and a normal component (that increases the confining pressure on the shear surface and then soil resistance).

Although many studies deal with root cohesion (e.g. Waldron 1977; Gray and Sotir 1996; Norris et al. 2008), they are mostly focused on tree and shrubs species connected with the control of landslides, riverbanks stabilization and bioengineering interventions, so that data on native herbaceous species are very limited (e.g. Simon & Collison 2002; Mattia et al. 2005; De Baets et al. 2008). Moreover, until now few studies have been applied to quarry areas to be restored. In this context stud on root cohesion should facilitate the selection of species favoring revegetation processes and slope stabilization. The principal aim of the present work is to test how herbaceous species with a different type of root system could contribute to the superficial stabilization of quarry dump deposits after their abandonment. We selected *Bromus erectus*, *Stachys recta* and *Anthyllis vulnereria* as study species and the limestone quarries of the Botticino extractive basin (Lombardy, Italy) as study area. In particular, we try to answer the questions: 1) Is a relationship root diameter – root tensile strength, that is usually found for tree and shrubs, valid for herbaceous species? 2) What type of root system (and what species) is the most suitable for restoration purpose in quarry areas?

Materials and methods

Study area. The study area is located on the Botticino basin, the second most important extractive basin in Italy (it counts over a hundred working quarries) and known worldwide for the extraction of a limestone, commercially known as "Botticino Marble" (Clerici & Meda 2005). The basin is located on the hill area (180-650 m a.s.l.) of the Brescia Province (Lombardy) over 5 Municipalities: Botticino, Nuvolento, Nuvolera, Paitone and Serle. Climate is continental, with cold and dry winters (mean annual temperature: 13.5°C), rainy springs and autumns (mean annual rainfall: 1026.13 mm), anticyclonic conditions and weak winds. Local lythology is composed by limestone and karst rocks of the "Corna" formation, with calcareous and breccia facies (Servizio Geologico d'Italia 2008). Vegetation growing on the quarries surroundings is mainly characterized by copse woodlands dominated by *Quercus pubescens*, with a high presence of *Ostrya carpinifolia* and *Fraxinus ornus*, locally replaced by woodlands dominated by *Castanea sativa*.

Most restoration projects regarding the quarries of the Botticino extractive basin include the landform modeling and the soil preparation before the revegetation phase. In order to create acceptable conditions for plant establishment by mitigating the physical and chemical limitations of the substrate (usually rocky outcrops or debris wastes characterized by low fertility), the areas to be restored are covered with a "soil layer" deep 50 cm (the depth decrease after the rainfall following its translocation) made by the original topsoil removed during the site preparation, according to Italian law (Fig. 1). Such an addiction creates a discontinuity surface, that could increase the superficial instability of the embankments, compromising the successful establishment of the vegetation.

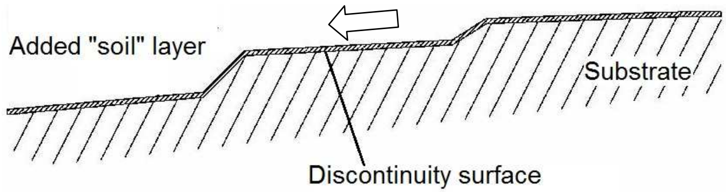

Fig. 1 Restoration of quarry areas: addition of the "soil" layer of limited depth on dump deposits and creation of a discontinuity surface; arrow: direction of mass movements

Study species. We selected three herbaceous species with different type of root systems and a widespread distribution along the dump deposits of the extractive basin: *Anthyllis vulnereria* L., *Bromus erectus* Hudson, and *Stachys recta* L.

A. vulnereria (Fabaceae) is a perennial short basal herb (H scap) of 8-40 cm, which grows on sunny environment with frequent clouds of the temperate zone (0-3000 m a.s.l.). It prefers arid and dry environments and basic or neutro-basic substrates even very poor of nutrients, such as arid grasslands (Pignatti 1982; Pignatti et al. 2005). The root system consist in one main tap root anchoring the plant to the soil and many much thinner lateral roots, bringing some mycorrhizes for the nitrogen-fixation. On the Botticino extractive basin, it is usually absent during the first and intermediate phase of the recolonization, but it is a typical species of the local grasslands that can be used as reference for the restoration.

B. erectus (Poaceae) is a perennial tussock (H caesp) of 40-60 cm, which grows on sunny environment with frequent clouds of the temperate zone (mostly low mountain; 0-1600 m a.s.l.). It prefers arid and dry environments and calcareous substrates poor of nutrients, such as arid grasslands (Pignatti 1982; Pignatti et al. 2005). The root system is fasciculated and composed by thick, dense and fibrous primary roots which anchored the plants to the soil. On the Botticino extractive basin, it is usually absent during the first and intermediate phase of the recolonization, but it is a typical species of the local grasslands that can be used as reference for the restoration.

S. recta (Lamiaceae) is an erect leafy perennial herb (H scap) of 20-40 cm, which grows on sunny environment (but even where light is reduced) of the temperate zone (0-2100 m a.s.l.). It prefers arid and dry environments and marked basic substrates even very poor of nutrients, such as rocks, heaps of stones and arid grasslands (Pignatti 1982; Pignatti et al. 2005). The root system is characterized by a main tap root that anchor the plant in a central position and many lateral roots acting as guys. On the Botticino extractive basin, it is present in all the phases of the recolonization, and especially on recent dump deposits abandoned from 1-10 years.

Sampling. For the root tensile strength tests, we sampled about 25 individuals of *A. vulneraria* on dump deposits of a working quarry (coordinates: 1607763-5047960; altitude: 641 m a.s.l. aspect: 69°; slope: 26°) characterized by high stoniness (50%, with stones of 1-60 cm) and by a ruderal vegetation typical of the pioneer phases of recolonization, with low vegetation cover (20%), only made by shrub (13%) and herb (7%) layers. We sampled about 25 individuals of *B. erectus* and *S. recta*, respectively, on similar dump deposits (coordinates: 1607763-5047960, altitude: 219 m a.s.l., aspect: 212°, slope: 41°), with lower stoniness (10%, with stones of 1-30 cm), higher rockiness (50%) and low vegetation cover (20%) only made by shrub (8%) and herb (12%) layers. In order to avoid the effect of temporal variability, we collected all the species almost at the same time by digging pits till a depth sufficient to include the whole root system.
In order to analyze the architecture of the root systems, we sampled 10 individuals of each species from the same sites, together with a soil parallelepiped deep 30 cm around the root system (about 30x15x15 cm), according to the fact that grasses have 75% of root biomass in the first 30 cm of soil (Jackson et al. 1996). In the study area, such depth can be considered sufficient to reach the discontinuity surface between the added topsoil and the substrate.

Tensile strength tests. We gently separated collected roots from soil by hand, we repeatedly washed them with jets of water and stored in 15% alcoholic solution in order to prevent mould and microbial degradation (Mattia et al. 2005). As soon as possible, we carried out 421 tensile strength tests on 15 cm long root samples, after having measured the diameter in the midpoint and at the endpoints: we analyzed 35 samples (17 individuals) for *A. vulneraria*, 262 samples (13 individuals) for *B. erectus* and 124 samples (23 individuals) for *S. recta*. We performed the tests by the Stable Micro System TA Hd Plus apparatus (load cell of 500 N, noise of 0.01%) at the CIRA laboratory of the University of Milan (Fig. 2), by using two non-serrated clamps specifically developed by the Institute of Agricultural Hydraulics of the University of Milan (Bischetti et al. 2003). Taking into account that the root tensile strength increase from 8% to 20% when the displacement rate increases drastically from 10 to 400 mm min^{-1} (Cofie and Koolen 2001), we used a constant speed of 10 mm min^{-1}, according to previous studies (Mattia et al. 2005). We do not considered samples that broke at the proximity of the clamps (50 tests, i.e. 11.88% of the total tests) because probably connected with the presence of damages of the root structure (e.g. Cofie and Koolen 2001; Mattia et al. 2005; De Baets et al. 2008).

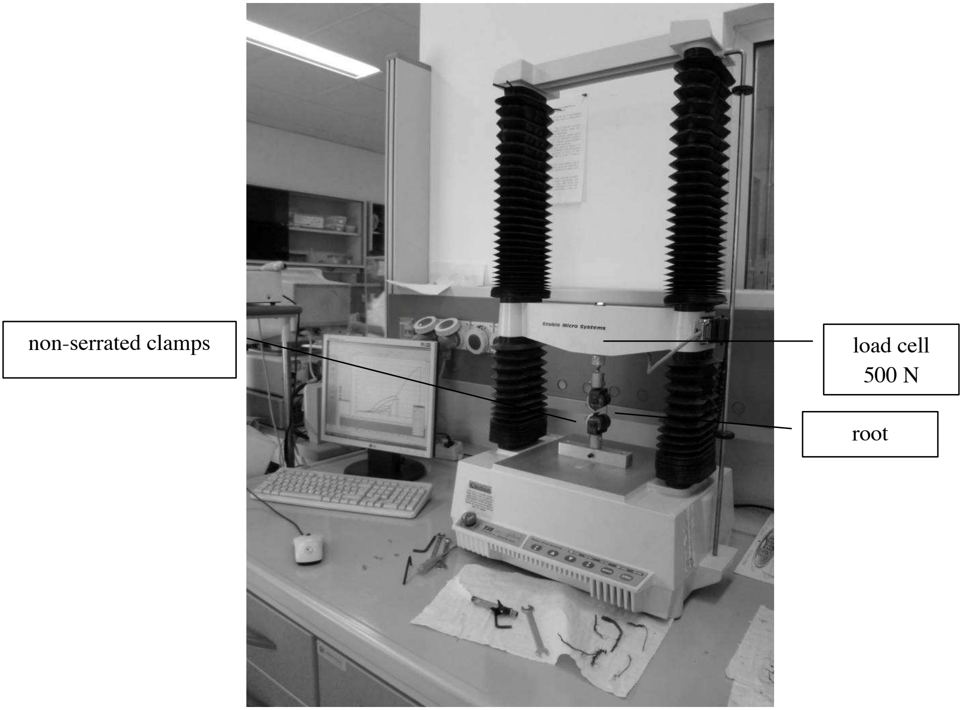

Fig. 2 Stable Micro System TA Hd Plus apparatus and non-serrated clamps constituted by a cylinder with a groove in the centre to hold the roots, which are rolled up for three quarters of their length and fastened by a semicircular plate screwed to the cylinder (CIRA laboratory of the University of Milan)

Data were acquired at 200 Hz and then elaborated by Texture Exponent 32 software; the tensile strength values T_r (MPa) were obtained as (Bischetti et al. 2003; De Baets et al. 2008):

$$T_r = \frac{F_{\max}}{\pi(D/2)^2}$$

where F_{max} is the maximum registered load (N) and D is the mean root diameter (mm).
In order to detect differences according to root diameter, we grouped analyzed data into 7 classes of root diameter: <0.1, 0.1-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, 2.0-3.0, >3.0 mm.
Before proceeding with the statistical analysis (made by PAST 2.14), we log-transformed data. In order to test the normality of the data at 1% of significance, we performed the Kolmogorov-Smirnov test (ks-test). We used the analysis of the covariance (ANCOVA), taking into account the root diameter as covariate factor, to test the differences between the tensile strength of the three species.

"Root Volume Ratio" evaluation. We separated roots firstly by use of jets of water and sieves with grid of 4.75, 2, 1 and 0.5 mm in order to remove soil and limestone debris; in a basin with water, we then remove all the organic matter different from alive roots (e.g. fragments of leaves, stems, invertebrates, partially decomposed organic matter, dead roots) by means of tweezers. Thus, we weighted the roots and stored them in distilled water.
Considering that the digital images acquisition and elaboration is a developing technique for estimating root area and volume (Tagliavini et al. 1993; Ortiz-Ribbing & Eastburn 2003), a part of the sampled roots were weighted and then acquired by means of Winrhizo at the laboratory of "ECOBIO" Université de Rennes 1 - CNRS. We acquired data according to 16 classes of root diameter, i.e. each 0.1 mm for roots with diameter under 1 mm, and then according to the following classes: 1.0-1.5, 1.5-2.0, 2.0-2.5, 2.5-3.0, 3.0-4.0, >4.0 mm. For the following analysis, we classified data according to the classification used for the tensile strength tests. On the basis of the weight of the scanned and not scanned roots, we calculated the total volume of the roots and thus, the Root Volume Ratio (RVR) as:

$$RVR = V_r / V$$

where: Vr is the total volume occupied by roots, and V is the total volume investigated.

Root cohesion evaluation. The most simple model for the calculation of root cohesion is the W&W model (Wu 1976; Waldron 1977), that is based on the assumption that roots are cylindrical, elastic and perpendicular to the shear surface. Thus, taking into account the variability of root diameter, the maximum potential reinforcement (i.e. the maximum root cohesion) can be calculated as (Bischetti et al. 2009):

$$c_r = k'k''\sum_{i=1}^{N}(T_r a_r)_i$$

where:

- k' is the factor accounting for the decomposition of root tensile strength according to the bending angle of roots with respect to the shear plane, i.e. $(\cos\theta\tan\phi + \sin\theta)$ where Φ is the soil friction angle, θ is the angle of root deformation from the vertical;
- k'' is a factor accounting that roots do not break simultaneously;
- T_r is the tensile strength of the roots, specified per root with diameter class i;
- a_r is the ratio between the root area and the rooted soil cross sectional area, specified per diameter class i;
- N is the number of diameter classes considered.

We attributed the value "1" to the coefficient k', because of the uncertainty of the root distortion angle and considering that in most real cases (with reliable values of 40°<θ<90° and 25°<φ<40°), k' varies between 1.0 and 1.3, and that values of 1.15 (Waldron 1977) or 1.2 (Wu et al. 1979) could cause an overestimation of root cohesion (Bischetti et al. 2009).
k'' is an empirical factor that was introduced in order to reduce the overestimation of the root cohesion connected to the W&W model. Hammond et al. (1992) proposed a reduction factor of 0.56 for forest vegetation; nevertheless, lower values were observed for herbaceous

plant species and very young trees (e.g. Waldron and Dakessian 1981; Docker and Hubble 2008), thus we considered k''=0.4, according to previous studies (Preti 2006; Ji 2012).
In a typical fasciculated root system (Fig. 3b), we can assume that all roots intersect perpendicularly the shear surface at 30 cm of depth. We made the same assumption for tap roots (Fig. 3a), taking into account that the calculated root cohesion will be overestimated.

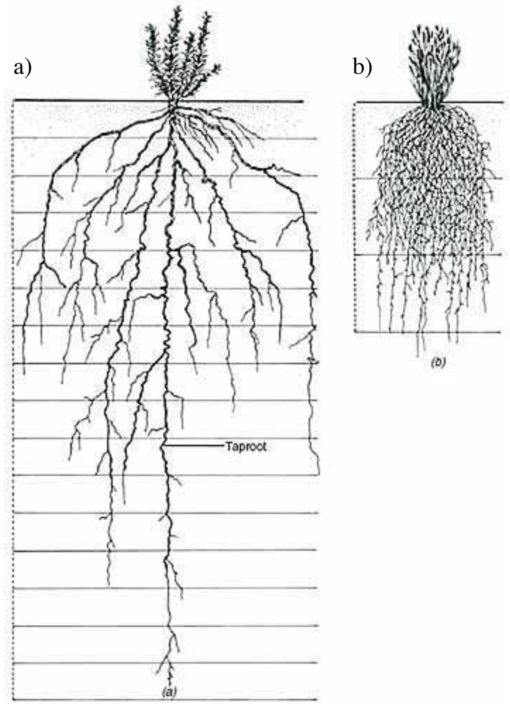

Fig. 3 Two types of root systems, as represented by two prairie plants: a) tap root system of a dicot, and b) fasciculated root system of a monocot. Each horizontal line correspond to 1 foot, i.e. about 30.5 centimeters (from: Raven et al. 1999)

Thus, stated that all the roots in the sampled soil volume are considered in the model, we can replace the ratio between the root area and the rooted soil cross sectional area (a_r) with the ratio between the root volume and the rooted soil volume (RVR). Thus, we can calculated the root cohesion as the sum of the product of the tensile strength and the RVR of the roots of each class of diameter, i.e. as:

$$c_r = k'k''\sum_{i=1}^{N}(T_r RVR_r)_i$$

Results

Tensile strength tests. The root tensile strength of the three species strongly decreased with root diameter according to a potential curve (Fig. 4), with a similar behavior of tree and shrub species (e.g. Mattia et al. 2005; Tosi 2007; De Baets et al. 2008; Comino & Marengo 2010). Thus, the root tensile strength (T_r) can be expressed as (e.g. Gray and Sotir 1996; Bischetti et al. 2005; Genet et al. 2005):

$$T_r(d) = ad^{-b}$$

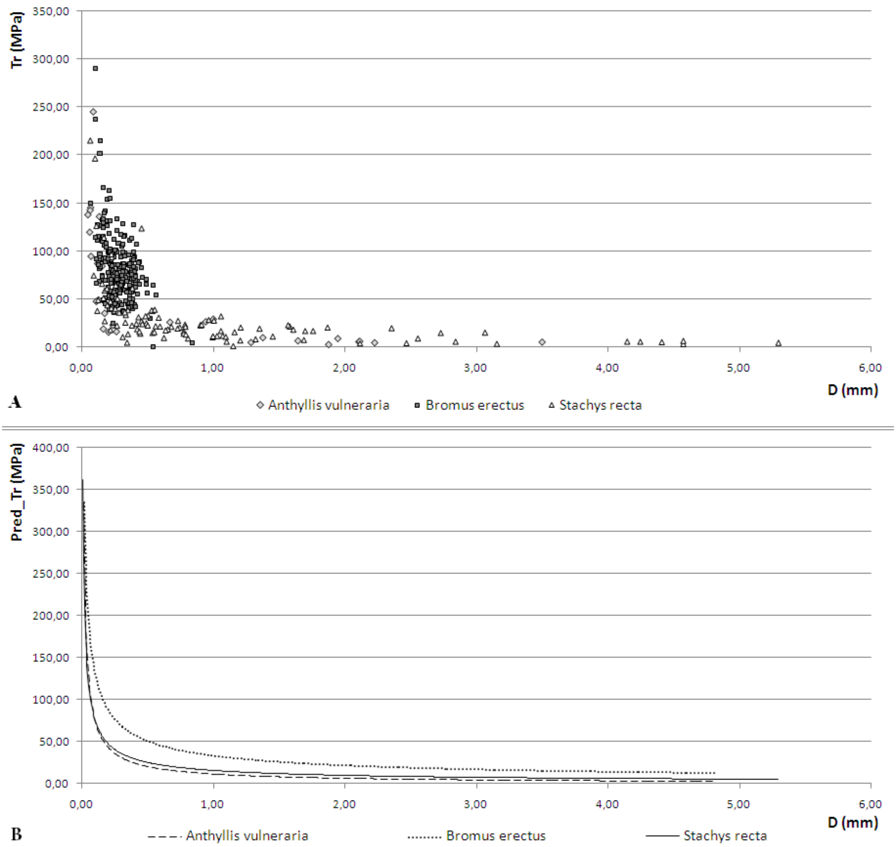

Fig. 4 A) Measured root tensile strength (T_r) and B) predicted values of root tensile strength (Pred_T_r) against root diameter (D)

The parameter a and b are species-specific (Table 1). In particular, *B. erectus* showed high *a* value and low *b* value, and its roots were significantly stronger than those of the other species ($F=49.11$, $p<0.001$, ANCOVA).

		A. vulneraria	*B. erectus*	*S. recta*
Number of valid tests		28/35	236/262	107/124
Lenght of the root (cm)	Mean	16.59	19.20	17.81
	St.dev	3.66	4.85	3.28
Mean diameter of the entire root (mm)	Mean	0.98	0.29	1.24
	St.dev	1.13	0.10	1.30
Mean diameter of the tested root (mm)	Mean	0.86	0.29	1.02
	St.dev	0.98	0.10	1.10
Max diameter of the tested roots (mm)		3.50	0.84	5.30
Min diameter of the tested roots (mm)		0.05	0.07	0.07
Root tensile strength (Mpa)	Mean	55.19	81.41	30.99
	St.dev	61.51	34.43	34.28
	Max	244.90	290.21	215.54
	Min	3.28	0.17	1.06
A		**11.88**	**33.30**	**15.27**
B		**-0.81**	**-0.61**	**-0.71**
adjusted R^2		0.82	0.16	0.59
p (ks-test)		<0.001	<0.001	<0.001

Table 1 Parameters (a and b values) and R^2 for the relation among root tensile strength and root diameter

Such a relationship was also evident by the analysis of the root tensile strength according to the diameter classes (Fig. 5).

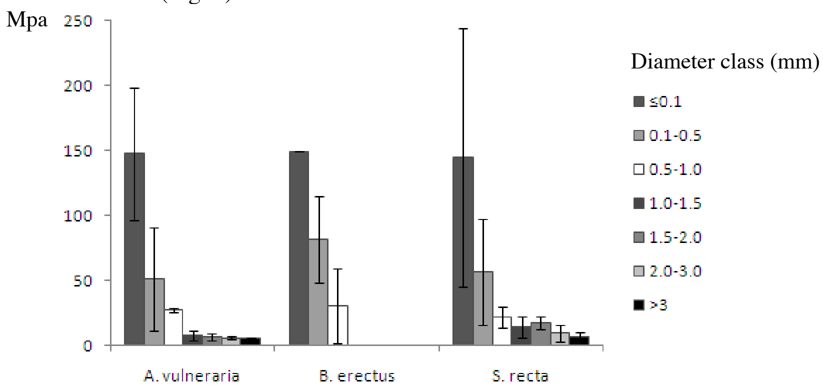

Fig. 5 Root tensile strength (Mpa) according to diameter classes (mm)

"Root Volume Ratio" evaluation. *B. erectus* showed the highest RVR, while the lowest values were calculated for *A. vulneraria*. As expected, the volume of the roots of different diameter reflected the type of root: the central tap root of *A. vulneraria* occupied the most rooted volume, while the fasciculated root system of *B. erectus* was mostly made by roots with diameter between 0.1 and 1.5 mm. Most rooted volume in *S. recta* was made by the primary root (diameter >3 mm), and secondly by the thinner roots with diameter between 0.1-0.5 mm occupy the most volume (Fig. 6).

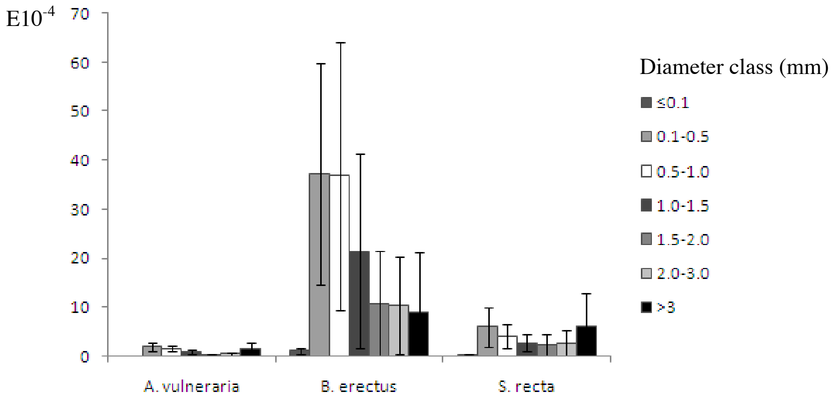

Fig. 6 RVR according to class of diameter (mm)

We recorded the highest value of total RVR in *B. erectus*, that was 0.012674 (±0.009401) and the lowest in *A. vulneraria*, i.e. 0.000752 (±0.000256); total RVR in *S. recta* was 0.002416 (±0.001113).

Root cohesion evaluation. The highest contribution to root cohesion was due to roots with diameter between 0.1-0.5 mm and secondly to those with diameter between 0.5-1.0 mm (Fig. 7). As for the total additional root cohesion ensured by the three species (all roots considered), we calculated the highest values of root cohesion for *B. erectus* (0.1740 Mpa), and secondly for *S. recta* (0.0243 Mpa); on the other hand, soil reinforcement by *A. vulneraria* was very low (0.0078 Mpa).

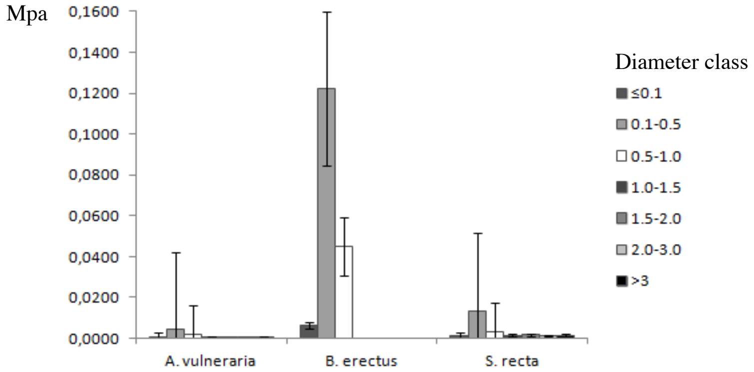

Fig. 7 Root cohesion (MPa) according to diameter classes (mm)

Results were comparable with previous studies on herbaceous species (Table 2).

Species	**D (mm)**	**A**	**b**	**Tr mean (Mpa)**	**RAR (%)**	**Root cohesion (MPa)**	**Author**
Herbaceous vegetation	<10				0.02-0.08		A
Ammophila spp.						0.005-0.010	B
Ammophila spp.	<0.3				0.015-0.15		C
Atriplex halimus	1.9 (0.8)	73	0.6	57.2 (23.1)			D
Avenula bromoides	0.15–0.32	4.77	–1.52		0.0033		E
Brachypodium retusum	0.10–1.45	45.05	–0.61				E
Helictotrichon filifolium	0.34–1.22	14.51	–1.08		0.0046		E
Hordeum vulgare	<0.5				0.002-0.008		B
Hordeum vulgare	<0.5				0.14-0.93		F
Hordeum vulgare						0.001-0.0025	B
Juncus acutus	0.18–1.10	23.23	–0.89			0.244-0.304	E
Limonium supinum	0.34–3.90	33.82	–0.85		0.00125		E
Lygeum spartum	0.26–2.72	19.28	–0.68		0.002575		E
Lygeum spartum	1.3-1.7	60.7	1.3	37.8 (12.5)			D
Phragmites australis	0.10–7.91	34.29	–0.78				E
Piptatherum miliaceum	0.10–0.64	11.49	–1.77				E
Plantago albicans	0.21–2.55	16.75	–0.52				E
Stipa tenacissima	0.43–1.34	24.34	–0.61				E

Table 2 Literature data on root tensile strength, RAR and root cohesion of herbaceous species; Legend author: A: Schiechtl 1980; B: Waldron 1977; C: Wu 1984; D: Mattia et al. 2005; E: de Baets et al. 2008; F: Mehegan et al 1978

Discussion and conclusion

At small spatial scale, the identification of the most suitable species to ensure slope stability is crucial for a successful environmental restoration especially in quarry areas after their abandonment, where the lack of a continuous topsoil layer may favor slope instability (Rickson et al. 2006). For this reason our results highlight that species-specific laboratory analysis are fundamental (e.g. Riestenberg & Sovonick-Dunford 1983): the W&W model (modified) can furnish some basic information about the root cohesion of herbaceous species, obtaining comparable results with literature data. Unless such a simple model can be improved, for example by using the more advanced Root Bundle Model (RBM; e.g. Schwarz et al. 2010), its application has a great relevance in the planning of the restoration of quarries.

The results regarding root tensile strength showed that the behavior of the roots of herbaceous species was similar to that one of the shrub and tree species: when subjected to shear forces, they can stretch, slip or break (e.g. Ennos 1989; Abe and Ziemer 1991). Our study underlined that the tensile strength decreases with increasing root diameter according to a potential curve (e.g. Hathaway & Penny 1975; Yang et al. 2006; Tosi 2007; Bischetti et al. 2009; Comino & Marengo 2010). Small flexible roots (diameter between 0.1 and 1.0 mm in our study) increase the soil-fibre strength thanks to the mobilization of their tensile strength by root-soil friction, according to previous studies (Waldron 1977; Gray & Leiser 1982). In tree and shrub species, such a behavior is connected to differences in root structure and especially to the higher content of cellulose in fine roots (Genet et al. 2005). The relationship among root tensile strength and root diameter also shows a certain degree of variability, which is species-specific and could be also due to root characteristics (e.g. morphology, architecture, age and growth rate), which are also affected by the root immediate environment. In quarry areas such a variability may depend on soil moisture (especially during and after intense precipitations), soil texture (presence of debris), nutrient availability, fertility and soil acidity, root orientation upstream/downstream (e.g. Hathaway & Penny 1975; Genet et al. 2005), besides used methods, instruments and sampling conditions, such as season and moisture (e.g. Makarova et al. 1998; De Baets et al. 2008).

The magnitude of root reinforcement is also correlated to the morphological characteristics of the root system, such as the root distribution with depth and over different root diameter classes, root tortuosity and number of root branches, root-soil interface friction and the orientation of roots to the principal direction of strain (e.g. Riestenberg 1994; Abernethy & Rutherford 2001). In general, the volume of the roots has a great spatial heterogeneity, since it is widely affected by the interaction among the genetic species characteristics (that determine the potential morphology of the root system, e.g. fasciculated or taproot; e.g. Abe and Ziemer 1991; Schmid & Kadza 2002) and the environmental conditions, such as climate, land use, vegetation and plant competition, randomness, root environment (e.g. texture, structure, moisture, nutrient and oxigen availability, temperature, mechanical

obstacles, soil depth; e.g. Sainju & Good 1993; Jackson et al. 1996). Root environment is not homogeneous in quarry areas, that present a high geomorphological heterogeneity, both at small and large scale. In general, we can identify three main artificial geomorphological features that are characterized by different environmental conditions: dump deposits, artificial cliffs and platforms. Since we collected all the individuals on dump deposits, our results can be considered representative only of such a geomorphological surface and only for the study area. On the contrary, deeper analysis are needed for artificial cliffs and platform, where the architecture of the root systems could vary a lot according to the different abiotic limits (e.g. water and nutrient availability, soil texture).
As regards root cohesion, the absolute calculated values of our analyses are hard to compare with previous studies, since most of them deal with tree and shrub species and/or most of them have been calculated for alien species in environmental conditions different from those that can be found in quarries (e.g. Abe and Ziemer 1991; Tosi 2007). In general, it should be taken into account that a) the tensile strength required to break a root is generally greater in laboratory than in situ tests (Tosi 2007) and that b) the maximum tensile strength of the whole root system is not the sum of the root tensile strength of every single root, but only of those that are effectively mobilized in relation to slide surface. Stated this, and considering that we hypothesized that all the roots intersect the shear surface for the calculation of root cohesion, our results could overestimate the total reinforcement by the roots of the analyzed species, especially of those with a taproot system (*A. vulneraria* and *S. recta*). Even more so, the fasciculated root system of *B. erectus* showed the highest values of root cohesion.
For the dump deposits of the limestone quarries of the Botticino extractive basin, we recommended the use of species with a fasciculated root system such as that one of *B. erectus* in order to guaranty slope stability on short and long term. Moreover, species with different type of root system can be also used in order to guaranty a more effective control of superficial mass movement thanks to a differentiated species-specific contribution.

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References

1. Abe K., Ziemer R.R. 1991. Effect of tree roots on a shear zone: modeling reinforced shear stress. Canadian Journal of Forest Research 21: 1012-1019
2. Abernerthy B., Rutherfurd I.D. 2001. The distribution and strength of riparian tree roots in relation to riverbank reinforcement. Hydrological Processes 15: 63-79
3. Baroni C., Bruschi G., Ribolini A., 2000. Human-induced hazardous debris flows in Carrara marble basins (Tuscany, Italy). Earth Surface Processes and Landforms 25: 93–103.

4. Bernini F., Di Fidio M., Villa M. 2003. Operatore nei cantieri d'ingegneria naturalistica. Quaderni della Scuola d'Ingegneria Naturalistica 2. Scuola Regionale di Ingegneria Naturalistica, Centro Regionale per la Flora Autoctona. 177 pages
5. Bischetti G.B. 2003. Il ruolo della vegetazione nella stabilità dei versanti. Quaderni della Scuola di Ingegneria Naturalistica 1. Scuola Regionale di Ingegneria Naturalistica, Centro Regionale per la Flora Autoctona. 45 pages
6. Bischetti G.B., Chiaradia E.A., Simonato T., Speziali B., Vitali B., Vullo P., Zocco A. 2005. Root strength and root area ratio of forest species in Lombardy (Northern Italy). Plant and Soil 278: 11-22
7. Bischetti G.B., Chiaradia E.A., Epis T., Morlotti E. 2009. Root choesion of forest species in the Italian Alps. Plant Soil 324: 71-89
8. Carrick P.J., Krüger R. 2007. Restoring degraded landscapes in lowland Namaqualad: lessons from the mining experience and from regional ecological dynamics. Journal of Arid Environments 70: 767-781
9. Clerici A., Meda A. 2005. Confronto tra le caratteristiche meccaniche di diversi livelli di estrazione del Botticino Classico. Giornale di Geologia Applicata 2: 307-312
10. Cofie P., Koolen A.J. 2001. Test speed and other factors affecting the measurements of tree root properties used in soil reinforcement models. Soil & Tillage Research 63: 51-56
11. Comino E., Marengo P. 2010. Root tensile strength of three shrub species: Rosa canina, Cotoneaster dammeri and Juniperus horizontalis. Catena 82: 227-235
12. Davoudi M.H. 2011. Influence of willow root density on shear resistance parameters in fine grain soils using in situ direct shear tests. Research Journal of Environmental Sciences 5 (2): 157-170
13. De Baets S., Poesen J., Knapen A., Barberá G.G., Navarro J.A. 2007. Root characteristics of representative Mediterranean plant species and their erosion-reducing potential during concentrated runoff. Plant Soil 294: 169-183
14. De Baets S., Poesen J., Reubens B., Wemans K., De Baerdemaeker J., Muys B. 2008. Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength. Plant Soil 305: 207-226
15. Docker B.B., Hubble T.C.T. 2008. Quantifying root-reinforcement of river bank soils by four Australian tree species. Geomorphology 100: 401-418
16. Ennos A.R. 1989. The mechanics of anchorage in seedlings of sunflowers, Helianthus annuus L. New Phytologist 113: 185-192
17. Genet M., Stokes A., Salin F., Mickovski S.B., Fourcaud T., Dumail J.-F., van Beek R. 2005. The influence of cellulose content on tensile strength in tree roots. Plant and Soil 278: 1-9
18. Gentili R., Sgorbati S., Baroni C. 2011. Plant species patterns and restoration perspectives in the highly disturbed environment of the Carrara marble quarries (Apuan Alps, Italy). Restoration Ecology Vol. 19 No. 101: 32-42
19. Gray D.H., Leiser A.T. 1982. Biotechnical slope protection and erosion control. Van Nostrand Reinhold, New York. 271 pages
20. Gray D.H., Sotir R.B. 1996. Biotechnical and soil bioengineering slope stabilization. A practical guide for erosion control. John Wiley & Sons Inc. 381 pages

21. Gyssels G., poesen J., Bochet E., Li Y. 2005. Impact of plant roots on the resistance of soils to erosion by water: a review. Progress in Physical Geography 29(2): 189-217
22. Hathaway R.L., Penny D. 1975. Root strength in some Populus and Salix clones. New Zealand Journal of Botany 13: 333-344
23. Istanbulluoglu E., Bras R.L. 2005. Vegetation-modulated landscape evolution: effects of vegetation on lanscape processes, drainage density, and topography. Journal of Geophysical Research Vol. 110 F02012, doi: 10.1029/2004JF000249
24. Jackson R.B., Canadell J., Ehleringer J.R., Mooney H.A., Sala O.E., Schulze E.D. 1996. A global analysis of root distribution for terrestrial biomes. Oecologia 108: 389-411
25. Ji J., Kokutse N., Genet M., Fourcaud T., Zhang Z. 2012. Effect of spatial variation of tree root characteristics on slope stability. A case study on Black Locust (*Robinia pseudoacacia*) and Arborvitae (*Platycladus orientalis*) stands on the Loess Plateau, China. Catena 92: 139-154
26. Mafian S., Huat B.B.K., Ghiasi V. 2009. Evaluation of root theories and root strength properties in slope stability. European Journal of Scientific Research 30 (4): 594-607
27. Makarova O.V., Cofie P., Koolen A.J. 1998. Axial stress – strain relationships of fine roots of beech and larch in loading to failure and in cyclic loading. Soil & Tillage Research 45: 175-187
28. Morgan R.P.C., Rickson R.J. 1995. Slope stabilization and erosion control. A bioengineering approach. E & FN Spon, an imprint of Chapman & Hall. 293 pages
29. Norris J.E., Stokes A., Mickovski S.B., Cammeraat E., van Beek R., Nicoll B.C., Achim A. 2008. Slope stability and erosion control: ecotechnological solutions. Springer. 287 pages
30. Ortiz-Ribbing L.M., Eastburn D.M. 2003. Evaluation of digital image acquisition methods for determining soybean root characteristics. Online. Crop Management doi:10.1094/CM-2003-0702-01-RS
31. Pignatti S. 1982. Flora d'Italia. Edagricolae, Bologna. 3 Volumes.
32. Pignatti S. Menegoni P., Pietrosanti S. 2005. Biondicazione attraverso le piante vascolari. Valori di indicazione secondo Ellenberg (Zeigerwerte) per le specie della Flora d'Italia. Braun-Blanquetia 39:1-97
33. Preti F. 2006. On root reinforcement modeling. European Geosciences Union 2006. Geophysical Research Abstracts 8, 04555
34. Raven P.H., Evert R.F., Eichhorn S.E. 1999. Biology of plants, 6th edition. WH Freeman, New York
35. Rickson R.J., Clarke M.A., Owens P.N. 2006. The use of vegetation for erosion control and environmental protection. Earth Surface Processes and landforms 31: 533-535.
36. Riestenberg M.M. 1994. Anchoring of thin colluvium by roots of sugar maple and white ash on hillslopes in Cincinnati. Landslides of the Cincinnati, Ohio, area. U.S. geological Survey Bulletin 2059-E: E1-E25
37. Riestenberg M.M., Sovonick-Dunford S. 1983. The role of woody vegetation in stabilizing scope in the Cincinnati area, Ohio. Geological Society of America Bulletin 94(4): 506-518
38. Sainju U.M., Good R.E. 1993. Vertical root distribution in relation to soil properties in New Jersey Pinelands forests. Plant and Soil 150: 87-97
39. Servizio geologico d'Italia 2008. Carta geologica d'Italia alla scala 1: 50000. Foglio 99 Iseo. Agenzia per la Protezione dell'Ambiente e per I Servizi Tecnici.

40. Schmid I., Kazda M. 2002. Root distribution of Norway spruce in monospecific and mixed stands on different soils. Forest Ecology and Management 159: 37-47
41. Schmidt K.M., Roering J.J., Stock J.D., Dietrich W.E., Montgomery D.R., Schaub T. 2001. The variability of root cohesion as an influence on shallow landslide susceptibility in the Oregon Coast Range. Canadian geotechnical Journal 38: 995-1024
42. Shu W.S., Ye Z.H., Zhang Z.Q., Lan C.Y., Wong M.H. 2005. Natural colonization of plants on five lead/zinc mine tailings in Southern China. Restoration Ecology Vol. 13 No. 1: 49-60
43. Simon A., Collison A.J.C. 2002. quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. Earth Surface Processes and Landforms 27: 527-546
44. Sort X., Alcañiz J.M. 1996. Contribution of sewage sludge to erosion control in the rehabilitation of limestone quarries. Land Degradation & Development 7: 69-76
45. Schwarz M., Cohen D., Or D. 2010. Root-soil mechanical interactions during pullout and failure of root bundles. Journal of Geophysical Research 115, F04035, 19 pages
46. Tagliavini M., Veto L.J., Looney N.E. 1993. Measuring root surface area and mean root diameter od peach seedlings by digital image analysis. Hort Science 28(11): 1129-1130
47. Tosi M. 2007. Root tensile strength relationships and their slope stability implications of three shrub species in the Northern Apennines (Italy). Geomorphology 87: 268-283
48. Waldron L.J., Dakessian S. 1981. Soil reinforcement by roots: calculation of increased soil shear resistance from root properties. Soil Science 132: 427–435
49. Waltron L.J. 1977. The Shear Resistance of Root-Permeated Homogeneous and Stratified Soil. Soil Science Society of American Journal 41(5): 843-849
50. Watson A., Phillips C., Marden M. 1999. Root strength, growth, and rates of decay: root reinforcement changes of two tree species and their contribution to slope stability. Plant and Soil 217: 39-47
51. Wu T.H. 1976. Investigation of landslides on prince of Wales Island, Alaska. Geotechnical Engineering Report, 5° edition. Ohio State University. Department of Civil Engineering. 94 pages
52. Yang Y., Liu S., Wang C., Tang C. 2006. A study on tensile strength tests of arboreous species root system in forest engineering technique of shallow landslide. Wuhan University Journal of Natural Sciences Vol. 11 No. 4: 892-896
53. Ziegler A.D., Giambelluca T.W. 1998. Influence of revegetation efforts on hydrologic response and erosion, Kaho‘Olawe Island, Hawai‘i. Land Degradation and Development 9: 189-206

4.6 Databases consulted, chapter 4

- A.O.P.A. Italia – Aircraft Owners and Pilot Association www.aopa.it
- Database Ufficio Autorizzazione Cave, Settore Ambiente - Provincia di Brescia
- GoogleMaps 2012. Immagini ©2012 Cnes/Spot Image, DigitalGlobe, European Space Imaging, GeoEye, Map Data ©2012 Google http://maps.google.it/maps?hl=it&tab=wl
- Geoportale della Provincia di Brescia. Aspetti morfologici del territorio provinciale. http://sit.provincia.brescia.it/
- Geoportale della Provincia di Brescia. Piano Territoriale di Coordinamento Provinciale vigente, Tavola 2: Paesaggio. Provincia di Brescia, Servizio Cartografia e GIS http://sit.provincia.brescia.it/PTCP
- Geoportale della Regione Lombardia. Dati, mappe, servizi geografici del territorio lombardo disponibili in rete. Sistema Informativo per la consultazione dell'Infrastruttura per l'Informazione Territoriale della Lombardia. Unità Organizzativa Infrastruttura per l'Informazione Territoriale, Direzione Generale Territorio e Urbanistica – Regione Lombardia http://www.cartografia.regione.lombardia.it/geoportale/
- Parco delle Colline di Brescia. Path map of the PLIS "Parco delle Colline di Brescia". http://www.comune.brescia.it/Eventi/Servizi+al+Cittadino/vivere+l+ambiente/il+parco+delle+colline/
- Servizio Meteorologico Regionale - Arpa Lombardia http://ita.arpalombardia.it/meteo/meteo.asp
- Seed Information Database. Kew Royal Botanic Gardens http://data.kew.org/sid/sidsearch.html

4.7 References, chapter 4

- Alegre J., Alonso-Blázquez N., de Andrés E.F., Tenorio J.L., Ayerbe L. 2004. Revegetation and reclamation of soils using wild leguminous shrubs in cold semiarid Mediterranean conditions: litterfall and carbon and nitrose returns under two aridity regimes. Plant and Soil 263: 203-212
- Andreis C., Levy C., 1988. Criteri per la scelta degli alberi ornamentali su basi autoecologiche. Acer, 6: 21-25.
- Auz F.F., Ferraz I.D.K. 2011. Seed size influence on germination reponses to light and temperature of seven pioneer species tree species from Central Amazon. Anais d Academia Brasileira de Ciências 84(3): 759-766
- Azcón R., Barea J.M. 1997. Mycorrhizal dependency of a representative plant species in Mediterranean shrublands (Lavandula spica L.) as a key factor to its use for revegetation strategies in desertification-threatened areas. Applied Soil Ecology 7: 83-92
- Barsoum N., 2002. Relative contributions of sexual and asexual regeneration strategies in Populus nigra and Salix alba during the first years of establishment on a braided gravel bed river. Evolutionary Ecology 15: 255-279
- Bernini F., Di Fidio M., Villa M. 2003. Operatore nei cantieri d'ingegneria naturalistica. Quaderni della Scuola d'Ingegneria Naturalistica 2. Scuola Regionale di Ingegneria Naturalistica, Centro Regionale per la Flora Autoctona. 177 pages

- Bischoff A., Vonlanthen B., Steinger T., Müller-Schärer H. 2005. Seed provenance matters – effects on germination of four plant species used for ecological restoration. Basic and Applied Ecology 7: 347-359
- Bradshaw R.H.W. 2004. Past anthropogenic influence on European forests and some possible genetic consequences. Forest Ecology and Management 197: 203-212
- Braun-Blaunquet J. 1928. Pflanzensoziologie. Sprinter, Verl. Wien; II ed. nel 1951, III ed. nel 1964. Schippmann U., 1991- Revisionder europaischen Arten der Gattung Brachypodium Palisot de Beauvois. Boissiera, Genève, 45.1-249
- Celesti-Grapow L., Alessandrini A., Arrigoni P.V., Banfi E., Bernardo L., Bovio M., Brundu G. Cagiotti M.R., Camarda I., Carli E., Conti F., Fascetti S., Galasso G., Gubellini L., La Valva V., Lucchese F., Marchiori S., Mazzola P., Peccenini S., Poldini L., Pretto F., Prosser F., Siniscalco C., Villani M.C., Viegi L., Wilhalm T., Blasi C. 2009. Inventory of the non-native flora of Italy. Plant Biosystem Vol. 143, No. 2: 386-430
- Chosa J.A., Shetron S.G. 1976. Use of willow cuttings to revegetate the "slime" areas of iron mine tailings basins. Research Notes 21: 1-5
- Claassen V.P., Hogan M.P. 2002. Soil nitrogen pools associated with revegetation of disturbed sites in the Lake Tahoe area. Restoration Ecology 10(2): 195-203
- Conedera M., Krebs P., Tinner W., Pradella M., Torriani D. 2004. The culòtivation of Castanea sativa (Mill.) in Europe, from its origin to its diffusion on a continental scale. Veget Hist Archaeobot 13: 161-179
- Decreto Ministeriale 13/09/1999. Approvazione dei "Metodi ufficiali di analisi chimica del suolo. Gazzetta Ufficiale Supplemento Ordinario no. 248 del 21/10/1999
- Decreto Ministeriale 25/03/2002. Rettifiche al decreto ministeriale 13 settembre 1999 riguardante l'approvazione dei metodi ufficiali di analisi chimica del suolo. Gazzetta Ufficiale no. 84 del 10/04/2002
- Deliberazione Consiglio Regionale 21 dicembre 2000 n. VI/120 – Nuovo Piano delle attività estrattive della Provincia di Brescia - settori argille, pietre ornamentali e calcari, ai sensi dell'art. 8 della l.r. n. 14/1998. Bollettino Ufficiale della Regione Lombardia 20 marzo 2001, n. 12, 1° supplemento straordinario
- De Carli C., Tagliaferri F., Bona E. 1999. Atlante corologico degli alberi e degli arbusti del territorio bresciano (Lombardia Orientale). Monografie di Natura Bresciana 23. 183 pag.
- Del Favero R. 2002. I tipi forestali nella Regione Lombardia. Regione Lombardia, Progetto Strategico 9.1.6. Azioni di salvaguardia e valorizzazione del patrimonio boschivo. 219 pag.
- Díaz M., Carbonell R., Santos T., Tellería J.L. 1998. Breeding bird communities in pine plantations of the Spanish plateaux: biogeography, landscape and vegetation effects. Journal of Applied Ecology 35: 562-574
- Ellenberg H. 1974. Zeigerwerte der Gefässpflanzen Mitteleuropas. Scripta Geobot. 9. Göttingen, 1974. 2. Aufl. (1979). 3. Aufl. (1992) in Ellenberg H. et al., Scripta Geobot. 18: 9-166.
- Elseroad A.C., Fulé P.Z., Covington W.W. 2003. Forest road revegetation: effects of seeding and soil amendments. Ecological Restoration 21(3): 180-185
- ENSCONET (European Native Seed Conservation Network) 2009. Manuale per la raccolta dei semi delle piante spontanee. 36 pag.

- FAO 2006. Guidelines for soil description. Fourth edition, Rome 97 pages
- Ferrario A. 2011. Impiego di fiorume (hay-seed) in interventi di conservazione e ripristino ambientale nella fascia monatno-alpina delle Alpi Lombarde. Tesi di Laurea, anno accademico 2010-2011; relatore: Cerabolini B.E., correlatore: Ceriani R.M. Università degli Studi dell'Insubria, Facoltà di Scienze Matematiche, Fisiche e Naturali, Corso di Laurea in Analisi e Gestione delle Risorse Naturali
- Florineth F. 2007. Piante al posto del cemento. Manuale di ingegneria naturalistica e verde tecnico. Il verde editoriale, 280 pages
- Franco A.A., De Faria S.M. 1997. The contribution of N2-fixing tree legumes to land reclamation and sustainability in the Tropics. Soil Biology & Biochemistry 29(5/6): 897-903
- Gallinaro N. (a cura di), 2004. Boschi di Lombardia. Un patrimonio da vivere. Regione Lombardia, Cierre Edizioni, 155 pages
- Garden D., Jones C., friend D., Mitchell M., Fairbrother P. 1996. Regional research on native grasses and native grass-based pastures. New Zealand Journal of Agricultural Research 39: 471-485
- Garcia X., Hong T.D., Ellis R.H. 2005. Seed dormancy and germination of Ficus lundellii and tropical forest restoration. Tree physiology 26: 81-85
- Groppali R., D'Amico G., Riccardi C. 2008. Osservare gli insetti, farfalle e libellule del Parco Adda Sud. Atlante-guida per la fruizione della fauna minore nell'area protetta. Parco Adda Sud. Conoscere il Parco 6: 206 pages.
- Guner S., Tilki F. 2009. Dormancy breaking in Cotinus coggygria Scop. Seeds of three provenances. Scientific Research and Essay 4(2): 73-77
- Izquierdo I., Caravaca F., Alguacil M.M., Hernández G., Roldán A. 2005. Use of microbiological indicators for evaluating success in soil restoration after revegetation of a mining area under subtropical conditions. AppliedSoil Ecology 30: 3-10
- Landi R. 1988. Revision of land management systems in Italian hilly area. In Schwertman, U., Rickson, J. R., eds. Soil erosion protection measures in Europe. Freising (Catena Verlag), pp. 175-188
- Landolt E. 1977. Oekologische Zeigerwerte zur Schweizer Flora. Veroffentlichhungen des Geobotanischen Instituts der ETH, 64. Heft, Stiftung Rubel, Zurich.
- Loch D.S., Johnston P.W., Jensen T.A., Harvey G.L. 1996. Harvesting, processing, and marketing Australian native grass seeds. New Zealand Journal of Agricultural Research 39: 591-599
- López-García M.C., Maillet J. 2005. Biological characteristics of an invasive south African species. Biological Invasions 7: 181-194.
- Ke X., Li W. 2006. Germination requirements of Vallisneria natans seeds: implications for restoration in Chinese lakes. Hydrobiologia 559: 357-362
- Maiti S.K., Ghose M.K. 2005. Ecological restoration of acidic coal-mine overburden dumps – an Indian case study. Land Contamination & Reclamation 13(4): 361-369
- Martínez-Ruiz C., Fernández-Santos B., Putwain P.D., Fernández-Gómez M.J. 2007. Natural and man-induced revegetation on mining wastes: changes in the floristic composition during early succession. Ecological Engineering 30: 286-294.

- Minelli A. (a cura di) 2005. I prati aridi. Coperture erbacee in condizioni critiche. Quaderni habitat. Ministero dell'Ambiente e della Tutela del Territorio, Museo Friulano di Storia Naturale – Comune di Udine. 159 pages
- Müller-Schneider, P. 1986. Verbreitungsbiologie der Blütenpflanzen Graubündens. Veröff. Geobot. Institute ETH, Stiftung Rübel, Zurigh, 85. 268 pages.
- Muzzi E., Rossi G. 2003. Il recupero e la riqualificazione ambientale delle cave in Emilia-Romagna. Manuale teorico-pratico. Regione Emilia-Romagna. Bologna, 491 pages
- Nodari S. 2006. I prati secchi delle Prealpi lombarde orientali: sin tassonomia, sinecologia e caratterizzazione fitogeografica. Tesi di Laurea, anno accademico 2005-2006; relatore: Andreis C., correlatore: Armiraglio S., Martini F. Università degli Studi di Milano, Facoltà di Scienze Matematiche, Fisiche e Naturali
- Orth R.J., Harwell M.C., Bailey E.M., Bartholomew A., Jaward J.T., Lombana A.V., MooreK.A., Rhode J.M., Woods H.E. 2000. A review of issues in seagrass seed dormancy and germination: implications for conservation and restoration. Marine Ecology Progress Series 200:277-288
- Parrotta J.A., Knowles O.H. 2001. Restoring tropical forests on lands mined for bauxite: examples from the Brazilian Amazon. Ecological Engineering 17: 219-239
- Patzelt A., Wild U., Pfadenhauer J. 2001. Restoration of wet fen meadows by topsoil removal: vegetation development and germination biology of fen species. Restoration Ecology 9(2): 127-136
- Perelli M. 1987. Le analisi del terreno. L'informatore agrario 6: 35-56
- Pesci I. 2004. Il recupero naturalistico delle cave di pietra nel bacino marmifero del Botticino (Brescia). Tesi di Laurea in Scienze e Tecnologie per la Natura. Relatore: Groppali R. Università degli Studi di Pavia, Facoltà di Scienze Matematiche, Fisiche e Naturali
- Pignatti S. 1953. Introduzione allo studio della pianura veneta orientale. Archivio botanico 29: 131-158
- Pignatti S. 1982. Flora d'Italia. Edagricole, Bologna. 3 vol.
- Pignatti S., Menegoni P. Pietrosanti S. 2005. Biondicazione attraverso le piante vascolari. Valori di indicazione secondo Ellenberg (Zeigerwerte) per le specie della Flora d'Italia.
- Ramírez N. 2006. Reproductive biology and plant species selection for habitat restoration in the Venezuelan Gran Sabana Plateau. Interciencia 31(5): 114-124
- Reed D.C., Holbrook S.J., Solomon E., Anghera M. 1998. Studies on germination and root development in the surfgrass Phyllospadix torreyi: implications for habitat restoration. Aquatic Botany 62: 71-80
- Regione Lombardia 2001. Inerbimenti tecnici ad alta quota. Quaderni della Ricerca n. 134 – Settembre 2011. 47 pages
- Reyes O., Trabaud L. 2009. Germination behavior of 14 Mediterranean species in relation to fire factors: smoke and heat. Plant Ecology 202: 113-121
- Rodríguez-Echeverría S., Pérez-Fernández M. 2005. Potential use of Iberian shrubby legumes and rhizobia inoculation in revegetation projects under acidic soil conditions. Applied Soil Ecology 29: 203-208
- Rowley G.D. 1956. Germination in Rosa canina. American Rose Annual 41: 70-73

- Sánchez-Coronado M.E., Coates R., Castro-Colina L., Gamboa de Buen A., Paez-Valencia J., Barradas V.L., Huante P., Orozco-Segovia A. 2007. Improving seed germination and seedling growth of Omphalea oleifera (Euphorbiaceae) for restoration projects in tropical rain forests. Forest Ecology and Management 243: 144-155
- Sharma D., Sunderraj S.F.W. 2005. Species selection for improving disturbed habitats in Western India. Current Science 88(3): 462-467
- Silcock R.G., Johnston P.W. 1993. Tropical pasture establishment. 9. Establishing new pastures in difficult tropical environments – do we expect too much? Tropical Grassland 27: 349-358
- Suardi A. 2005. Il Parco delle Colline di Brescia: un Parco Locale di Interesse Sovracomunale. Tesi di Laurea in Paesaggio, Parchi e Giardini. Università degli Studi di Padova, Facoltà di Agraria. Relatore: Prof. Cattaneo D.
- Università di Milano-Bicocca 2011. Repertorio dei metodi d'analisi; Dipartimento di Scienze dell'Ambiente e del Territorio - Lab protocols
- United States Department of Agriculture (USDA) Soil Survey Staff 2003. Keys to soil taxonomy. 9th edition. Washington DC, Natural Resources Conservation Service, USDA, 322 pages
- Van Assche J.A., Vandelook F.E.A. 2006. Germination ecology of eleven species of Geraniaceae and Malvaceae, with special reference to the effects of drying seeds. Seed Science Research 16: 283-290
- Van der Berg L.J.L., Vergeer P., Roelofs J.G.M. 2003. Heatland restoration in The Netherlands: effects of turf cutting depth on germination of Arnica montana. Applied Vegetation Science 6: 117-124
- Wagner M., Pywell R.F., Knopp T., Bullock J.M., Heard M.S. 2011. The germination niches of grassland species targeted for restoration: effects of seed pre-treatments. Seed Science Research 21: 117-131
- Waters C.M., Loch D.S., Johnston P.W. 1997. The role of native grasses and legumes for land revegetation in central and eastern Australia with particular reference to low rainfall areas. Tropical Grasslands 31: 304-310
- Wilson A.D. 1996. Native and low-input grasses for pastoral and marginal cropping land. New Zealand Journal of Agricultural Research 39: 465-469
- Wilson S.D. 1989. The suppression of native prairie by alien species introduced for revegetation. Landscape and Urban Planning 17: 113-119
- Windsor D.M., Clements A.M. 2001. A germination and establishment field trial of Themeda australis (Kangaroo Grass) for mine site restoration in the Central Tablelands of New South Wales. Restoration Ecology 9(1): 104-110
- Zanotti E. 1996. Prontuario per la scelta e l'impiego razionale degli alberi e degli arbusti più diffuse nella Provincia di Brescia. Provincia di Brescia, Settore ecologia – Ufficio ambiente naturale. 35 pag.

4.8 Appendix chapter 4

Appendix 4.1

Characterization of the experimental site: list of plant species present in the quarry "Ex Sgotti – Cava Alta" (ATE 13/12), in the surroundings of the experimental site

Species	Corology	Biological form
Acer pseudoplatanus L.	European, Caucasian	P scap
Ambrosia artemisiifolia L.	Alien (Canada&USA)	T scap
Anthyllis vulneraria L. (Agg.)	Euri-Mediterranean	H scap
Arenaria serpyllifolia L.	Subcosmopolitan	T scap
Arrhenatherum elatius (L.) Presl	Paleotemperate	H caesp
Artemisia alba Turra	S-European, Sub-Mediterranean	Ch suffr
Artemisia vulgaris L.	Circum-Boreal	H scap
Brachypodium rupestre (Host) R. et S.	Subatlantic	H caesp
Bromus erectus Hudson	Paleotemperate	H caesp
Bromus sterilis L.	Euri-Mediterranean, Turanian	T scap
Buglossoides purpurocaerulea (L.) Johnston	S-European, Pontine	H scap
Bupleurum baldense Turra	Euri-Mediterranean	T scap
Calamintha nepeta (L.) Savi	Euri-Mediterranean Mountain	H scap (Ch suffr)
Campanula sibirica L.	SE-European, S-Siberian	H bienn
Celtis australis L.	Euri-Mediterranean	P scap
Centaurea nigrescens Willd.	European	H scap
Centranthus ruber (L.) DC.	Steno-Mediterannean	Ch suffr
Cephalanthera longifolia (Hudson) Fritsch	Eurasiatic	G rhiz
Cerastium glomeratum Thuill.	Subcosmopolitan	T scap
Cichorium intybus L.	Cosmopolitan	H scap
Cirsium arvense (L.) Scop.	Subcosmopolitan	G rad
Cirsium vulgare (Savi) Ten.	Subcosmopolitan	H bienn
Clematis vitalba L.	European, Caucasian	P lian
Conyza canadensis (L.) Cronq.	Alien (N America)	T scap
Coronilla emerus L.	Centre-European	NP
Cotinus coggygria Scop.	S-European, Turanian	NP/P caesp/P scap
Crepis vesicaria L.	Submediterranean, Subatlantic	T scap/H bienn
Dactylis glomerata L.	Paleotemperate	H caesp
Daucus carota L.	Subcosmopolitan	H bienn (T scap)
Dorycnium pentaphyllum Scop.	Unknown	H scap/Ch suffr
Dryopteris filix-mas (L.) Schott	Subcosmopolitan	G rhiz
Echium vulgare L.	European	H bienn
Epilobium dodonaei Vill.	Orophyte S-European, Caucasian	H scap (Ch frut)
Erigeron annuus (L.) Pers.	Alien (Canada&USA)	T scap

Euphorbia amygdaloides L.	Centre-European, Caucasian	Ch suffr
Euphorbia cyparissias L.	Centre-European	H scap
Fraxinus excelsior L.	European, Caucasian	P scap
Fraxinus ornus L.	Euri-N-Mediterranean, Pontine	P scap/P caesp
Galium lucidum All.	Euri-Mediterranean	H scap
Genista germanica L.	Centre-European	Ch suffr/NP
Geranium robertianum L.	Subcosmopolitan	T scap/H bienn
Geum urbanum L.	Circum-Boreal	H scap
Globularia punctata Lapeyr.	Orophyte S-European	H scap
Helianthemum nummularium (L.) Miller	European, Caucasian	Ch suffr
Hypericum perforatum L.	Cosmopolitan	H scap
Lactuca serriola L.	Euri-Mediterranean, S-Siberian	H bienn/T scap
Lathyrus latifolius L.	S-European	H scand
Lolium multiflorum Lam.	Euri-Mediterranean	T scap/H scap
Lotus corniculatus L. s.s.	Cosmopolitan	H scap
Medicago lupulina L.	Paleotemperate	T scap (H scap)
Medicago sativa L.	Eurasiatic	H scap
Melica ciliata L.	Euri-Mediterranean, Turanian	H caesp
Ostrya carpinifolia Scop.	Pontine	P caesp/P scap
Papaver rhoeas L.	E-Mediterranean	T scap
Peucedanum oreoselinum (L.) Moench	European, Caucasian	H scap
Picris hieracioides L.	Eurosiberian	H scap/H bienn
Plantago lanceolata L.	Cosmopolitan	H ros
Plantago major L.	Subcosmopolitan	H ros
Poa pratensis L.	Circum-Boreal	H caesp
Polygala comosa Schkuhr	Centre-European, S-Siberian	H scap
Polygonatum verticillatum (L.) All.	Eurasiatic	G rhiz
Populus alba L.	Paleotemperate	P scap
Populus nigra L.	Paleotemperate	P scap
Potentilla reptans L.	Subcosmopolitan	H ros
Prunus avium L.	Pontine	P scap
Prunus mahaleb L.	S-European, Pontine	P caesp/P scap
Quercus pubescens Willd.	SE-European (sub-Pontine)	P caesp/P scap
Rhinanthus alectorolophus (Scop.) Pollich	Centre-European	T scap
Robinia pseudoacacia L.	Alien (USA)	P caesp/P scap
Rosa arvensis Hudson	Submediterranean, Subatlantic	NP
Rosa canina L. sensu Bouleng.	Paleotemperate	NP
Rubus ulmifolius Schott	Euri-Mediterranean	NP
Ruscus aculeatus L.	Euri-Mediterranean	G rhiz/Ch frut
Salix alba L.	Paleotemperate	P scap
Salix caprea L.	Eurasiatic	P caesp/P scap
Sanguisorba minor Scop.	Subcosmopolitan	H scap
Scabiosa gramuntia L.	S-European	H scap

Sedum acre L.	European, Caucasian	Ch succ
Sedum sexangulare L.	Centre-European	Ch succ
Senecio inaequidens DC.	Alien (S Africa)	T scap
Setaria viridis (L.) Beauv.	Subcosmopolitan	T scap
Spartium junceum L.	Euri-Mediterranean	P caesp
Stachys recta L.	Orophyte N-Mediterannean	H scap
Tamus communis L.	Euri-Mediterranean	G rad
Taraxacum officinale Weber	Circum-Boreal	H ros
Teucrium chamaedrys L.	Euri-Mediterranean	Ch suffr
Thymus pulegioides L.	Euroasiatic	Ch suffr
Trifolium montanum L.	S-European, Pontine	H scap
Trifolium pratense L.	Subcosmopolitan	H scap
Trifolium rubens L.	Centre-European	H scap
Tussilago farfara L.	Paleotemperate	G rhiz
Verbascum chaixii Vill.	European, W-Asiatic	H scap
Vicia sativa L.	Subcosmopolitan	T scap

Appendix 4.2

Germination tests: stational and ecological data of the sampled populations. Legend: Ant_vul: *Anthyllis vulneraria*; Car_fla: *Carex flacca*; Cot_coc: *Cotinus coggygria*; Ger_mol: *Geranium molle*; Lot_cor: *Lotus corniculatus*; Pop_nig: *Populus nigra*; Ros_can: *Rosa canina*; San_min: *Sanguisorba minor*; Sen_ina: *Senecio inaequidens*; Sta_rec: *Stachys recta*; Tra_pra: *Tragopogon pratensis*

	Ant_vul	**Car_fla**	**Cot_coc**	**Ger_mol**	**Lot_cor**	**Pop_nig**	**Ros_can**	**San_min**	**Sen_ina**	**Sta_rec**	**Tra_pra**
Municipality	Botticino	Botticino	Botticino	Botticino	Botticino	Nuvolera	Botticino	Botticino	Botticino	Nuvolera	Botticino
Coordinates (grid UTM, datum WGS 84)	1602472 5044857	1602551 5045638	1602529 5045590	1602370 5044839	1602577 5045240	1605176 5045352	1602581 5045597	1602529 5045590	1602611 5045008	1605999 5044685	1602591 5045336
Aspect (°)	-	283	244	172	299	98	219	244	-	212	172
Slope (°)	-	3	45	13	45	36	42	45	-	41	8
Elevation (m a.s.l.)	188	306	292	195	212	291	326	292	219	219	233
Vegetation cover (%)	70	10	90	70	10	90	70	90	5	20	50
Soil cover (%)	24	30	2	10	40	3	20	2	1	20	25
Stoniness (%)	5	60	6	20	50	7	10	6	94	10	23
Rockiness (%)	0	0	0	0	0	0	0	0	0	50	0
Stone dimension (cm)	<1 – 30	<1 – 2000	<1 – 60	<1 – 90	<1 – 30	<1 – 60	<1 – 50	<1 – 60	<1 – 30	<1 – 30	<1 – 30
Trees cover (%)	0	0	40	0	50	70	0	40	0	0	0
Shrubs cover (%)	0	4	80	30	5	10	50	80	0	8	0
Herbs cover (%)	100	6	20	40	10	20	50	20	100	12	95
Moss cover (%)	0	0	0	0	1	0	0	0	0	0	5
Habitat (1 dump deposit; 2 platform)	2	2	1	1	1	1	1	1	2	1	1
Population extension (m^2)	1	1	>500	3	100	500-600	2	3	1	40	10
Individuals (N°)	1	10	>500	15	50	20	3	6	5	50	50
Mature individuals (N°)	1	10	50	10	10	6	3	6	5	30	5
Sampled individuals (N°)	1	10	30	10	10	6	3	6	5	20	5
Phenology (1 more fruits; 2 more flowers)	1	1	1	1	1	1	1	1	2	1	1

Appendix 4.3

Redesign of the tree and shrub layer: data recorded on the vegetation plots on the P.L.I.S. "Parco delle Colline di Brescia"

No. of plot	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Path	3	3V	3V	3V	3V	SP	SP
Coordinates (grid UTM, datum WGS 84)	1598806 5042939	1598411 5043744	1598456 5043841	1598486 5043848	1598373 5043752	1599948 5044076	1600014 5044064
Aspect (°)	266	204	225	184	216	204	186
Slope (°)	26	35	21	26	24	39	18
Elevation (m a.s.l.)	340	513	558	561	510	684	695
Vegetation cover (%)	60	90	75	85	95	90	90
Soil cover (%)	35	7	5	10	3	7	7
Stoniness (%)	5	3	20	5	2	3	3
Rockiness (%)	0	0	0	0	0	0	0
Trees cover (%)	50	40	70	80	25	60	75
Shrubs cover (%)	65	60	35	35	20	90	20
Herbs cover (%)	30	90	50	50	70	40	40
Moss cover (%)	1	0	0	0	0	3	1
Total number of trees	22	15	16	16	14	12	13
Tree density	0.44	0.30	0.32	0.32	0.28	0.24	0.26
Trees (No. of individuals)							
Cotinus coggygria Scop.			2				
Crataegus monogyna Jacq.				2		3	
Erica arborea L.							1
Fraxinus ornus L.	8	2	1	2	2	3	
Ostrya carpinifolia Scop.	2				1	3	7
Pinus sylvestris L.	1			1			1
Quercus ilex L.	3						
Quercus pubescens Willd.	8	13	13	11	11	3	4
Mean distance (m)	**2.05**	**2.84**	**2.00**	**2.11**	**3.36**	**2.41**	**2.50**
Herbs (presence)							
Anthericum liliago L.	X	X		X	X		
Brachypodium rupestre (Host) R. et S.	X			X	X		
Bromus erectus Hudson	X	X		X			
Bromus hordeaceus L.	X						
Buglossoides purpurocaerulea (L.) Johnston	X		X	X	X	X	X
Carex flacca Schreber	X	X	X	X	X	X	X
Cephalanthera longifolia (Hudson) Fritsch	X		X	X			

Carduus defloratus L.			X	X	X		
Cirsium arvense (L.) Scop.		X		X			
Clematis vitalba L.	X	X	X	X	X	X	X
Coronilla emerus L.			X				
Cornus sanguinea L.						X	
Corylus avellana L.				X			
Cotinus coggygria Scop.	X	X	X	X	X	X	X
Crataegus monogyna Jacq.			X	X	X	X	X
Cruciata glabra (L.) Ehrend.	X			X		X	X
Cytisus sessilifolius L.	X	X	X	X	X	X	X
Dactylis glomerata L.		X		X	X		
Dorycnium pentaphyllum Scop.		X			X		
Erica arborea L.	X						
Euphorbia dulcis L.	X	X		X	X	X	X
Euphorbia cyparissias L.	X	X			X		
Ferulago campestris (Besser) Grec.	X	X	X		X		
Filipendula vulgaris Moench		X			X		
Fraxinus ornus L.						X	X
Genista germanica L.	X	X		X			
Geranium sanguineum L.	X	X		X		X	X
Geum urbanum L.				X			
Globularia punctata Lapeyr.	X	X			X		
Hedera helix L.			X			X	X
Hepatica nobilis Miller						X	
Hippocrepis comosa L.					X	X	
Hypochoeris radicata L.	X				X		
Ilex aquifolium L.	X						
Juniperus communis L.			X				
Lathyrus niger (L.) Bernh.		X					
Ligustrum vulgare L.						X	X
Lotus corniculatus L.						X	
Melica ciliata L.		X					
Melica uniflora Retz.					X		
Melittis melissophyllum L.			X	X		X	
Mercurialis perennis L.	X					X	
Peucedanum cervaria (L.) Lapeyr.	X	X	X	X	X	X	X
Polygala comosa Schkuhr	X					X	
Polygonatum multiflorum			X	X			

(L.) All.							
Potentilla alba L.		X		X	X		
Potentilla recta L.		X					
Prunus spinosa L.		X					X
Quercus pubescens Willd.							X
Rosa canina L. sensu Bouleng.		X		X		X	X
Rubus ulmifolius Schott			X			X	X
Ruscus aculeatus L.			X	X		X	
Salvia pratensis L.	X	X		X	X		
Scabiosa gramuntia L.					X		
Silene nutans L.			X				
Succisa pratensis Moench		X					
Tamus communis L.	X		X	X		X	X
Tanacetum corymbosum (L.) Sch.-Bip.	X	X		X	X	X	X
Teucrium chamaedrys L.		X	X		X		
Thymus pulegioides L.		X			X		
Viburnum lantana L.	X						
Vinca minor L.				X			
Vincetoxicum hirundinaria Medicus		X	X		X		
Viola riviniana Rchb.	X					X	

Appendix 4.4

Redesign of the tree and shrub layer: total score of the selected species

Species	**F**	**R**	**N**	**H**	**D**	**L**	**T**	**K**	**Final destination**	**Improvement of site conditions**	**Dispersal**	**Total score**
Cotoneaster nebrodensis (Guss.) C.Koch	9	7	7	7	1	7	7	7	0	9	7	**220**
Cotinus coggygria Scop.	9	7	7	5	3	7	7	5	9	0	1	**215**
Fraxinus ornus L.	7	7	7	5	5	5	7	5	9	4	1	**211**
Quercus pubescens Willd.	7	7	7	5	5	5	7	5	9	4	1	**211**
Buxus sempervirens L.	7	7	7	5	3	5	7	5	9	4	1	**209**
Erica arborea L.	9	3	7	3	5	7	9	5	9	4	1	**209**
Sorbus torminalis (L.) Crantz	7	7	7	5	5	5	7	3	7	4	1	**201**
Pistacia terebinthus L.	9	7	7	5	3	7	9	5	0	6	0	**200**
Quercus cerris L.	7	5	7	5	7	5	5	3	9	4	1	**199**
Crataegus monogyna Jacq.	5	7	7	5	7	7	7	7	0	9	7	**198**
Sorbus aria (L.) Crantz	7	5	7	5	5	5	5	7	7	4	5	**197**
Castanea sativa Miller	5	3	7	3	5	5	7	5	9	9	5	**196**
Prunus mahaleb L.	9	7	7	5	7	7	7	5	0	4	1	**195**
Cytisus sessilifolius L.	7	7	7	5	3	5	7	5	0	9	7	**194**
Hippophae rhamnoides L.	7	7	7	7	5	7	5	7	0	4	5	**193**
Quercus ilex L.	9	5	5	5	7	5	9	5	5	4	1	**193**
Rosmarinus officinalis L.	9	7	7	5	5	5	9	3	0	4	7	**193**
Celtis australis L.	7	5	5	5	5	5	7	5	7	6	0	**190**
Ostrya carpinifolia Scop.	7	7	5	3	7	3	7	3	9	4	5	**189**
Cotoneaster integerrimus Medicus	9	7	7	7	3	7	7	5	0	0	0	**186**
Cercis siliquastrum L.	7	7	7	5	3	7	7	5	0	4	5	**185**
Acer campestre L.	5	7	5	5	7	5	5	3	7	4	5	**183**
Sorbus domestica L.	7	7	7	5	7	5	7	3	0	6	0	**180**
Rhamnus catharticus L.	5	7	7	3	9	5	7	5	0	9	5	**180**
Colutea arborescens L.	7	7	7	5	5	5	7	5	0	4	5	**179**
Corylus avellana L.	5	5	5	5	5	5	5	5	7	4	9	**179**
Populus tremula L.	5	5	5	5	7	7	3	7	7	4	1	**179**
Tilia cordata Miller	7	5	7	5	3	5	5	3	5	4	1	**179**
Viburnum lantana L.	7	7	7	5	5	5	7	5	0	4	5	**179**
Coronilla emerus L.	7	7	7	5	5	5	7	7	0	4	1	**177**
Rosa agrestis Savi	7	7	5	5	7	7	7	5	0	4	3	**177**
Amelanchier ovalis Medicus	7	7	7	7	0	7	7	5	0	1	0	**176**
Acer opulifolium Chaix	5	7	7	5	7	3	5	5	0	9	7	**176**
Acer monspessulanum L.	7	7	7	5	5	5	7	5	0	4	1	**175**

Rhamnus saxatilis Jacq.	9	5	7	5	3	5	7	5	0	4	1	**175**
Taxus baccata L.	7	7	7	5	0	5	7	5	1	4	1	**174**
Paliurus spina-christi Miller	9	7	7	5	3	5	7	5	0	1	0	**173**
Quercus petraea (Mattuschka) Liebl.	7	0	7	5	5	5	5	7	9	1	0	**171**
Laburnum anagyroides Medicus	5	5	5	5	3	5	5	5	7	4	3	**171**
Prunus spinosa L.	7	7	5	5	5	7	7	5	0	1	7	**170**
Rosa gallica L.	7	5	7	5	9	5	7	7	0	0	9	**169**
Acer pseudoplatanus L.	5	5	5	5	7	3	3	3	7	4	9	**167**
Spartium junceum L.	7	5	5	5	3	7	7	5	0	4	5	**167**
Chamaecytisus hirsutus (L.) Link	7	7	7	5	3	5	7	5	0	0	5	**165**
Salix eleagnos Scop.	3	5	7	7	5	7	5	7	0	4	5	**165**
Rosa micrantha Sm.	7	7	5	5	5	7	5	7	0	0	5	**163**
Ligustrum vulgare L.	5	7	7	5	7	5	5	5	0	4	1	**163**
Pyrus pyraster Burgsd.	7	7	5	5	0	5	7	5	0	4	3	**162**
Salix daphnoides Vill.	3	7	7	7	5	7	5	5	0	0	7	**161**
Berberis vulgaris L.	7	7	7	5	5	5	5	7	0	0	0	**160**
Staphylea pinnata L.	7	7	5	5	5	5	7	3	0	1	7	**160**
Carpinus betulus L.	5	3	5	3	7	3	5	3	9	4	5	**159**
Ficus carica L.	7	5	5	3	7	7	7	5	0	4	1	**159**
Salix purpurea L.	5	5	5	7	5	7	5	5	0	4	1	**159**
Juniperus communis L.	7	5	7	3	0	7	3	7	0	4	3	**158**
Chamaecytisus purpureus (Scop.) Link	7	5	7	5	5	5	7	5	0	1	0	**157**
Rosa arvensis Hudson	5	7	5	5	7	5	7	3	0	4	3	**157**
Rosa canina L. sensu Bouleng.	7	5	7	5	5	5	5	5	0	0	5	**155**
Ulmus minor Miller	5	7	5	5	7	5	5	3	3	0	5	**155**
Fraxinus excelsior L.	3	7	3	5	7	5	3	3	7	4	1	**155**
Salix myrsinifolia Salisb.	3	7	5	5	7	7	5	5	0	4	5	**155**
Salix triandra L.	3	7	5	7	7	7	7	5	0	1	0	**153**
Cornus mas L.	5	7	5	5	7	5	5	3	0	4	3	**153**
Lonicera caprifolium L.	5	7	5	5	7	5	5	3	0	4	3	**153**
Populus alba L.	5	7	3	5	5	7	5	7	0	4	3	**153**
Populus canescens (Aiton) Sm.	5	7	3	5	5	7	5	7	0	4	3	**153**
Tilia platyphyllos Scop.	5	7	5	5	5	3	5	3	5	1	0	**151**
Fagus sylvatica L.	5	0	5	5	7	3	5	3	9	4	1	**151**
Rosa rubrifolia Vill.	7	5	5	5	3	5	5	5	0	4	1	**151**
Crataegus oxyacantha L.	5	5	5	5	7	5	7	5	0	4	1	**149**
Salix caprea L.	5	5	5	5	7	5	5	5	0	4	5	**149**
Sorbus aucuparia L.	5	3	7	5	7	5	3	7	0	4	5	**149**
Acer platanoides L.	5	7	5	5	7	3	5	3	0	4	5	**147**
Euonymus latifolius (L.) Miller	5	7	5	5	7	3	7	3	0	4	1	**147**
Rosa tomentosa Sm.	5	5	5	5	5	5	7	5	0	4	1	**147**
Cornus sanguinea L.	5	7	5	5	7	5	5	7	0	1	0	**145**
Cytisus scoparius (L.) Link	7	3	5	3	7	7	5	3	0	4	1	**145**
Rubus canescens DC.	7	5	5	5	3	3	5	5	0	4	3	**145**

Salix alba L.	3	7	3	7	5	5	7	5	0	4	3	**145**
Salix rosmarinifolia L.	3	5	7	1	9	7	7	7	0	4	1	**145**
Hedera helix L.	5	5	5	5	7	3	7	3	0	4	5	**143**
Laburnum alpinum (Miller) Berchtold et Presl	5	5	5	5	3	5	3	7	0	4	3	**141**
Rubus ulmifolius Schott	5	5	3	5	7	5	7	5	0	4	3	**141**
Salix fragilis L.	3	5	5	3	7	7	7	5	0	4	3	**141**
Lonicera xylosteum L.	5	5	5	5	7	5	7	5	0	1	0	**139**
Prunus padus L.	3	7	5	5	9	3	5	3	0	4	5	**139**
Viburnum opulus L.	5	5	5	3	7	5	7	3	0	4	1	**139**
Calluna vulgaris (L.) Hull	5	1	9	1	7	5	5	5	0	4	5	**137**
Euonymus europaeus L.	5	7	5	3	9	3	5	3	0	4	1	**137**
Salix pentandra L.	3	5	5	3	5	7	3	7	0	6	0	**136**
Sambucus nigra L.	5	5	3	5	7	5	5	3	0	4	3	**135**
Alnus incana (L.) Moench	3	7	3	5	7	5	3	7	0	4	3	**133**
Ilex aquifolium L.	5	5	5	3	7	3	7	3	0	4	3	**133**
Populus nigra L.	3	7	3	5	5	5	5	7	0	4	1	**133**
Fraxinus oxycarpa Bieb.	3	5	5	5	9	5	3	3	0	4	1	**131**
Salix appendiculata Vill.	3	5	5	3	9	5	3	5	0	4	3	**127**
Rubus hirtus W.et K.	5	5	3	5	3	5	5	5	0	0	5	**123**
Salix aurita L.	1	3	7	1	9	7	5	3	0	4	5	**123**
Rubus caesius L.	3	5	3	5	7	3	7	5	0	4	1	**121**
Ulmus glabra Hudson	3	5	3	3	9	5	5	3	0	4	5	**121**
Quercus robur L.	5	0	5	3	7	5	3	7	0	4	5	**119**
Pinus sylvestris L.	0	0	7	0	0	7	5	7	7	1	7	**118**
Alnus glutinosa (L.) Gaertner	1	5	3	3	9	5	5	7	0	4	7	**117**
Frangula alnus Miller	3	5	7	3	9	3	3	7	0	0	0	**116**
Betula pendula Roth	0	0	7	0	0	7	3	7	7	1	7	**114**
Malus sylvestris Miller	5	3	3	0	0	7	5	7	0	4	1	**110**
Salix cinerea L.	1	5	3	3	9	5	5	5	0	4	1	**109**
Abies alba Miller	3	5	5	3	7	3	3	3	0	1	0	**103**
Phillyrea latifolia L.	0	0	0	0	0	7	9	5	0	4	1	**64**

Appendix 4.5

Redesign of the herb layer: flora of the "donor grassland"

Species	frequency
Bromion erecti (mesobromion)	
Anthyllis vulneraria L. (Agg.)	2
Thymus pulegioides L.	+
Sanguisorba minor Scop.	+
Ranunculus bulbosus L.	+
Brometalia erecti	
Bromus erectus Hudson	3
Polygala comosa Schkuhr	+
Trifolium montanum L.	+
Onobrychis viciifolia Scop.	+
Stachys recta L.	+
Festucetalia valesiaca	
Anthericum liliago L.	+
Festuca rupicola Heuffel	+
Festuco-Brometea	
Filipendula vulgaris Moench	1
Salvia pratensis L.	1
Centaurea scabiosa L.	+
Euphorbia cyparissias L.	+
Fragaria viridis Duchesne	+
Helianthemum nummularium (L.) Miller	+
Scabiosa gramuntia L.	+
Galium verum L.	r
Arrhenatherion	
Arrhenatherum elatius (L.) Presl	1
Galium album Miller	r
Arrhenatheretalia	
Bellis perennis L.	+
Poa pratensis L.	+
Rumex acetosa L.	+
Phleum pratense L.	+
Molinietalia	
Anthoxanthum odoratum L.	+
Lychnis flos-cuculi L.	r
Molinio-Arrhenatheretea	
Dactylis glomerata L.	2
Achillea millefolium L.	+
Centaurea jacea L.	+
Leucanthemum vulgare Lam.	+
Lotus corniculatus L. s.s.	+
Plantago lanceolata L.	+
Tragopogon pratensis L.	+
Trifolium pratense L.	+
Rhinanthus alectorolophus (Scop.) Pollich	+
Lathyrus pratensis L.	r
Other species	
Bromus sterilis L.	1
Lolium multiflorum Lam.	1
Allium sphaerocephalon L.	+
Asperula purpurea L.	+
Brachypodium rupestre (Host) R. et S.	+
Buglossoides purpurocaerulea (L.) Johnston	+
Calamagrostis arundinacea (L.) Roth.	+
Clinopodium vulgare L.	+
Crataegus monogyna Jacq.	+
Crepis vesicaria L.	+
Cruciata glabra (L.) Ehrend.	+
Geranium columbinum L.	+
Hieracium pilosella L.	+
Medicago lupulina L.	+
Medicago sativa L.	+
Ostrya carpinifolia Scop.	+
Potentilla heptaphylla L.	+
Quercus pubescens Willd.	+
Silene vulgaris (Moench) Garcke	+
Vicia sativa L.	+
Arenaria serpyllifolia L.	r
Cerastium dubium (Bastard) Guepin	r
Glechoma hederacea L.	r
Hordeum murinum L.	r
Pulmonaria officinalis L.	r
Veronica chamaedrys L.	r

5 Field experiment

I've been impressed with the urgency of doing. Knowing is not enough, we must apply. Being willing is not enough, we must do - Leonardo da Vinci -

In order to recover stone quarries, many methods are available according to the principles of the Restoration Ecology. One of the most used technique is the "reconstructive method", which consists in the artificial assemblage of the ecosystem, through four main phases: landform modeling, substrate preparation, revegetation and post-plantation interventions. Every phase should be planned on detail according to the specific aims, the interested landscape units, the final destination, the desired level of complexity and the expected effects on medium and long term of the restoration. Thus, even if a deep knowledge of the initial local environmental characteristics is fundamental in order to plan a restoration project, scientific studies and laboratory analysis are not enough to guaranty its success. In fact, it is also fundamental to test on field the predictability of the acquired knowledge. For such a reason, in situ experiments on small quarry areas are of great importance since they allow to verify knowledge, techniques and procedure, before extending the restoration design to the whole quarry area.

5.1 Manuscript to be submitted: Restoration trials on limestone quarries: a comparison among three different techniques (Botticino basin, Italy)

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Abstract

Great efforts have been made all over the world in order to ensure the rehabilitation of the quarries; nevertheless, studies comparing different techniques are scarce. We investigated the ecological suitability, the short term effects and the economic advantages of three different restoration techniques based on a) hayseed ("hay_exp"), b) commercial seed mixture ("com_exp"), and c) trees and shrubs ("no_exp"). We compared results with two reference areas, i.e. a) the seminatural grassland where we collected the hayseed ("don_gra") and an area very close to the experimental site subjected to spontaneous revegetation dynamics ("nat_rev"). We selected as a case study an experimental site on an abandoned limestone quarry located in the Botticino extractive basin (Lombardy, Italy). We surveyed vegetation plots (3x3 m with four subplot of 20x20 cm) in which we measured stational parameters, plant species cover (%) and mean plant height of each vegetation layer and investigated ecological trends by means of Canonical Correspondence Analysis (CCA). For each restoration technique, we also measured the dry biomass and the mortality of tree and shrub species and finally economic advantages (cost benefit analysis). Results showed that main differences were due to biotic factors such as the cover of the herbaceous layer and its mean plant height. The last was higher on com_exp (100 cm) and lower on no_exp (16.3 cm). We found the greatest species richness on don_gra (28 species); the lowest value was recorded on com_exp (10 species). No_exp showed the lowest vegetation and herb layer cover, 15% and 10%, respectively. The CCA showed the main biotic and abiotic trend of different plots: hay_exp and don_gra sites plotted towards an increase of species richness; no_exp plotted toward a decrease of herb layer. The analysis of the subplots showed that don_gra held the maximum number of species (20), and com_exp the lowest (6), the last with also 100% of the total made by only one species, i.e. *Lolium perenne*. The highest number of dead trees and shrubs were on com_exp (74.49% in mean) and the lowest in no_exp (4.08% in mean). The biomass production was higher in com_exp (355.23 g) and lower in hay_exp (190.19 g) and no_exp (30.70 g). Although hay_exp was the highest costly technique in term of economic price and time, it was the best one in term of biodiversity such as species richness, vegetation structure and green effect at the landscape level. The use of ordinary revegetation techniques (com_exp) created a too monotonous, dense and compact herb layer. No_exp was the most economical technique but discouraged biodiversity levels. Our work highlight that a deeper knowledge on the most suitable restoration technique to be use in quarry areas can improve renaturation practices. Then, restoration may contribute to other objectives, such as rehabilitation and conservation, biodiversity, landscape amelioration, and economic advantages.

Keywords: quarry restoration, hayseed, commercial seed mixture, hydroseeding, transplantation, ecological suitability, short term effects, cost-benefit analysis

Introduction

Over the last thirty years, great efforts have been made all over the world in order to ensure the rehabilitation of stone quarries, by improving environmental conditions, removing impacts and damages, improving the quality of life and ensuring the reuse of the degraded areas (Neri & Sánchez 2010; Abakumov et al. 2011).

Where the naturalistic destination is promoted, the spontaneous succession is often not sufficient to recover the ecosystem and its natural self-regulatory processes. This is due to consistent abiotic limits, such as water and nutrient deficiency, critical distance of valuable natural patches, and/or to very negative impacts of the quarry on the surroundings, such as visual impact on landscape, risk of landslides and erosion, soil and water contamination (e.g. Duan et al. 2008; Ballesteros et al. 2012). In such cases, technical measures are required in order to increase the speed of the regeneration processes towards an earlier development of site-specific and self-sustaining plant communities and ecosystems (e.g. Kather & Arnaud 2007; Prach & Hobbs 2008).

The ecological recreation of valuable (semi)natural habitats from high disturbed ecosystems is not a simple process, and quarry restoration is even a greater challenge since the starting point is usually an almost bare and low fertile substrate (Tishew & Kirmer 2007). For this reason, the identification of the most suitable technique is fundamental in order to plan a successful restoration, based on scientific site-specific studies, detailed quantitative case study, field experiments and comparative studies over an extended geographical area (Yundt & Lowe 2002; Prach 2003). The acquired knowledge and the consequent prediction of the spontaneous successional dynamics allow to plan the target ecosystem, the successional phase and the complexity level at which to aim (e.g. Prach et al. 2001; Tischew & Kirmer 2007). Only after the identification of such criteria and aims, the quarry restoration can take place, through some key steps, such as landform modeling, substrate preparation, plant species selection, revegetation s.s. (i.e. plant traslocation) and post-plantation interventions (e.g. Warman 1988; Bernini et al. 2003).

As for the revegetation, which starts on bare substrates, different techniques have been developed, such as: application of diasporas-rich plant clipping material, dumping of overburden with seed bank and vegetative propagules, mulch seeding, plantation of shrubs and trees (e.g. Muzzi & Rossi 2003; Tishew & Kirmer 2007). One of the most successful sowing technique, almost for the herbaceous layer, is the hydroseeding, since it could significantly increase biodiversity and plant cover within few years after its application (Martínez-Ruiz et al. 2007). As for the tree and shrub layer, seeding usually produces a more patches coverage than transplantation, which needs however more intensive efforts (Mendez & Maier 2008), while the use of fresh plant clippings could accelerate vegetation development (Kirmer & Mahn 2001).

Despite the high number of studies dealing with single restoration method, since now, only few studies tested the efficacy of different revegetation techniques. Thus, the principal aim of the present study is to furnish preliminary results on the effectiveness of three different restoration techniques based on the use of hydroseeding and/or transplantation: a) hayseed, b) commercial seed mixture, and c) trees and shrubs. In order to identify the most suitable technique we investigate them at different levels: 1) ecological suitability (comparison with natural conditions); 2) short term effects (mortality and biomass production); 3) comparative economic advantages (cost-benefit analysis). As a case study we selected an experimental site on an abandoned limestone quarry located in the Botticino extractive basin (Lombardy, Italy).

Material and methods

Study area and experimental site. The experimental site was located on the Brescian "Botticino extractive basin" (Lombardy, Italy), which is the second biggest Italian extractive basin and it is famous worldwide for the extraction of the limestone commercially known as "Botticino marble". 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 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 (Fig. 1). An homogeneous topsoil with an average thickness of 50 cm was created by use of waste material (mostly made by clayey soil and limestone fragments) of a working quarry close to the experimental site (quarry "Marmi Spinetti S.r.l."; ATE 13). Thus, topographic and environmental conditions of the three adjacent terraces were the same.

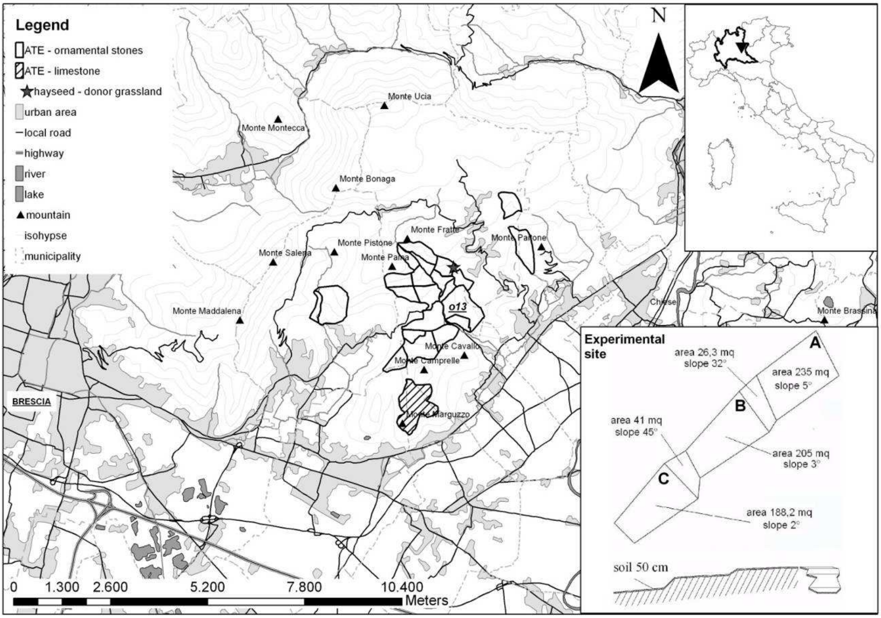

Fig. 1 Study area and experimental site (data from: Geoportale della Regione Lombardia, Geoportale della Provincia di Brescia). Legend: o13: ATE 13 (“Ambito Territoriale Estrattivo”: area where the extractive activity is allowed)

We characterized the soil according to the Italian legislation parameters (regional law “D.G.R. 21.12.2000, n. VI/120”; Supplementary File 1). During the site preparation (03-04.10.2011), we removed superficial stones of greater dimension (diameter > 50 cm), i.e. blocks and masses.

Experimental design. We tested three different techniques on the three terraces: 1) hayseed, 2) commercial seeds, and 3) trees and shrubs:

1. *Hayseed* (“hay_exp”; terrace A). This technique consisted in the hydroseeding of hayseed with a successive plantation of shrubs and trees (the last following the same procedure of no_exp; see point 3). We selected as “donor grassland” an annually mowed grassland close to the experimental site, referred to the *mesobromion* and located in a clearing of a woodland dominated by *Quercus pubescens* (40x4 m; Municipality of Serle; coordinates: 1606045 – 5046163; altitude: 438 m a.s.l.; mean aspect: 147°; mean slope: 15°; Supplementary File 2a). We collected 8.2 Kg of hayseed on may 2011 by a brush harvester bring to shoulder and we characterized it for seed density, once dried. We also carried out germination tests lasting one month,

according to protocols of the Native Flora Centre (CFA) of the Lombardy Region (Regione Lombardia 2011): tests were made on a greenhouse, by use of a substrate made by 50% of commercial universal soil and 50% of sand, maintained always wet (Supplementary File 2b). During the preparation of the experimental site, we spread by hand the hayseed on terrace A with a density of 36.28 g/m^2 (i.e. 40% of the optimal calculated sowing density); thus, we sown the following mixture by use of the "potentiated Hydroseeding" (Full Service 2008): a) 100 g/m^2 of granular humate; b) 100 g/m^2 of organic-mineral dung 12-12-17; c) 120 g/m^2 of mulch made by virgin wood fibres; d) 5 g/m^2 of natural glue (Supplementary File 3).

2. *Commercial seeds* ("com_exp"; terrace B). The technique consisted in the hydroseeding of a commercial seed mixture with a successive plantation by hand of shrubs and trees (the last following the same procedure of no_exp; see point 3). In order to mime an ordinary restoration, we used a commercial seed mixture made by *Poaceae* and *Fabaceae* adapt to a wide range of environmental conditions (Table 1). We added 40 g/m^2 of the seed mixture to the mixture for "potentiated Hydroseeding" (see point 1), together with 20 g/m^2 of dung with starter effect (Supplementary File 3) and we hydrosown the mixture on terrace B.

Species and variety	**Purity (%)**	**Germination (%)**	**Provenience**	**% on the total weight**
Festuca arundinacea var. FAWN	95	80	USA	25.0
Lolium perenne var. NAPOLEON	96	80	Denmark	25.0
Festuca rubra var. ECHO	90	75	Denmark	15.0
Phleum pratense var. KAMPE	96	80	Denmark	10.0
Dactylis glomerata var. AMERA	90	80	Denmark	5.0
Festuca ovina var. PINTOR	85	75	Czech Republic	5.0
Festuca pratense var. SENU P.	95	80	Denmark	5.0
Trifolium hybridum var. AURORA	97	80	California	5.0
Lotus corniculatus var. LEO	95	75	California	2.5
Poa pratensis var. GERONIMO	85	75	USA	2.5

Table 1: Commercial seed mixture used for the restoration experiment: "Mixture for slopes F.S. Nord"

3. *Trees and shrubs plantation* ("no_exp"; terrace C). This technique consisted in the only planting by hand of young individuals (1-2 years) of shrub and tree species; we did not sowed any herb layer. We previously selected species composition and density of plantation (Table 2) by means of a semi-quantitative procedure (data not showed), taking into account the limiting environmental site characteristics (also considering soil analysis) and the type of woodlands growing on the quarries surrounding and the restoration aim.

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. Species and number of plants for each terrace

Post-plantation interventions. We watered plants the same day of the transplantation (04/10/2011). After that, we made 6 successive watering ("help irrigations") in the following year according to rainfall distribution (Fig. 2), both during the first phase of plant establishment (10/10/2011, 13/10/2011, 17/10/2011) and during prolonged periods without rainfall (28/06/2012, 02/08/2012, 21/08/2012).

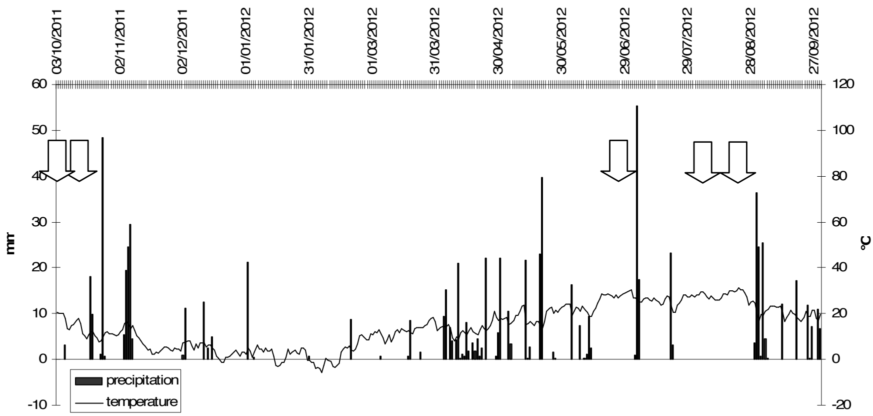

Fig. 2. Temperature and precipitations on Brescia – ITAS Pastori (data from: ARPA); arrow: "help irrigation"

Reference sites. In order to test the suitability of the three tested restoration techniques, we selected two areas as reference sites: a) the donor grassland where we collected the hayseed ("don_gra") and b) an abandoned area in the same quarry of the experimental site (very close to it) and subjected to spontaneous revegetation dynamics by almost five years ("nat_rev").

Data collection and analysis. We collected data on the basis of the protocol recommended by the regional administrative authority for monitoring the success of restoration interventions in natural areas (Regione Lombardia 2011), with some modifications. In

particular, we surveyed vegetation plots of 3x3 m both on the experimental site and on the references areas. In order to detect differences linked to local environmental heterogeneity, we recorded or estimated abiotic factors such as: a) elevation (m a.s.l.), b) aspect (°), c) slope (°), d) percent stoniness, e) percent rockiness and f) maximum stone dimension (cm). In addition, we collected biotic factors by estimating the following parameters: g) percent cover of tree, h) shrub, i) herb and l) moss layers and m) species richness. We estimated plant species cover according to Braun-Blanquet (1928) scale modified by Pignatti (1953). With the aim to estimate competition, we measured the mean plant height of the herbaceous and of the low shrub layers by using a ruler. Inside each plot, we also identified four subplot of 20x20 cm; here, in order to assess the effectiveness of the different restoration techniques we collected or estimated, for each species, the following data: a) number of individuals or stems (i.e. species diversity), b) percent cover, c) maximum height (as indicator of competition), d) presence of flower and fruits (as indicator of self-propagation).
In order to estimate the productivity of the herbaceous layer, we sampled the biomass from each terrace of the experimental site in July 2012 (on an area of 1x1 m). We cut plants at one cm above ground and dried for almost one week at 60°C; then we weighted the biomass. On the experimental site, we also counted the number of alive/dead individuals (i.e. mortality) of the planted tree and shrub species.
We investigated ecological trends related to different restoration techniques and plant species patterns on the 3x3 m plots in relation to biotic and abiotic factors, by means of Canonical Correspondence Analysis (CCA), performed by the software CANOCO.
We calculated and estimated cost and benefit for restoration in limestone quarries (from the phase of substrate preparation) according to the three different techniques we used and based on three different kind of indicators: economic, time, and ecosystemic.

Results

Ecological suitability. As regard abiotic factors, we detected main differences among sites (both experimental and references) for slope, soil cover, maximum stone dimension and stoniness (Table 3; Fig. 3; Supplementary File 4). As regard biotic factors, we recorded the highest values in the height of the herbaceous layer on com_exp (100 cm), and secondly on hay_exp (93.3 cm), while the lowest value on no_exp (16.3 cm). We found the highest level of species richness on don_gra (28 species) and then on nat_rev (20 species) and hay_exp (16 species); the lowest values was recorded on com_exp (10 species). No_exp showed the lowest vegetation cover and the lowest herb layer cover (15% and 10%, respectively); except for nat_rev, all the other sites showed very high vegetation and herb cover over 80%.

	hay_exp	com_exp	no_exp	don_gra	nat_rev
Aspect (°)	209.7	219.7	222.3	145.0	222.5
Slope (°)	2.3	2.3	2.3	20.0	10.0
Elevation (m a.s.l.)	399.0	396.0	390.0	443.0	406.5
Maximum stone dimension (cm)	23.0	18.7	19.3	0.0	46.0
Herb layer - mean plant height (cm)	93.3	100.0	16.3	72.5	45.0
Shrub layer - mean plant height (cm)	57.7	47.3	43.3	35.0	135.0
Shrub layer - number of individuals	3.7	3.7	4.7	2.5	1.5
Species richness	16	10	13	28	20

Table 3 Environmental characteristics of the recorded plots

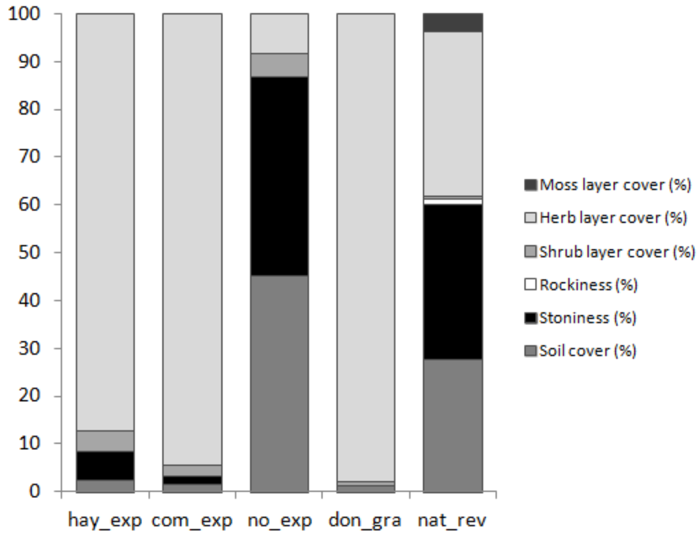

Fig 3 Abiotic and biotic factors of the recorded plots

The CCA analysis plotted species distribution and experimental/references sites according to biotic factors of vegetation structure and abiotic factors (Fig. 4; Table 4). 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 (LambdA = 0.49; F = 0.17; p = 0.001), species richness (LambdA = 0.38; F = 3.40; p=0.013), and moss layer (LambdA = 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. Hay_exp and don_gra sites plotted towards an increase of species richness; main species reference were *Anthyllis vulneraria*, *Dactylis glomerata*, *Medicago lupulina*, *Sanguisorba minor* and *Trifolium pratense*. Com_exp sites plotted along a decrease of species richness; main reference species were *Festuca rubra* and *Lolium prerenne*. No_exp sites plotted toward an increasing of maximum stone dimension (abiotic) and toward a decreasing of herb layer; main reference species were *Setaria viridis* and *Senecio inaequidens*. Nat_rev sites plotted toward an increasing of maximum stone dimension (abiotic) and moss layer (biotic) and toward a decreasing of herb layer; main reference species were *Arenaria serpyllifolia*, *Daucus carota* and *Lotus corniculatus*.

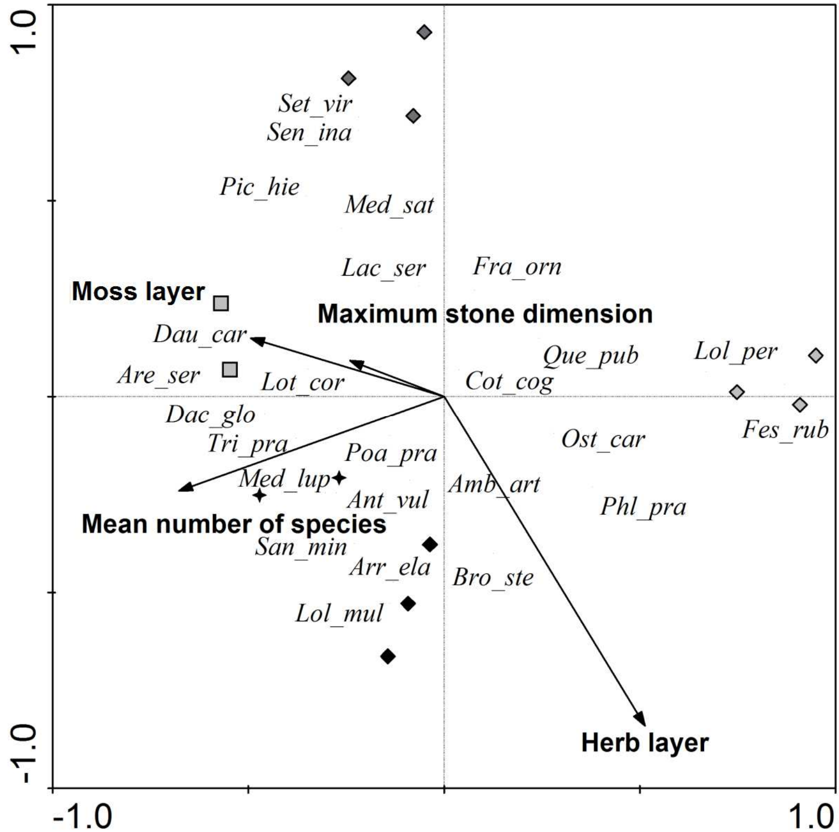

Fig. 4 CCA according to biotic and abiotic factors. Legend: black diamond: hay_exp; pale gray diamond: com_exp; gray diamond: no_exp; star: donor grassland; square: nat_rev

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 percentage variance					
of species data	31.9	55.3	73.8	80.2	
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) Effect	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**	**3.4**
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
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	0.1	0.08	0.334	1.16

Table 4 a) Eingenvalues of the CCA and b) Significance of the environmental variables

The analysis of species mainly contributing to the percent cover and abundance on the subplots (Fig. 5) showed that:

a) don_gra held the maximum number of species (20). The species with the highest values of cover were: *Brachypodium rupestre*, *Fragaria viridis* and *Lotus corniculatus*, each one with a mean cover less than 15% of the total;
b) hay_exp and nat_rev showed the same medium number of species (16). The species with the highest cover were: *Arrenatherum elatius* and *Lolium perenne* for hay_exp and *Epilobium dodonei* for nat_rev. Species cover in nat_rev was low (each species covered less than 10%), while vegetation cover on hay_exp was higher (*Arrenatherum elatius* covered more than 15% of the total);
c) no_exp and com_exp held the lowest number of species (11 and 6, respectively). Species that most contribute to vegetation cover were *Lactuca serriola*, *Setaria viridis* and *Senecio inaquidens* for no_exp (each species covered less than 5%).

Lolium perenne showed the highest cover in com_exp, reaching also 100% of the total.

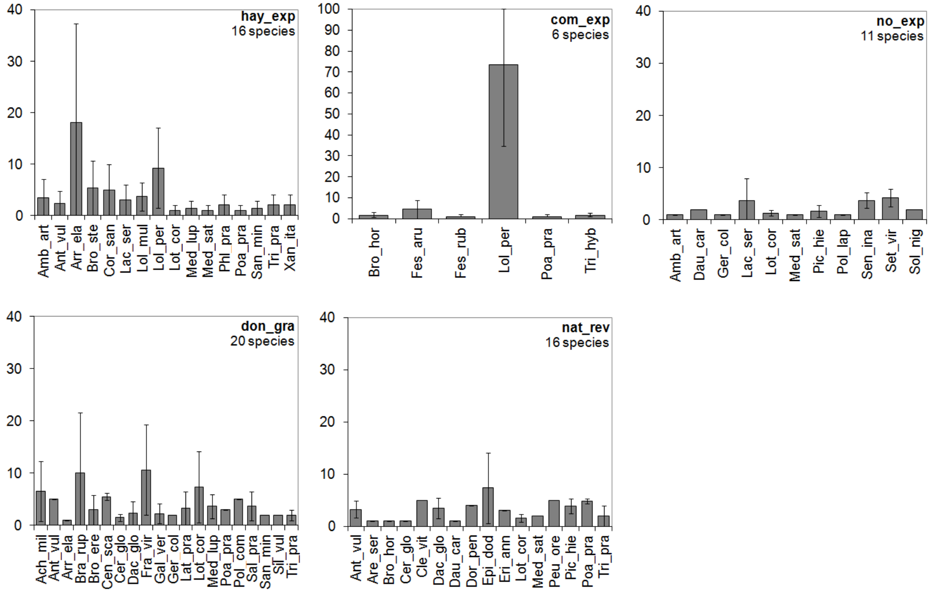

Fig. 5 Plant species cover (%) on the subplot (20x20 cm)

Short term effect of the restoration techniques. We recorded the highest number of dead trees and shrubs on com_exp (74.49% in mean) for all the planted species; in particular, *Corylus avellana*, *Quercus pubescens* and *Ostrya carpinifolia* showed mortality over 80% in com_exp (Fig. 6). No_exp sites showed the lowest mortality, that was lower than 20% for most species (4.08% in mean). We recorded intermediate values of mortality on hay_exp (18.37% in mean).

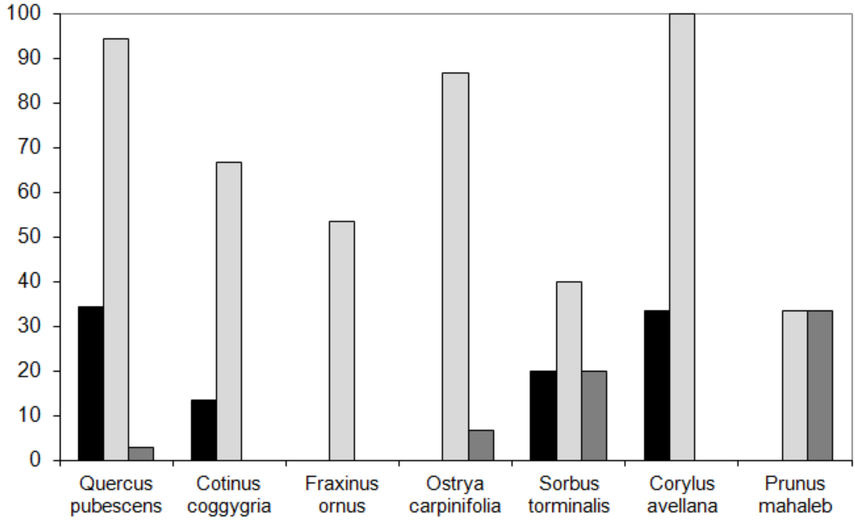

Fig. 6 Mortality of tree and shrub species (%) on the experimental site. Legend: black: hay_exp; gray: no_exp; pale gray: com_exp

The biomass production (Fig. 7) was higher in com_exp (355.23 g; at about the same mean plant height of the herbaceous layer for com_exp and hay_exp: 100 cm and 93.33, respectively). We recorded lower values in hay_exp (190.19 g) and no_exp (30.70 g).

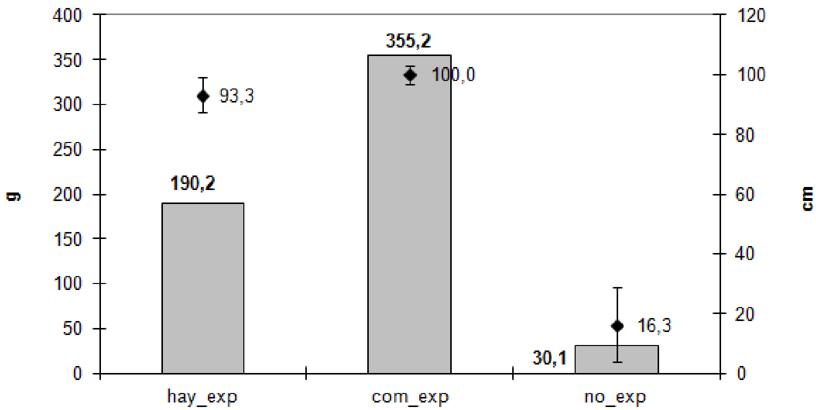

Fig. 7 Biomass production (g) and mean plant height of the herbaceous layer (cm) on the experimental site

Cost-benefit analysis. Hay_exp showed the highest economic cost (Table 5), while no_exp was the most economical technique. Main differences among techniques were due to the collection and characterization of the hayseed, both regarding economic price and time required. However, both hay_exp and com_exp showed an immediate green effect and an expected lower term for restoration. Qualitative ecosystem indicators showed that hay_exp was the most advantageous in term of naturalistic value (similarity with natural or seminatural surrounding areas and esthetic shape), number of species (biodiversity), and lower impact due to the invasion of alien species.

Indicator	Cost - benefit	Hay_exp	Com_exp	No_exp
Economic	Mechanical ground preparation	€1.67	€1.67	€1.67
	Tree and srubs 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	Low
	No. of herbaceous species*	6	4	5
	No. of herbaceous exotic species or commercial varieties*	2	3	2
	Invasion rate by exotic species	Low	Very low	High

Table 5 Cost-benefit analysis of the tested techniques; economic costs are expressed as net price/m^2; *calculated on 100 m^2

Discussion and conclusions

The main goal of any quarry restoration s.s. is the creation of a self-sustaining ecosystem resilient to perturbations, so that no further manipulations are required in order to ensure its health and integrity (e.g. SER 2004; Zhang et al. 2006). Generally such an evaluation can be made only on long term since the future vegetation dynamics are not always easy to predict because of, for example, the different influence of the surrounding vegetation during time

(Martínez-Ruiz et al. 2007) and the possible suffering of commercial species, that is visible only many years after the seeding (Tishew & Kirmer 2007; Prach & Hobbs 2008). However, preliminary considerations on short term, also in comparison with some reference sites, are very useful in order to monitor the state of the restoration and if and in what measure post-transplantation treatments are required (Hobbs and Norton 1996; Hobbs and Harris 2001; Mendez & Maier 2008).

Our results highlighted that, with the exception of the semi-natural donor grassland, the others sites had very similar abiotic conditions, so that only the abiotic factor "maximum stone dimension" (i.e. grain size) was significant. This means that species composition and structure for the different techniques in relation to the reference sites seems to be primarily affected by biotic factors such as percent cover of the herb layer and number of species. Thus, differences in vegetation features mostly depends on the used restoration technique. Ruiz-Jaén & Aide (2008) stressed that vegetation (biotic) parameters are very useful to characterize the state of the restoration: for example, vegetation structure provides information about habitat suitability, ecosystem productivity and vegetation succession, while species diversity is an indicator of the susceptibility to invasions and ecosystem resilience. Our experiment showed that, in general, an artificial herbaceous layer characterized by a too high plant density (com_exp in particular) could compete with the transplanted shrubs and trees, resulting in a high mortality of the lasts (and especially of the light-demanding ones, such as *Quercus pubescens*). Such a trend was already observed in similar condition by Wolf et al. (2004). In order to overcome the problem, two devices could be preached: a) anticipate the tree and shrub plantation (so that they are more developed when the herb layer is sown) or b) modify the sowing density of the herbaceous layer. According to Bernini et al. (2003), 20-30 g/m^2 is an optimal sowing density for the hydroseeding to ensure a rapid vegetation establishment, control erosion, rebuild soil, maintain biodiversity and ecosystem functions, provide wildlife habitats and improve the aesthetic appeal of the quarry (Burton et al. 2006). Such values were lower to those we applied to com_exp but quite higher in comparison to hay_exp (that also comprise other vegetative parts as well as seeds).

Nevertheless, we found that species density (and, indirectly, the "immediate green effect" and the minimization of short-term erosion) should not be considered as an indicator of the success of the restoration, by itself. The creation of a too monotonous, dense and compact herb layer, made by few dominant competitive grasses, as in the case of com_exp, could divert or arrest the succession on long-term because of the not suitable specific composition (Prach 2003). In fact, artificially introduced species could compete with the valuable autochthonous colonizing ones (coming from the quarry surroundings), maintaining very low levels of biodiversity for long time (Hodačová & Prach 2003; Moreno-de las Heras et al. 2008) and impeding to recover a valuable target ecosystem (Bernini et al. 2003; Ballesteros et al. 2012). Moreover, com_exp was dominated by genotypes artificially selected and with foreign provenience, that are a potential threat (i.e. genetic pollution) for the local flora.

As for vegetation structure, hay_exp and com_exp were very similar. The height and the cover of the herbaceous layer was much higher in comparison with no_exp (and nat_rev), as also demonstrated by a high and quickly biomass production (with values depending on the sowing density). The rapid establishment of a continuous herb layer also in hay_exp may depend on the sowing technique, i.e. the "potentiated hydroseeding". In fact, the mulch is a thermic insulating, absorbs and keeps water (soil evaporation and plants transpiration are reduced), represents a "buffer layer" on the beating action of the meteoric water and favors the infiltration of the water drops in the soil (the superficial water runoff is reduced), protects soil and the seedbed from wind and water erosion, and thus it creates an ideal microclimate for the seed germination (Kirmer & Mahn 2001; Muzzi & Rossi 2003). Literature data highlight that besides the sowing technique, also the time of sowing and the post-plantation irrigation could be a key element for a successful restoration (Glenn et al. 2001; Brofas & Karetsos 2002). We selected the autumn transplantation, that is usually recommended in areas where summers are characterized by soil-water deficiency and precipitations are low and erratic. In fact, high precipitations at the beginning of spring and autumn, supported by artificial irrigation for at least 3-6 month after the restoration could be fundamental for plants establishment (Mendez & Maier 2008) and for the maintaining of suitable temperatures on the aboveground (Muzzi & Rossi 2003).

Cost benefit analysis highlighted that even if hay_exp has a higher economic and time costs than com_exp and no_exp, it allowed to recreate ecological conditions more similar to those of a semi-natural herbaceous communities (i.e. arid grasslands, don_gra). For this reason, also the expected time for the recovery of a valuable ecosystem is lower than the other techniques, especially if the spontaneous succession (no_exp) is selected for the establishment of the herbaceous layer. In term of ecosystem indicators, since native species are supposed to have evolved survival mechanisms suitable for local conditions, being resistant or resilient to possible fluctuations and/or sudden changes of environmental conditions, a plurispecific autoctonous mixture harvested on quarry natural surroundings (e.g. the hayseed) is recommended in order to facilitate the colonization by a self-sustaining valuable plant community, explore more diversified soil layers, maintain a local species diversity and minimize human efforts on medium-long term (Chosa & Shetron 1976; Khater et al. 2003; Mendez & Maier 2008). Moreover, the deliberate introduction of native plant species could overcome the lack of suitable local ones able to colonize the quarry site and could supply food for wildlife (Chosa & Shetron 1976), also avoiding the massive colonization of ruderal or exotic species.

Data

1. Geoportale della Provincia di Brescia. Piano Territoriale di Coordinamento Provinciale vigente, Tavola 2: Paesaggio. Provincia di Brescia, Servizio Cartografia e GIS http://sit.provincia.brescia.it/PTCP
2. Geoportale della Regione Lombardia. Dati, mappe, servizi geografici del territorio lombardo disponibili in rete. Sistema Informativo per la consultazione dell'Infrastruttura per l'Informazione Territoriale della Lombardia. Unità Organizzativa Infrastruttura per l'Informazione Territoriale, Direzione Generale Territorio e Urbanistica – Regione Lombardia http://www.cartografia.regione.lombardia.it/geoportale/
3. Servizio Meteorologico Regionale - Arpa Lombardia http://ita.arpalombardia.it/meteo/meteo.asp

References

1. Abakumov E.V., Maksimova E.I., Lagoda A.V., Koptseva E.M. 2011. Soil formation in the quarries for limestone and clay production in the Ukhta Region. Eurasian Soil Science Vol. 44 No. 4: 417-423
2. Ballesteros M., Cañadas E.M., Foronda A., Fernádez-Ondoño E., Peñas J., Lorite J. 2012. Vegetation recovery of gypsum quarries: short-term soling response to different soil treatments. Applied Vegetation Science 15: 187-197
3. Bernini F., Di Fidio M., Villa M. 2003. Operatore nei cantieri d'ingegneria naturalistica. Quaderni della Scuola d'Ingegneria Naturalistica 2. Scuola Regionale di Ingegneria Naturalistica, Centro Regionale per la Flora Autoctona. 177 pages
4. Braun-Blaunquet J. 1928. Pflanzensoziologie. Sprinter, Verl. Wien; II ed. nel 1951, III ed. nel 1964. Schippmann U., 1991- Revisionder europaischen Arten der Gattung Brachypodium Palisot de Beauvois. Boissiera, Genève, 45.1-249
5. Brofas G., Karetsos G. 2002. Revegetation of mining spoils by seeding of woody species on Ghiona Mountain, Central Greece. Land Degradation & Development 13: 461-467
6. Burton C.M., Burton P.J., Hedba R., Turner N.J. 2006. Determining the optimal sowing density for a mixture of native plants used to revegetate degraded ecosystems. Restoration Ecology 14(3): 379-390
7. Chosa J.A., Shetron S.G. 1976. Use of willow cuttings to revegetate the "slime" areas of iron mine tailings basins. Research Notes 21: 1-5
8. Deliberazione del Consiglio Regionale 21 dicembre 2000, n. VII/120 – Nuovo piano delle attività estrattive della Provincia di Brescia – Settori argille, pietre ornamentali e calcari, ai sensi dell'art. 8 della l.r. n. 14/98. Bollettino Ufficiale della Regione Lombardia 20.03.2001, n. 12, 1° supplemento straordinario
9. Duan W., Ren H., Fu S., Wang J., Yang L., Zhang J. 2008. Natural recovery of different areas of a deserted quarry in South China. Journal of Environmental Sciences 20: 476-481
10. Florineth F. 2007. Piante al posto del cemento. Manuale di ingegneria naturalistica e verde tecnico. Il verde editoriale, 280 pages
11. Full Service 2008. Idrosemine: tipologie. Newsland, periodic informative per enti, imprese e progettisti 2: 1-2

12. Glenn E.P., Waugh W.J., Moore D., McKeon C., Nelson S.G. 2001. Revegetation of an abandoned uranium millsite on the Colorado Plateau, Arizona. Journal of Environmental Quality 30: 1154-1162
13. Hobbs R.J., Harris J.A. 2001. Restoration Ecology: repairing the Earth's ecosystems in the new millennium. Restoration Ecology 9(2): 239-246
14. Hobbs R.J., Norton D.A. 1996. Towards a conceptual framework for restoration ecology. Restoration Ecology Vol. 4 No. 2: 93-110
15. Hodačová D., Prach K. 2003. Spoil heaps from brown coal mining: technical reclamation versus spontaneous revegetation. Restoration Ecology Vol. 11 No. 3: 385-391
16. Khater C., Martin A., Maillet J. 2003. Spontaneous vegetation dynamics and restoration prospects for limestones quarries in Lebanon. Applied Vegetation Science 6: 199-204
17. Khater C., Arnaud M. 2007. Application of Restoration Ecology principles to the practice of limestone quarry rehabilitation in Lebanon. Lebanese Science Journal Vol. 8 No. 1: 19-28
18. Kirmer A., Mahn E.-G. 2001. Spontaneous and initiated succession on unvegetated slopes in the abandoned lignite-mining area of Goitsche, Germany. Applied Vegetation Science 4: 19-27
19. Martínez-Ruiz C., Fernández-Santos B., Putwain P.D., Fernández-Gómez M.J. 2007. Natural and man-induced revegetation on mining wastes: changes in the floristic composition during early succession. Ecological Engineering 30: 286-294
20. Mendez M.O., Maier R.M. 2008. Phytostabilization of mine tailings in arid and semiarid environments – an emerging remediation technology. Environmental Health Perspectives Vol. 116 No.3: 278-283
21. Moreno-de las Heras m., Nicolau J.M., Espigares T. 2008. Vegetation succession in reclaimed coal-mining slopes in a Mediterranean-dry environment. Ecological Engineering 34: 168-178
22. Muzzi E., Rossi G. 2003. Il recupero e la riqualificazione ambientale delle cave in Emilia-Romagna. Manuale teorico-pratico. Regione Emilia-Romagna, Bologna. 491 pages
23. Neri A.C., Sánchez L.E. 2010. A procedure to evaluate environmental rehabilitation in limestone quarries. Journal of Environmental Management 91: 2225-2237
24. Pignatti S. 1953. Introduzione allo studio della pianura veneta orientale. Archivio botanico 29: 131-158
25. Prach K. 2003. Spontaneous succession in Central-European man-made habitats: what information can be used in restoration practice? Applied Vegetation Science 6: 125-129
26. Prach K., Bartha S., Joyce C.B., Pyšek P., van Diggelen R., Wiegleb G. 2001. The role of spontaneous vegetation succession in ecosystem restoration: a perspective. Applied Vegetation Science 4: 111-114
27. Prach K., Hobbs R.J. 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restoration Ecology Vol. 16 No. 3: 363-366
28. Regione Lombardia 2011. Inerbimenti tecnici ad alta quota. Quaderni della ricerca n. 134 – Settembre 2011. 47 pages
29. Ruiz-Jéan M.C., Aide T.M. 2005. Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. Forest Ecology and Management 218: 159-173
30. Society for Ecological Restoration International Science & Policy Working Group 2004. The SER international primer on ecological restoration. www.ser.org & Tucson: Society for Ecological Restoration International

31. Tishew S., Kirmer A. 2007. Implementation of basic studies in the ecological restoration of surface-mined land. Restoration Ecology Vol. 15 No. 2: 321-325
32. Warman P.R. 1988. The gays river mine tailing revegetation study. Landscape and Urban Planning 16: 283-288
33. Wolf A., Møller P.F., Bradshaw R.H.W., Bigler J. 2004. Storm damage and long-term mortality in a semi-natural, temperate deciduous forest. Forest Ecology and Management 188: 197-210
34. Yundt S., Lowe S. 2002. Quarry rehabilitation – cliffs, landforms and ecology. Proceedings of the 26th Annual British Columbia Mine Reclamation Symposium in Dawson Creek, BC. The Technical and Research Committee on Reclamation
35. Zhang C.-B., Huang L.-N., Luan T.-G., Jin J., Lan C.-Y. 2006. Structure and function of microbial communities during the early stage of revegetation of barrens soils in the vicinity of a Pb/Zn smelter. Geoderma 136: 555-565

Supplementary file 1

Results of the analysis of the topsoil used for the restoration experiment. We collected 2 samples on each terrace by a hand drill: 1 superficial (0-20 cm of depth) and 1 composed (0-50 cm of depth); results showed that the topsoil was homogeneous and with some chemical and physical limitations (e.g. clayey texture, low nutrient availability).

	Sample	**1**	**2**	**3**	**4**	**5**	**6**	**Mean**	**St.dev**
Terrace		A	A	B	B	C	C	-	-
Explored depth	cm	0-50	0-20	0-50	0-20	0-50	0-20	-	-
Sand (2-0.05 mm)	g/Kg	260	269	257	252	247	252	**256.17**	**7.73**
Silt (0.05-0.0002mm)	g/Kg	305	293	309	319	299	317	**307.00**	**10.12**
Clay (< 0.0002 mm)	g/Kg	435	438	434	429	454	431	**436.83**	**8.98**
Total CO_3^{2-}	g/Kg	162	228	210	236	226	214	**212.67**	**26.58**
Organic C	g/Kg	6.1	5.8	6.0	6.1	6.6	6.5	**6.18**	**0.31**
Organic matter	mg/Kg	10.5	10.0	10.3	10.5	11.4	11.2	**10.65**	**0.54**
Assimilable P	mg/Kg	2.26	2.45	1.52	1.89	2.08	1.89	**2.01**	**0.33**
CEC	cmol(+)/Kg	17.23	19.11	18.44	18.32	19.23	20.34	**18.78**	**1.05**
BSR	%	100	100	100	100	100	100	**100.00**	**0.00**
Ca	cmol(+)/Kg	15.03	16.72	15.66	15.63	16.45	17.61	**16.19**	**0.93**
Mg	cmol(+)/Kg	2.10	2.27	2.65	2.56	2.64	2.56	**2.46**	**0.23**
K	cmol(+)/Kg	0.07	0.09	0.09	0.09	0.09	0.11	**0.09**	**0.01**
Na	cmol(+)/Kg	0.03	0.03	0.04	0.04	0.05	0.06	**0.04**	**0.01**

Supplementary file 2a

Annually mowed "donor grassaland" referring to the *mesobromion*; species cover was estimated according to Braun-Blanquet (1928) scale modified by Pignatti (1953).

Species	Cover
Bromion erecti (mesobromion)	
Anthyllis vulneraria L. (Agg.)	2
Thymus pulegioides L.	+
Sanguisorba minor Scop.	+
Ranunculus bulbosus L.	+
Brometalia erecti	
Bromus erectus Hudson	3
Polygala comosa Schkuhr	+
Trifolium montanum L.	+
Onobrychis viciifolia Scop.	+
Stachys recta L.	+
Festucetalia valesiaca	
Anthericum liliago L.	+
Festuca rupicola Heuffel	+
Festuco-Brometea	
Filipendula vulgaris Moench	1
Salvia pratensis L.	1
Centaurea scabiosa L.	+
Euphorbia cyparissias L.	+
Fragaria viridis Duchesne	+
Helianthemum nummularium (L.) Miller	+
Scabiosa gramuntia L.	+
Galium verum L.	r
Arrhenatherion	
Arrhenatherum elatius (L.) Presl	1
Galium album Miller	r
Arrhenatheretalia	
Bellis perennis L.	+
Poa pratensis L.	+
Rumex acetosa L.	+
Phleum pratense L.	+
Molinietalia	
Anthoxanthum odoratum L.	+
Lychnis flos-cuculi L.	r
Molinio-Arrhenatheretea	
Dactylis glomerata L.	2
Achillea millefolium L.	+
Centaurea jacea L.	+
Leucanthemum vulgare Lam.	+
Lotus corniculatus L. s.s.	+
Plantago lanceolata L.	+
Tragopogon pratensis L.	+
Trifolium pratense L.	+
Rhinanthus alectorolophus (Scop.) Pollich	+
Lathyrus pratensis L.	r
Other species	
Bromus sterilis L.	1
Lolium multiflorum Lam.	1
Allium sphaerocephalon L.	+
Asperula purpurea L.	+
Brachypodium rupestre (Host) R. et S.	+
Buglossoides purpurocaerulea (L.) Johnston	+
Calamagrostis arundinacea (L.) Roth.	+
Clinopodium vulgare L.	+
Crataegus monogyna Jacq.	+
Crepis vesicaria L.	+
Cruciata glabra (L.) Ehrend.	+
Geranium columbinum L.	+
Hieracium pilosella L.	+
Medicago lupulina L.	+
Medicago sativa L.	+
Ostrya carpinifolia Scop.	+
Potentilla heptaphylla L.	+
Quercus pubescens Willd.	+
Silene vulgaris (Moench) Garcke	+
Vicia sativa L.	+
Arenaria serpyllifolia L.	r
Cerastium dubium (Bastard) Guepin	r
Glechoma hederacea L.	r
Hordeum murinum L.	r
Pulmonaria officinalis L.	r
Veronica chamaedrys L.	r

Supplementary file 2b

a) Characterization and b) number of seedlings germinated on greenhouse tests. Seed density was 103 seeds/g of hayseed and 11067 seedlings/m^2 were expected to germinate; in order to obtain 8000 germinated plants/m^2 for the restoration (considered a successful result for grassing), the optimal hayseed density was 77.97 g/m^2, that should be increased till 90.36 g/m^2 of hayseed, taking into account the results of the germination tests.

a)	Seeds weight (%)	Number of seeds (n°/g)	Optimal seed density (g/m^2)
Sample 1	18.0	106.4	75.19
Sample 2	12.0	91.5	87.43
Sample 3	20.0	109.8	72.86
Mean	**16.67**	**102.6**	**77.97**

b)	replica 1 (n°/m^2)	replica 2 (n°/m^2)	replica 3 (n°/m^2)	Mean (n°/m^2)
Sample 1	7600	14000	6800	9467
Sample 2	12400	16000	11600	13333
Sample 3	12000	11600	7600	10400
Mean	**10667**	**13867**	**8667**	**11067**

Supplementary file 3

Mixture for the “potentiated Hydroseeding”: a) granular humate, b) organic-mineral dung 12-12-17; c) mulch made by virgin wood fibres, d) natural glue, e) dung with starter effect.

a) Biosol forte	**Minimum content (%)**
Total nitrogen (N)	7-9
Total phosphorous (P_2O_5)	3
Total potassium (K_2O)	0.5
Organic substance	70

b) Hydrofibre - mulch for hydroseeding	**Content (%)**
Fybres of wood (virgin)	100
Moisture	15.0 ± 3.0
Organic matter	98
Ashes	2
Min capacity of water retention (1:10)	100 mulch/1000 g water

c) Fertilizer Dung – organic-mineral fertilizer containing sulphur, low in chlorine NPK + SO_3 + C (12.12.17 + 15SO_3 + 18C)	**Content (%)**
Total nitrogen (N)	12
Organic nitrogen (N)	4.5
Ammonia nitrogen (N)	4.5
Urea nitrogen (N)	3
Total phosphorus pentoxide (P_2O_5)	12
Phosphorus pentoxide (P_2O_5) soluble in neutral ammonium citrate and in water	10
Water-soluble potassium oxide (K_2O)	17
Water-soluble sulfur trioxide (SO_3)	15
Organic carbon (C) of biological origin	18
Raw material were both organic (flagpole, dried blood) and mineral (urea, ammonium bi phosphate, potassium sulphate)	

d) Idrostarter EC Fertilizer – NP fertilizer NP 8 40 with molybdenum (Mo) and zinc (Zn), low in chloride	**Content (%)**
Total nitrogen (N)	8
Ammoniacal nitrogen (N)	8
Phosphorus pentoxide (P_2O_5) soluble in neutral ammonium citrate and in water	40
Water-soluble phosphorus pentoxide (P_2O_5)	36
Water-soluble molybdenum (Mo)	0.002
Water-soluble zinc (Zn)	2

Supplementary file 4

Plots 3x3 m on the experimental sites and on the reference area. Species cover was estimated according to Braun-Blanquet (1928) scale modified by Pignatti (1953).

No. of plot	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
Site	don_gra	don_gra	hay_exp	hay_exp	hay_exp	no_exp	no_exp	no_exp	com_exp	com_exp	com_exp	nat_rev	nat_rev
Coordinate (grid UTM,	1605981	1606071	1606630	1606629	1606628	1606602	1606602	1606596	1606623	1606619	1606615	1606666	1606685
datum WGS 84)	5046121	5046181	5044933	5044936	5044938	5044904	5044895	5044893	5044918	5044913	5044909	5044992	5044994
Aspect (°)	140	150	210	210	209	225	220	222	220	219	220	185	260
Slope (°)	20	20	2	3	2	2	3	2	3	2	2	18	2
Elevation (m a.s.l.)	443	443	398	394	405	390	391	389	393	397	398	406	407
Soil cover (%)	1	1	1	3	3	40	45	50	1	1	2	15	40
Stoniness (%)	0	0	4	7	7	45	40	40	1	1	3	30	35
Rockiness (%)	0	0	0	0	0	0	0	0	0	0	0	0	2
Maximum stone dimension (cm)	0	0	25	15	29	15	25	18	20	20	16	42	50
Vegetation cover (%)	99	99	95	90	90	15	15	10	98	98	95	55	23
Tree layer cover (%)	0	0	0	0	0	0	0	0	0	0	0	0	0
Shrub layer cover (%)	1	1	5	5	3	5	5	5	2	3	2	0	1
Herb layer cover (%)	98	98	90	85	87	10	10	5	96	95	93	50	20
Moss layer cover (%)	0	0	0	0	0	0	0	0	0	0	0	5	2
Herb layer - mean plant height (cm)	75	70	100	90	90	14	30	5	100	103	97	50	40
Shrub layer - mean plant height (cm)	60	10	60	70	43	48	32	50	40	55	47	0	270
Diameter at the base of the stem (mm)	4	8	8	8	6	8	7	9	7	6	4	0	40
Mean lateral spread (cm)	54	25	20	27	17	20	23	40	22	14	15	0	63
Number of individuals	4	1	4	4	3	5	5	4	2	5	4	0	3

Species													
Lotus corniculatus	1	+		+	r		+	r				2	1
Medicago sativa	+	r				+	+	+				+	
Poa pratensis	+	+	+	+	+		+		+			+	+
Quercus pubescens	+			+	+	+	+	+	+	1	+		
Dactylis glomerata	+	1	+									3	+
Festuca rubra									+	+	+		
Lactuca serrriola			+	+		1	1	+			+		+
Medicago lupulina	+	+	+	+	+							+	+
Picris hieracioides						+		+				+	+
Sanguisorba minor	+	+	+	+									
Trifolium pratense	+	+		+								+	+
Ostrya carpinifolia	+	+							+	+			
Anthyllis vulneraria	+		+	+	+							+	+
Daucus carota			+			+						+	+
Lolium perenne			1				+	+	5	5	5		
Onobrychis vicifolia	+	r											
Senecio inaequidens						+	1	+				+	
Cotinus coggygria			+		+	+	+				+		
Arrhenatherum elatius	+	+	3	4	4								
Bromus sterilis			2	2	1					+	+		
Lolium multiflorum	+		3	+	+								
Setaria viridis						1	+	1				+	
Trifolium repens													
Fraxinus ornus			+			+		+			+		
Ambrosia artemisiifolia			+	+	+		+						
Arenaria serphyllifolia		r										+	+
Bromus erectus	+	1											
Phleum pratense			+	+					+		+		
Corylus avellana				+				+		+			
Cerastium glomeratum		+										+	+

Cirsium vulgare											+		
Crepis capillaris													
Epilobium dodonei												1	1
Festuca arundinacea									1	2	1		
Geranium columbinum		r					+	+					
Hordeum murinum			+	+	+								
Polygonum lapathifolia						+	+	+					
Stachys recta	+											+	
Trifolium hybridum									+	+	+		
Vicia cracca													
Cornus sanguinea				+							+		
Crataegus monogyna	+							+					
Populus nigra													2
Prunus mahaleb			+	+									
Achillea millefolium	+	1											
Brachypodium rupestre	2	3											
Bromus hordeaceous											r	+	
Catapodium rigidum												+	+
Centaurea scabiosa	+	+											
Centranthus ruber													
Cichorium intybus						+					+		
Clematis vitalba												1	+
Dorycnium pentaphyllum												+	2
Erigeron annuus												+	1
Fragaria viridis	+	+											
Galium verum	+	1											
Peucedanum oreoselinum													+
Salvia pratensis	+	+											
Scabiosa gramuntia	+	+											
Trifolium montanum	+	+											

Xanthium italicum				r									+
Celtis australis							+						
Coronilla emerus													
Anthericum liliago		r											
Calamagrostis arundinacea	+												
Centaurea jacea		+											
Cirsium arvense								+					
Clinopodium vulgare		r											
Echium vulgare										+			
Euphorbia cyparissias		+											
Filipendula vulgaris		+											
Geranium sanguineum													
Helianthemum nummularium	+												
Hypericum perforatum												+	
Lathyrus pratensis		+											
Plantago lanceolata													
Polygala comosa	+												
Rhinanthus alectorolophus			r										
Sedum acre													
Sedum album													
Silene vulgaris	+												
Solanum nigrum								r					
Veronica persica						+							

6 Discussion and conclusion

6.1 Vegetation dynamics

The general trend. The results of the present thesis showed that spontaneous vegetation dynamics on abandoned quarries follow, as a general rule, the course of a succession comparable to a primary natural one, as it starts from bare soil (e.g. Wali 1999; Frouz et al. 2008). However, we underline that succession is sometime partial or incomplete or may follow different directions due to the fast colonization of ruderal and alien species and for the environmental heterogeneity present within quarries.

As for primary successions, time is the key factor affecting vegetation dynamics (Wheater & Cullen 1997; Wali 1999), even if its role is not always detectable, especially on extreme environmental conditions (Konvalinková & Prach 2010) such as on artificial cliffs, where vegetation dynamics are very slow (Yuan et al. 2006). For such a reason, plant colonization on quarries can be generally described as a succession of different phases characterized by different and heterogeneous plant communities (Tischew & Kirmer 2007). In particular, some authors identified four main successional phases during the quarry recolonization, i.e. “pioneer phase”, “intermediate phase”, “late colonizer phase” and “fluctuating phase” (e.g. Wiegleb & Felinks 2001; Martínez-Ruiz & Fernández-Santos 2005). Generally, with the sequence of the phases, vegetation cover and ecosystem complexity increase, vegetation structure, richness and diversity improve, resources portioning becomes more equilibrate and environmental and edaphic conditions are progressively less limiting (e.g. Martínez-Ruiz et al. 2001; Frouz et al. 2008). The results of the present thesis are generally in accordance with such a trend, although the phases did not correspond exactly. In fact, we identified five main phases thanks to a new objective temporal characterization of the local vegetation succession: “pioneer phase”, “early phase”, “intermediate phase”, “later phase” and “advanced phase”.

Moreover, most previous studies stressed the existence of a last phase, named generally “fluctuating phase”, characterized by a much improved soil characteristics and lower light conditions (Bernini et al. 2003). At this phase, vegetation tends to be in dynamic equilibrium with the (semi)natural surrounding communities for floristic composition and diversity, characteristics and fluctuations (e.g. Martínez-Ruiz et al. 2001; Konvalinková & Prach 2010). In our study area (Botticino extractive basin) such a situation is very far from reality. In fact, the natural vegetation of the quarry surroundings (i.e. arid grasslands and woodlands, the “advanced phase”) is very different from any type of vegetation that characterize the successional phases in the quarry areas. This means that an hypothetical “fluctuating phase” is not here reached, even after more than 50 years from quarry abandonment. Phases could present unforeseeable and very different directions, so that different final plant communities (from almost bare ground to woodlands) could develop from the same initial condition, according to variations on environmental factors, both abiotic, biotic and their interaction (Tischew & Kirmer 2007).

Factors affecting the direction of the succession. On limestone quarries, small variations in historical and environmental conditions may lead to great differences in ecosystem dynamics as for vegetation pattern, species diversity and duration of the recolonization phases (Prach 2003; Dana & Mota 2006; Konvalinková & Prach 2010). In particular, considering the multifactorial nature of the vegetation, the vegetation pattern and the speed of species replacement are affected, especially at earlier phases, by two main filters, i.e. the availability and dispersion of plant diaspores (including clonality) and the suitability of site conditions for plant establishment. The lasts include a great variety of factors such as geomorphological features, altitude, climate, physical-chemical characteristics of the substrate on one hand, and historical traits of dominant species, seed availability and proximity of plant diaspores sources on the other hand (Jochimsen 2001; Wiegleb & Felinks 2001; Prach 2003; Martínez-Ruiz & Fernández-Santos 2005). Also the interaction of dissimilar environmental conditions has usually a relevant effect (Martínez-Ruiz et al. 2001): for example, distance and direction of seed dispersal can be affected (almost on short distances) by the interaction between seed availability and wind, slope and soil characteristics (Leavitt et al. 2000).

Among site conditions affecting plant establishment in quarry areas, geomorphological features are usually responsible of most differences (Wali 1999; Konvalinková & Prach 2010), so that different plant communities can establish on different type of surface at the same time from the quarry abandonment (Duan et al. 2008). The present thesis showed that quarry geomorphological heterogeneity greatly affect plant communities by selecting species traits, especially those connected to plant morphology, water requirement and seed dispersal. In fact, we found that different plant strategies are positively selected according to the three main geomorphological surfaces that characterize quarries, i.e. artificial cliffs, embankments and platforms. In particular, artificial cliffs are the most extreme habitats: plant colonization is here a very slow (although steady) process, being limited by soil depth and volume, that is usually accumulated in concaves and cracks through a secondary migration process (Yuan et al. 2006). Another problem of artificial cliffs is the water availability, on the contrary of platforms, where the frequency of some species traits (e.g. high Ellenberg indicator for moisture, dispersal by hydrochory) highlighted the presence of a water film mostly connected with the stamping by man of the clayey soil. On the other hand, the effect of aspect along the vegetation succession over the Botticino basin is not detectable, probably because of the slow rate of soil formation, the great geomorphological differences within small areas (Martínez-Ruiz et al. 2001; Martínez-Ruiz & Fernández-Santos 2005) and especially the more direct and predominant limiting factors, i.e. the anthropic disturbance.

On abandoned quarries, the closeness of the (semi)natural surrounding vegetation can enhance the colonization rate by local species, and improve the speed of the succession, species richness, density and diversity, also creating a high variety of plant communities (Parrotta & Knowles 2001; Novák & Prach 2003; Martínez-Ruiz & Fernández-Santos 2005; Moreno-de las Heras et al. 2008), eventually introducing interesting and/or rare plant species (Tischew & Kirmer 2007). In the study area, such a contribution was very low, as typical of the initial phases of the recolonization (Martínez-Ruiz et al. 2007), where wind (and secondly man) is the most important dispersal agent because of dispersal limitations. In fact, in accordance with Shu et al. (2005), species with small and wind-borne seeds (as those of *Poaceae* and *Asteraceae* families) and rhizomes showed the greater dispersal potential. On the other hand, species with larger seeds are less represented and might establish only when vegetation structure and composition become more favorable for a greater diversity of seed-dispersing birds and mammals (Parrotta & Knowles 2001); such a conditions in the Botticino quarries is present only on the embankments.

6.2 The quarry restoration

The study of spontaneous vegetation dynamics on the limestone quarries of the Botticino extractive basin showed that the artificial recreation of valuable ecosystems is here necessary, but it also represents a great challenge, as generally observed for quarries (Schultz & Wiegleb 2000; Tischew & Kirmer 2007). In fact, the environmental characteristics are very adverse and natural processes, whose interference is not eliminable (Parrotta & Knowles 2001; Holl 2003; Courtney et al. 2009), do not ensure the establishment of valuable vegetation communities in acceptable time. The acquired knowledge also allows to identify in what measure human interventions can be successfully applied or are even necessary for a coherent restoration project over the whole extractive basin (Hodačová & Prach 2003). In particular, different restoration strategies are needed according to the quarry-specific geomorphological heterogeneity. As for artificial cliffs, the spontaneous succession could be a feasible restoration technique, since the very adverse site conditions could control the invasion by alien species and favor the spontaneous establishment (however on very long term) of the local colonizing ones (e.g. Lavoie et al. 2003; Prach & Hobbs 2008). Moreover, the extreme environmental conditions could frustrate any expensive human interventions. On the contrary, the technical restoration is recommended on embankments and quarry platforms.

6.2.1 Human efforts on embankments and platforms

On the Botticino extractive basin, embankments and platforms are very degraded areas because of the intensive quarry activity, that is responsible of consistent biotic and abiotic limits, such as direct disturbance, low resources availability and dispersal limitations (e.g. Prach & Pyšek 2001; Prach & Hobbs 2008; Tischew & Kirmer 2007). For such a reason, spontaneous succession is here not sufficient for restoration purposes, contrary to other cases (Novák & Prach 2003; Prach 2003; Duan et al. 2008). Here, thanks to the lower costs (also economic) in comparison with artificial cliffs, human interventions can actually increase the naturalistic, productive and aesthetic value of the quarry sites and decrease possible environmental risks (e.g. superficial mass movements) by accelerating the development of site-specific and self-sustaining plant communities (e.g. Hodačová & Prach 2003; Kather & Arnaud 2007; Ballesteros et al. 2012).

In particular, the present site-specific study, supported by more targeted laboratory analysis, allowed to define the target ecosystem, the successional phase and the complexity level of the new recreated plant community (e.g. Prach et al. 2001; Pamukçu & Simsir 2006). Moreover, the field experiment gave preliminary information about the suitability of different restoration techniques, by using (semi)natural surrounding plant communities and spontaneous quarry revegetation as reference areas.

"Soil" preparation. The "soil" used for the restoration experiment was mostly made by quarry wastes produced during the extractive activities (Savoldi et al. 2011), so that it showed bad physical and chemical properties according to previous studies (e.g. Wali 1999; Ortiz et al. 2012). Since such characteristics could negatively affect microbial activity and plant establishment, growth and reproductive capacity (Leavitt et al. 2000; Jim 2001; Ortiz et al. 2012), many authors tested on field some amelioration techniques. They paid particular attention to the application of different slow-release fertilizers and amendments during the first phases of revegetation (e.g. Chambers et al. 1987; Conesa et al. 2007b). Besides positive effects (species-specific), such as the increase of the initial plant diversity, density and cover (Jochimsen 2001; Andrews & Broome 2006; Martínez-Ruiz et al. 2007), authors underlined possible significant negative effects, both during the first years after the restoration and on long-term, especially on sensitive areas (e.g. Jasper et al. 1988; Courtney et al. 2009). Since soil and water contamination are included in such risks (e.g. Mendez & Maier 2008) and the aboveground water network in the Botticino extractive basin is generally vulnerable because of the karst nature of the local lithology, we avoided such experimentations. We used the "potentiated hydroseeding" as the only measure to contrast the initial very limiting soil chemical properties. On the other hand, we spent more efforts for the amelioration of the physical soil properties, by use of minimally invasive and cost-effective methods such as the scarification of the surface and the removal of stone fragments of greater size. The hand-labor allowed to ecreate the microtopography heterogeneity, which has a fundamental ecological role for small-scale dynamics for water, nutrients and seeds dispersal and germination (Olyphant & Harper 1995; Carrick & Krüger 2007).

The use of local hayseed for grassing. The present thesis stresses the importance of basing species selection on the study of site conditions (e.g. agroecological constraints, natural surrounding vegetation and spontaneous vegetation succession), autoecology of introduced species (e.g. ecological needs, type of reproduction and seed dispersal) and economic feasibility (e.g. Warman 1988; Forbes & Jefferies 1999; Tischew & Kirmer 2007). The surrounding (semi)natural plant communities are constantly taken as a guide, as showed for the design of the shrub and tree layer.

Our field experiment showed that the local hayseed could successfully establish, survive, adapt and compete on local stressing conditions (almost on short term). In fact, local species growing on quarry natural surroundings (principle of availability) or adapted to live on quarry comparable sites (principle of adaptability) are supposed to be resistant or resilient to possible fluctuations and/or sudden changes of environmental conditions (e.g. Chosa & Shetron 1976; Mendez & Maier 2008; Meira-Neto et al. 2011). This way, not only long-term human efforts could be minimized, but also the naturalistic value of the restored site will be higher. On the other hand, commercial seed mixtures (that could include alien and potentially invasive species) showed a much lower naturalistic value since a) they do not reflect the typical local flora and vegetation and b) only one or two species (such as *Lolium perenne* in the experiment) greatly dominate, so that species diversity is very low (e.g. Bernini et al. 2003; Prach & Hobbs 2008; Ballesteros et al. 2012).

Nevertheless, commercial seed mixtures are often used in quarry restoration for their high initial productivity, that allows to rapidly minimize the visual impact (by obtaining a "sudden green effect") and the geomorphological processes, such as erosion, runoff, long-term slope instability and pollutants dispersion (e.g. Olyphant & Harper 1995; Istanbulluoglu & Bras 2005; Tordoff et al. 2000). Our field experiment showed that such an aim can be reached also by use of the local hayseed, made by perennial species with different growth habits, that ensured a complete, fast and supposed long lasting vegetation cover. In fact, both in commercial seed mixture and in local hayseed, the presence of species belonging to the *Poaceae* family, characterized by high growth rate and root cohesion (as shown by our laboratory analysis) is high. It should be underlined that the higher productivity of commercial seed mixtures (depending on the selected seed density) is not always positive, since, as in the present study, a too dense herb layer could compete with young trees and shrubs, determining their suffering and mortality on short time. Thus, it could also compete with autochthonous colonizing species coming from the surroundings, causing the stop or the distortion of the vegetation succession on the medium and long term (Chosa & Shetron 1976; Densmore 2005; Moreno-de las Heras et al. 2008). On the other hand, if the herb layer is not well structured, slope protection and the control of alien species could be less effective than that obtained by spontaneous succession (Hodačová & Prach 2003; Holl 2003). Moreover, the use of hayseed could allow to ameliorate environmental characteristics: we observed a high germination of species belonging to the *Fabaceae* family, that could enhance the fixing of nitrogen from the atmosphere thanks to the activity of arbuscolar mychorrizal fungi, improving nutrient content and ecosystem biodiversity (Chen et al. 2005).

Considering that tree and shrub species can ameliorate chemical and physical soil properties and geomorphological processes (Maiti & Ghose 2005), the combined grassing with hayseed (with a suitable seed density) and the plantation of autochthonous trees and shrubs could be a successful restoration technique. In fact, it allows to recreate a plant community similar to those present in the quarry natural surrounding (e.g. the donor grassland for hayseed) and much improved than vegetation types characterizing the successional phases of the spontaneous quarry recolonization. Thus, the only disadvantage of such a technique is the higher cost in terms of economic price (and secondly of time), connected with the collection and characterization of the hayseed.

Hydroseeding and tree plantation. Different techniques have been developed for plants translocation, such as: application of diasporas-rich plant clipping material, dumping of overburden with seed bank and vegetative propagules, seeding and tree plantation (Muzzi & Rossi 2003; Shu et al. 2005; Tischew & Kirmer 2007). Our results showed that the "potentiated hydroseeding" of the herbaceous layer contributes to stabilize soil (mainly thanks to the use of mulch and natural glue), creating suitable conditions for plant germination, that could be drastically inhibited in extreme site conditions (Kirmer & Mahn 2001). Thus, it contributes to increase biodiversity and vegetation cover on short term (Martínez-Ruiz et al. 2007), also if unconventional seeds (i.e. the hayseed) are used. As for the tree and shrub layer, plant transplantation should be preferred to sowing, since, although requiring more efforts, it produces a less patches coverage (Mendez & Maier 2008) and allows to overcome germination problems connected with the seed dormancy of some species (as shown by our laboratory analysis), shortcutting the first phases of the recolonization.
For the time of restoration, autumn is recommended in the study area because summers could be characterized by soil-water deficiency. According to economic costs, an initial irrigation is recommended till plants establishment, during the first years after the restoration, especially when precipitations are low and discontinuous during year (Glenn et al. 2001; Mendez & Maier 2008).

6.3 Conclusion and future work

The present thesis proposed a multidisciplinary approach for planning the quarry restoration on the basis of a deep knowledge of local site characteristics (especially of vegetation dynamics), laboratory analysis and a field experiment testing different techniques. Even if it was developed for the limestone quarries of the Botticino extractive basin, the method can be improved and adapted for the naturalistic restoration of quarries in different areas with dissimilar environmental conditions.
This study stresses the importance of an experimental phase before the start of the restoration process in a quarry area. Moreover, the evaluation of medium-long term effects of the tested restoration techniques is required in order to verify their suitability for the establishment of a valuable self-sustaining vegetation community on long-term. A careful long-term monitoring, that is often lacking in many restoration programs (Mendez & Maier 2008), is fundamental in order to check the progressive achievement of the targets of the restoration, besides environmental and ecological variations and risks (Dana & Mota 2006; Ballesteros et al. 2012). Monitoring is also a very useful prediction tool, that allows to recalibrate the restoration actions by identifying possible measures and treatments that are often necessary during the first years after the restoration (Tischew & Kirmer 2007), such as cuttings (Warman 1988), repeated seedings and/or plantations (Olyphant & Harper 1995) and control of invasive plant species (Andrews & Broome 2006). In order to obtain data that can give a scientifically relevant, practicable and cost-effective feedback, monitoring should be based on an analytical, periodical and systematic evaluation of some indicators that are

target-oriented, robust, simple to record and easy to handle (Tischew & Kirmer 2007). Thus, the indicators used in the field experiment (e.g. survival of transplanted plants, plant biomass, percentage of plant cover) can be also evaluated in the future and compared with the preliminary data of the present thesis and with reference non-disturbed site. In addiction, many other indicators (e.g. regarding soil characteristics and animal community) can be evaluated in order to check the improvement of abiotic site conditions and the development of the whole ecosystem (e.g. Schmidt et al. 1999).

6.4 References, chapter 6

- Andrews R.L., Broome S.W. 2006. Oak flat restoration on phosphate-mine spoils. Restoration Ecology 14(2): 210-219
- Ballesteros M., Cañadas E.M., Foronda A., Fernádez-Ondoño E., Peñas J., Lorite J. 2012. Vegetation recovery of gypsum quarries: short-term soling response to different soil treatments. Applied Vegetation Science 15: 187-197
- Bernini F., Di Fidio M., Villa M. 2003. Operatore nei cantieri d'ingegneria naturalistica. Quaderni della Scuola d'Ingegneria Naturalistica 2. Scuola Regionale di Ingegneria Naturalistica, Centro Regionale per la Flora Autoctona. 177 pages
- Carrick P.J., Krüger R. 2007. Restoring degraded landscapes in lowland Namaqualad: lessons from the mining experience and from regional ecological dynamics. Journal of Arid Environments 70: 767-781
- Chambers J.C., Brown R.W., Johnston R.S. 1987. A comparison of soil and vegetation properties of seeded and naturally revegetated pyritic alpine mine spoil and reference sites. Landscape and Urban Planning 14: 507-519
- Chen B., Tang X., Zhu Y., Christie P. 2005. Metal concentrations and mycorrhizal status of plants colonizing copper mine tailings: potential for revegetation. Science in China Ser. C Life Science Vol. 48 Suppl. I: 156-164
- Chosa J.A., Shetron S.G. 1976. Use of willow cuttings to revegetate the "slime" areas of iron mine tailings basins. Research Notes 21: 1-5
- Conesa H.M., García G., Faz Á., Arnalsos R. 2007a. Dynamics of metal tolerant plant communities' development in mine tailings from the Cartagena-La Unión Mining District (SE Spain) and their interest for further revegetation purposes. Chemosphere 68: 1180-1185
- Conesa H.M., Schulin R., Nowack B. 2007b. A laboratory study on revegetation and metal uptake in native plant species from neutral mine tailings. Water Air and Soil Pollution 183: 201-212
- Courtney R., Mullen G., Harrington T. 2009. An evaluation of revegetation success on bauxite residue. Restoration Ecology 17(3): 350-358
- Dana E.D., Mota J.F. 2006. Vegetation and soil recovery on gypsum outcrops in semi-arid Spain. Journal of Arid Environments 65: 444-459
- Densmore R.V. 2005. Succession on subalpine placer mine spoil: effects of revegetation with Alnus viridis, Alaska, U.S.A. Arctic, Antarctic, and Alpine Research 37(3): 297-303
- Duan W., Ren H., Fu S., Wang J., Yang L., Zhang J. 2008. Natural recovery of different areas of a deserted quarry in South China. Journal of Environmental Sciences 20: 476-481

- Frouz J., Prach K., Pižl V., Háněl L., Starý J., Tajovský K., Materna J., Balík V., Kalčík J., Řehounková K. 2008. Interactions between soil development, vegetation and soil fauna during spontaneous succession in post mining sites. European Journal of Soil Biology 44: 109-121
- Glenn E.P., Waugh W.J., Moore D., McKeon C., Nelson S.G. 2001. Revegetation of an abandoned uranium millsite on the Colorado Plateau, Arizona. Journal of Environmental Quality 30: 1154-1162
- Hodačová D., Prach K. 2003. Spoil heaps from brown coal mining: technical reclamation versus spontaneous revegetation. Restoration Ecology Vol. 11 No. 3: 385-391
- Holl K.D. 2002. Long-term vegetation recovery on reclaimed coal surfaces mines in the eastern USA. Journal of Applied Ecology 39: 960-970
- Istanbulluoglu E., Bras R.L. 2005. Vegetation-modulated landscape evolution: effects of vegetation on lanscape processes, drainage density, and topography. Journal of Geophysical Research Vol. 110 F02012, doi: 10.1029/2004JF000249
- Jasper D.A., Robson A.D., Abbott L.K. 1988. Revegetation in an iron-ore mine – Nutrient requirements for plant growth and the potential role of vescicular-arbuscular (VA) mycorrhizal fungi. Australian Journal of Soil Research 24: 497-507
- Jim C.Y. 2001. Ecological and landscape rehabilitation of a quarry site in Hong Kong. Restoration Ecology Vol. 9 No. 1: 85-94
- Jochimsen M.E. 2001. Vegetation development and species assemblages in a long-term reclamation project on mine spoil. Ecological Engineering 17: 187-198
- Khater C., Arnaud M. 2007. Application of Restoration Ecology principles to the practice of limestone quarry rehabilitation in Lebanon. Lebanese Science Journal Vol. 8 No. 1: 19-28
- Kirmer A., Mahn E.-G. 2001. Spontaneous and initiated succession on unvegetated slopes in the abandoned lignite-mining area of Goitsche, Germany. Applied Vegetation Science 4: 19-27
- Konvalinková P., Prach K. 2010. Spontaneous succession of vegetation in mined peatlands: a multi-site study. Preslia 82: 423-435
- Lavoie C., Grosvernier P., Girard M., Marcoux K. 2003. Spontaneous revegetation of mined peatlands: an useful restoration tool? Wetlands Ecology and Management 11: 97-107
- Leavitt K.J., Fernandez G.C.J., Nowak R.S. 2000. Plant establishment on angle of repose mine waste dumps. Journal of Range Management Vol. 53 No. 4: 442-452
- Maiti S.K., Ghose M.K. 2005. Ecological restoration of acidic coal-mine overburden dumps – an Indian case study. Land Contamination & Reclamation 13(4): 361-369
- Majer J.D., Brennan K.E.C, Moir M.L. 2007. Invertebrates and the restoration of a forest ecosystem: 30 years of research following bauxite mining in Western Australia. Restoration Ecology Vol. 15 No. 4 (Supplement): S104-S115
- Martínez-Ruiz C., Fernández-Santos B., Gómez-Gutiérrez J.M. 2001. Effects of substrate coarness and exposure on plant succession in uranium-mining wastes. Plant Ecology 155: 79-89
- Martínez-Ruiz C., Fernández-Santos B. 2005. Natural revegetation on topsoiled mining-spoils according to the exposure. Acta Oecologica 28: 231-238
- Martínez-Ruiz C., Fernández-Santos B., Putwain P.D., Fernández-Gómez M.J. 2007. Natural and man-induced revegetation on mining wastes: changes in the floristic composition during early succession. Ecological Engineering 30: 286-294

- Meira-Neto J.A.A, Clemente A., Oliveira G., Nunes A., Correia O. 2011. Post-fire and post-quarry rehabilitation successions in Mediterranean-like ecosystems: implications for ecological restoration. Ecological Engineering 37:1132-1139
- Mendez M.O., Maier R.M. 2008. Phytostabilization of mine tailings in arid and semiarid environments – an emerging remediation technology. Environmental Health Perspectives Vol. 116 No.3: 278-283
- Moreno-de las Heras M., Nicolau J.M., Espigares T. 2008. Vegetation succession in reclaimed coal-mining slopes in a Mediterranean-dry environment. Ecological Engineering 34: 168-178
- Muzzi E., Rossi G. 2003. Il recupero e la riqualificazione ambientale delle cave in Emilia – Romagna. Manuale teorico – pratico. Regione Emilia-Romagna. Bologna, 491 pp.
- Novák J., Prach K. 2003. Vegetation succession in basalt quarries: pattern on a landscape scale. Applied Vegetation Science 6: 111-116
- Olyphant G.A., Harper D. 1995. Effects of direct revegetation on the hydrology, erosion and sediment yield of an abandoned deposit of coal-mine refuse. Geomorphology 11: 261-272
- Ortiz O., Ojeda G., Espelta J.M., Alcañiz J.M. 2012. Improving substrate fertility to enhance growth and reproductive ability of a Pinus halepensis Mill. afforestation in a restored limestone quarry. New Forests 43: 365-381
- Pamukçu C., Simsir F. 2006. Example of reclamation attempts at a set of quarries located in Izmir, Turkey. Journal of Mining Science Vol. 42 No. 3: 304-308
- Parrotta J.A., Knowles O.H. 2001. Restoring tropical forests on lands mined for bauxite: examples from the Brazilian Amazon. Ecological Engineering 17: 219-239
- Prach K. 2003. Spontaneous succession in Central-European man-made habitats: what information can be used in restoration practice? Applied Vegetation Science 6: 125-129
- Prach K., Bartha S., Joyce C.B., Pyšek P., van Diggelen R., Wiegleb G. 2001. The role of spontaneous vegetation succession in ecosystem restoration: a perspective. Applied Vegetation Science 4: 111-114
- Prach K., Hobbs R.J. 2008. Spontaneous succession versus technical reclamation in the restoration of disturbed sites. Restoration Ecology Vol. 16 No. 3: 363-366
- Prach K., Pyšek P. 2001. Using spontaneous succession for restoration of human-disturbed habitats: experience from Central Europe. Ecological Engineering 17: 55-62
- Savoldi S., Agostini M., Lucchini F., Papa F., Quecchia G., Serena C., Bellini R., Gilardelli F., Motta M., Nicoli B., Testa R., Zola G. 2011. S.I.A. di bacino. Bacino estrattivo delle pietre ornamentali e dei pietrischi. Regione Lombardia, Provincia di Brescia, Comune di Botticino, Comune di Nuvolento, Comune di Nuvolera, Comune di Paitone, Comune di Serle. 974 pages.
- Shu W.S., Ye Z.H., Zhang Z.Q., Lan C.Y., Wong M.H. 2005. Natural colonization of plants on five lead/zinc mine tailings in Southern China. Restoration Ecology Vol. 13 No. 1: 49-60
- Shultz F., Wiegleb G. 2000. Development options of natural habitats in a post-mining landscape. Land Degradation & Development 11: 99-110
- Schmidt S., Stewart G.R., Ashwath N. 1999. Monitoring plant physiological characteristics to evaluate mine site revegetation: a case study from the wet-dry tropics of northern Australia. Plant and Soil 215: 73-84
- Sort X., Alcañiz J.M. 1996. Contribution of sewage sludge to erosion control in the rehabilitation of limestone quarries. Land Degradation & Development 7: 69-76

- Tischew S., Kirmer A. 2007. Implementation of basic studies in the ecological restoration of surface-mined land. Restoration Ecology Vol. 15 No. 2: 321-325
- Tordoff G.M., Baker A.J.M., Willis A.J. 2000. Current approaches to the revegetation and reclamation of metalliferous mine wastes. Chemosphere 41: 219-228
- Wali M.K. 1999. Ecological succession and the rehabilitation of disturbed terrestrial ecosystems. Plant and Soil 213: 195-220
- Warman P.R. 1988. The gays river mine tailing revegetation study. Landscape and Urban Planning 16: 283-288
- Wheater C.P., Cullen W.R. 1997. The flora and invertebrate fauna of abandoned limestone quarries in Derbyshire, United Kingdom. Restoration Ecology Vol. 5 No. 1: 77-84
- Wiegleb G., Felinks B. 2001. Primary succession in post-mining landscapes of Lower Lusitania – chance or necessity. Ecological Engineering 17: 199-217
- Yuan J.-G., Fang W., Fan L., Chen Y., Wang D.-Q., Yang Z.-Y. 2006. Soil formation and vegetation establishment on the cliff face of abandoned quarries in the early stages of natural colonization. Restoration Ecology Vol. 14 No. 3: 349-356
- Zhang Z.Q., Shu W.S., Lan C.Y., Wong M.H. 2001. Soil seed bank as an input of seed source in revegetation of lead/zinc mine tailings. Restoration Ecology 9(4): 378-385

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The best time to plant a tree is twenty years ago.
The second best time is now. (Proverb)