Index System to Evaluate the Quarries Ecological Restoration

Qiuqin Zhang *, Tianzhu Zhang and Xiang Liu
School of Environment, Tsinghua University, Beijing 100084, China; hangtz@mail.tsinghua.edu.cn (T.Z.);
x.liu@tsinghua.edu.cn (X.L.)
* Correspondence: Zhangqiuqin2002@ruc.edu.cn
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Abstract: The restoration and evaluation of degraded ecosystems is an important component of the sustainable development of complex “human-natural-economic” ecosystems. Based on an analysis of ecosystem evolution and the integration of structure, function, and services, this study proposes that ecosystems can be returned to a self-maintaining, dynamic balance by enriching system elements, strengthening the relationships between the different elements and diverse ecological processes, and restoring internal functions, which includes the self-regulation of degraded ecosystems. This study developed and categorized quarry ecosystem recovery indicators based on the Core Capabilities of the Society for Ecological Restoration (SER) International through literature review and the development of recovery plans. Metrics identified in the literature were validated through the recovery plan review and the case study, and based on the findings, a user-friendly checklist for practitioners was established. Three elements and 17 indicators representing ecological processes, vegetation structures, and ecological functions were developed to evaluate and manage the ecological restoration of an abandoned quarry.

Keywords: quarry; ecological processes; vegetation structure; ecological function; ecological restoration; restoration evaluation; index system

1. Background

The excessive use of natural resources by human societies has increased the stress on natural ecosystems and resulted in climate change, environmental pollution, vegetation damage, biodiversity loss, etc. The constant acceleration of urbanization and industrialization worldwide, along with the accompanying demand for mineral resources, has led to the development of new quarries that have largely destroyed many natural ecosystems [1]. Quarrying results in significant visual and ecological impacts [2], not all of which have been identified [3]. Quarrying drastically destroys flora and fauna, thereby reducing biodiversity and disrupting fundamental ecological relationships. Moreover, it extensively damages soil by modifying the original site topography and depleting and altering soil microbial communities [3–7]. Because ecosystem degradation has increased in severity, investigations into ecosystem restoration are urgently required.

Although human technology cannot restore natural systems, it can be applied to improve natural restorations by introducing important plants and animals into ecosystems to generate the basic habitat conditions and promote natural evolution and ecosystem recovery. Thus, many quarries implement rehabilitation or reclamation actions that benefit biodiversity [8–10]. Rehabilitation seeks to repair one or more ecosystem attributes, processes, or services. Reclamation, on the other hand, includes land stabilization, public safety guarantees, aesthetic improvement, and usually a return of the ecosystem considered useful in the regional context [11,12].

However, whether recovery is occurring during the process of restoration can be unclear due to a lack of relevant reports and research. Ecological restoration assessment takes a specific target and
system as a reference and evaluates the changes in structure, function, quality, health, and safety [13], and studies have indicated that ecological restoration evaluations play an important role in promoting restoration ecology as an area of scientific research [14–16]. Thus, a set of generally accepted criteria should be defined for use by ecologists and project engineers so that they can evaluate the success of ecological restorations in restoration projects [17], as a set of guiding criteria will greatly promote the evaluation of restoration projects and the reporting of recovery results [18].

The key to evaluating ecological restoration lies in the selection of the evaluation indicator and the construction of the indicator system. Methods of comprehensively and objectively selecting the evaluation indicator and scientifically designing the indicator system represent a hot topic in the field of ecological restoration and evaluation [19].

2. Literature Review

Diamond (1987) [20], who focuses on the restoration of vegetation, believes that ecological restorations can reconstruct a self-maintaining natural community and maintain its continuity, while Egan (1996, quoted in Hobbs and Norton, 1996) [15] indicates that ecological restoration is the process of reconstructing historical regional plant and animal communities and maintaining the sustainability of the ecological system as well as its traditional cultural functions. An ecosystem is affected by non-biological factors, such as solar energy, light, temperature, rainfall, wind, rock, soil, water, air, CO$_2$, O$_2$, N$_2$, inorganic salts, humus, proteins, and carbohydrates, as well as biological factors, such as producers, consumers, and decomposers. These factors are interrelated, and their roles constitute the entire functioning of the ecosystem and provide services for the environment and the functional maintenance of the ecosystem. The foundation for ecosystem restoration and construction is an increase in biodiversity, and plant diversity is particularly important. Sustaining plant diversity can increase the species diversity of ecosystems because high plant diversity promotes high productivity and provides a material basis for the ecological diversity of the ecosystem. Furthermore, different plant species within an ecological system can create a variety of heterogeneous habitats, which accommodate a greater number of species assemblages, and the multiple layers of roots of different plants lead to various soil micro-habitats that accommodate a diverse array of soil animals and microorganisms [21].

According to the vertical structure of its plant community, an ecological system can be divided into several layers, such as trees, shrubs, herbs, and the surface layer (mosses and lichens) [22]. The tree layer has tall stems and foliage, which perform photosynthesis and regulate gas exchange. Leaf transpiration can inhibit high temperatures and increase air humidity to adjust the microclimate. Trees, shrubs, and herbs combine to form a landscape, which provides scenic and recreation services for society. In the community ecosystem, pollination and seed dispersal for reproduction can be conducted via wind energy. Green plants primarily produce energy via photosynthesis and chemical energy bacteria to provide a variety of crops, fruit, prey, and other resources for consumers (human beings and animals). The plant community is the primary producer, and it is also the habitat of animals. The ground layer (lichen or moss and other plants) can be used for water penetration and as an adsorbent for water conservation to achieve efficient water regulation. The soil is held in place by the root systems of plants, thereby preventing soil collapse and soil erosion. Microorganisms and fungi in the soil decompose biological debris to generate, store, and accelerate the internal cycle of nutrients.

Therefore, the natural ecological recovery process is essentially the synergy of the evolution of the soil and plant systems, and the degree of ecological restoration can be most directly represented by the characteristics of the soil and vegetation in different phases [23]. As for the indicators used to evaluate recovery, it must first be possible to repeatedly measure and assess them over time. Second, indicators should be sensitive to changes in the status of the recovery of the community over time or within key ecosystems, which allows for interactions to be explored. Third, the effects of community- and individual-level experiences also should be considered concurrently [24].

Quarries produce sand and stone used for different purpose, and sandstone ore is generally exposed at the surface. Therefore, most sandstone mining is open-pit mining. Thus, the surface
vegetation and soil must first be stripped off during excavation. During this process, the entire quarry ecosystem is degraded and disappears, primarily due to man-made interference and damage to the ground vegetation. Anthropogenic deforestation and mining has resulted in the destruction of the vegetation community structure, biodiversity reductions, soil erosion, and ecosystem degradation. Mining induces damage to vegetation, exposes the soil layers and leads to soil erosion and soil loss, and forest felling is another primary factor that causes vegetation degradation. Vegetation degradation is a dominant factor driving soil erosion, and both combine to drive the simplification of ecosystem elements and ecological processes. So, it is important to reconstruct the ecosystem and quantify the ecological success of the restoration project.

Ecological restoration assessment is defined by three concepts: evaluation of the results, evaluation of the effects, and evaluation of the benefits. Results evaluation is a comparison with the stated goals or reference system and focuses on the recovery of the ecosystem composition, structure, and pattern. Effect evaluation refers to whether the recovery of the ecological system has positive or negative impacts on other aspects of the environment, such as the influence of vegetation restoration on the water, atmosphere, soil, and other organisms. Benefit evaluation refers to the social, economic, and ecological values following ecosystem restoration. In other words, results evaluation emphasizes the restoration of ecosystem structure and the integrity of the ecosystem; effect evaluation emphasizes the recovery of ecosystem function, that is, the recovery of energy flow, material circulation, and information transfer, which affect ecosystem balance and stability; and benefit evaluation emphasizes the recovery of ecosystem services, that is, the recovery of the capacity to provide services for humans and promote socioeconomic and environmental change, which reflect ecosystem externalities [13].

Quarry mining results in severe environmental damage, which requires a long period of time to undergo a recovery cycle. Therefore, when evaluating ecological recovery, the priority should be to consider the changes in ecosystem composition, structure, and pattern; that is, results evaluation should be dominant. Once the result evaluation is established, and the effects and benefits evaluations can be carried out in the follow up.

3. Methods

3.1. Indicator Development

In this study, potential indicators were initially identified through a systematic review of the literature and categorized based on the Core Capabilities of the Society for Ecological Restoration (SER) International [12]. After aggregating the identified indicators, several methods were used to validate the final list including reviews of the literature, quarry or mining reclamation plans, and recovery plan case studies from CNKI (the largest Chinese literature database) and the Web of Science. A flow chart of the methodology follows (see Figure 1).

![Figure 1](image)

The ecosystem recovery literature was systematically reviewed to identify research related to measuring the recovery progress to extract potential recovery indicators and metrics. First,
citations were obtained from mine and quarry reclamation and recovery management scheme reports, and second, a supplemental University of Tsinghua Libraries Articles+ search was conducted using the keywords “quarry,” “recovery,” and “ecosystem.” A total of 22 scholarly, peer-reviewed articles published between 2010 and 2017 were retrieved from the CNKI database, all of which involved environmental science and resource utilization, mining engineering, building science and engineering, agricultural disciplines, etc. Using the keywords “ecological,” “restoration,” and “quarry” to search the Web of Science database, a total of 60 meetings, five reviews, and 128 articles published between 2010 and 2017 were retrieved. Altogether, a total of 118 peer-reviewed publications and conference presentations were reviewed to determine if they incorporated metrics or measures to gauge the progress of ecosystem recovery (Table 1).

Table 1. The checklist and the corresponding SER Core Capabilities and recovery focus areas.

| Core Capability | Recovery Focus Area | Total Number of Indicators |
|-----------------|---------------------|-----------------------------|
| soil physical and chemical properties | Topsoil sickness, soil texture, organic matter Water content, pH value, compactness Soil quality, available NPK, soil organic carbon | Fei et al., 2009 [25]; Wang, 2009 [26]; Zhang, 2013 [23]; Rivera et al., 2014 [27]; Redente et al., 1997 [28]; Holmes, 2001 [29]; Chenot et al., 2017 [11]; Song, 2008 [30]; Chen, 2009 [31] |
| terrain | Gradient, slope direction Slope damage and slope formation time | Wang, 2009 [26]; Zhang, 2013 [23] |
| climate | Rainfall; Temperature | Wang, 2009 [26]; Zhang, 2013 [23] |
| vegetation | Ratio of native plants to evergreen tree species Vegetation cover, woody plant cover Evenness of trees and shrubs Species diversity, species richness Litter structure Existing vegetation cover Root system status, community structure | Fei et al., 2009 [25]; Zhang, 2013 [23]; Song, 2008 [30]; Liu et al., 2014 [13]; Li, 2010 [32] |
| biodiversity | Animal and plant species richness Biological abundance Existing species | Xu and Chen, 2008 [33]; Hao et al., 2016 [34]; Zhang, 2015 [35] |

(SER means Society for Ecological Restoration; N means nitrogen; P means phosphorus; K means kalium)

Ruiz-Jaén and Aide (2005) [36] summarized and analyzed articles published on “restoration ecology” over 11 years following the founding of the discipline (1993–2003) and found that species diversity, vegetation structure, and ecological processes are the main measures of ecological recovery. In terms of species diversity, researchers typically considered plants in their ecological recovery indicators, which accounted for 79% of the articles, while arthropods accounted for 35%. Vegetation coverage, density, biomass, and height are common measures of vegetation structure and corresponded to 62%, 58%, 39%, and 39% of the studies, respectively. In the research of ecological processes, the use of biological interactions as the ecological recovery indicator accounted for 60%, followed by soil deposits (47%) and organic matter (39%) [30].

Abandoned quarries generally consist of four parts: (1) the quarry rock, that is, the bare wall remaining after ore mining; (2) the stone pit, that is, the pit that forms as quarrying progresses; (3) rock dumps, which are produced by the stripping of the topsoil and rubble during the mining process; and (4) the storage and transportation platform, that is, the ore deposit, processing, and transport platform, which is an area of flat land after mining. The factors that restrict quarry recovery are shown in Table 2.
Table 2. Structural characteristics and key elements restricting the ecological restoration of quarries.

| Structure                  | Characteristics                                                                 | Key Ecological Restoration Elements                                                                 |
|----------------------------|--------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| waste stacking yard        | Stacked stripped topsoil and mining gangue. Loose sand and gravel structure with a gentle gradient. | Soil matrix improvement. Topsoil restoration. Gentle gradient to promote survival of the flora. Vegetation restoration is the key element. |
| remaining excavation slope | Gentle gradient, usually between 40 and 70 degrees. Hard rock and stone with scant soil on top. | Soil matrix improvement. Reinforcement of the slope and fixation of surface soil to ensure habitat for flora. |
| platform or pithead        | Hard rock remaining after the excavation of the stone.                           | Soil matrix improvement. Soil dressing to form a soil profile at least 20-cm thick on the platform surface. |
| stonewall                  | Smooth slope surface and steep gradient without any soil.                        | Restore soil. Hang net spray grass and incorporate comprehensive slope engineering technology.          |

3.2. Indicator Validation

As a first step in validating the indicators identified in the literature, quarry recovery plans whose contents had been analyzed for another project were reviewed to determine whether the indicators were used in practice. Sixty-nine recovery plans had previously been collected from all of China and included the quarries in Beijing City [23,30,37,38], Chongqing City [39], Guangdong Province [40], Hunan Province [31], Zhejiang Province [26,41], Guangxi Province [42], Jiangsu Province [43,44], and so forth; these plans were included in this study if they scored above the overall mean in the original plan quality assessment [45]. Each of these plan-based indicators could be categorized within aggregate indicators, illustrating that all of the plan-based indicators validated the existing literature-based indicators. Table 3 shows the quarries with recovered ecosystems and validated recovery evaluation indicators.

Table 3. The validated recovery evaluation indicators.

| Quarry Location                      | Author                  | Track Time | Recovery Evaluation Indicator                                                                 |
|--------------------------------------|-------------------------|------------|------------------------------------------------------------------------------------------------|
| Beijing, Changping, Fangshan District | Zhang, 2013 [23]       | 2a         | Soil, plant species, Simpson and Shannon indicators                                            |
| Beijing, Miyun County                | Li, 2010 [32]           | 13a        | Plant community structure, soil physical and chemical properties                              |
| Beijing, Fangshan, Huangyuan Village | Zhang et al., 2013 [38] | 1-3a, 3-5a, 5-10a | Species importance value, diversity, richness, and evenness                                   |
| Beijing, Fangshan, Ligezhuang Village | Liu, 2011 [37]        | 2a         | Soil seed bank, plant community structure                                                     |
| Beijing, Mentougou District, Xishan   | Song, 2008 [30]         | 1, 5, 15, 32a | Soil seed bank and physical and chemical properties, community structure                      |
| Zhejiang Province, Zoushan City      | Chang and Wang, 2011 [46]| 6a         | Soil physical and chemical properties                                                          |
| Hunan Province, Hengyang City        | Chen, 2009 [31]         | 50a        | Plant community structure and species, Shannon and Simpson indicators                         |
| Shandong Province, Zibo City         | Han et al., 2008 [47]   | 50a        | Plant community characteristics                                                                |
| East China region                    | Wang, 2009 [26]         | 25a        | Soil physical and chemical properties, plant community structure                              |
| Hubei Province, Huangshi City        | Shao et al., 2014 [48]  | 3a         | Soil physical and chemical properties                                                          |
Therefore, based on the above validated evaluation indicators and the Core Capabilities proposed by SER International, we consolidated the ecosystem restoration evaluation indicators as follows (see Table 4).

Table 4. Indicator system to evaluate quarry ecological restorations.

| Elements               | Indicators                                           | Indication                                      |
|------------------------|------------------------------------------------------|-------------------------------------------------|
| Ecological Process Indicator | Top soil sickness, Soil bulk density/soil moisture, Soil available N, P, K, Soil organic matter, Soil enzyme activity | Bearing capacity, Water/fertility retaining ability, Soil productivity/carrying capacity |
|                        | Species of arbor layer, Species of shrub layer, Species of herb layer, Shannon diversity index, Ecological dominance indicator, Pioneer species, Constructive species | System productivity, Energy storage and conversion capacity, Community structure and function Ecological niche diversity |
|                        | Soil microbial diversity, Soil microflora diversity, Soil fauna functional group diversity, Biomass | Niche diversity, Diversification of decomposition process and material circulation, Material cycle diversification |

The plan-based indicators were then reviewed to identify potential metrics to be added to the list of possible measurements, and the case studies highlighted the potential use of the recovery indicators by a community to evaluate recovery success based on actual recovery experiences. The validation of the indicators through case studies may elucidate potential sources of data to evaluate the ongoing ecosystem recovery of a quarry as well as its pre-disaster baseline status. In addition, the case studies may help further demonstrate how local planning can be used to fulfill national recovery priorities as outlined in the Core Capabilities.

4. Results and Discussion

Ecological processes are interrelated; an ecological system can achieve “structure-function-service” integration. From the above mentioned, we found that the indicator system used to evaluate an ecological restoration must be composed of three aspects: vegetation structure, ecological process, and ecological function (the soil physical and biochemical characteristics and subsurface water system are already included in the ecological process). Among the ecological process indicators, the soil thickness, quality, parent material (lithology), and physical and chemical properties characterize the
soil-bearing capacity and soil fertility after restoring quarry waste dumps and the platform (or pithead) via soil dressing measures.

The nutrient and enzyme activities characterize the diversification of the soil material cycling process and the carrying capacity of the land [35]. The effects of an ecological restoration are usually measured by the attributes of ecological systems, such as the biodiversity, vegetation structure, and ecological processes [9,53]. The quantity of biological species, the rate of biomass increase, the soil physical and chemical properties, etc. are among the recognized indicators of ecological restoration [34,54]. The soil seed bank is the sum of all seeds surviving in the aboveground litter and the soil [55] and represents the latent phase of the plant population. On the one hand, the ground vegetation is the direct provenance of many species in the soil seed bank, and the biological rhythm and seasonal changes in the ground vegetation influence the composition, size, and dynamics of soil seed banks. On the other hand, seeds in these banks can participate in the natural regeneration of the ground vegetation by germinating and forming sturdy seedlings, which directly affect the structure, composition, and biodiversity of the ground plant community [56,57]. Changes in the soil properties, nutrient cycling, and biological interactions are ecological processes that can reflect the success of an ecosystem restoration. The recovery of biological interactions is essential for long-term ecosystem functioning.

In the vegetation structure indicator, the Shannon diversity indicator is used to estimate the diversity of a community. When only one population is observed in the community, the Shannon indicator is equal to 0; when there are more than two populations in a community and only one member in each population, the Shannon indicator reaches the maximum value. The Shannon diversity indicator is a good method of characterizing the statistics of community diversity in an ecosystem restoration; therefore, it is suitable for evaluating ecological restorations. Dominant species have the highest number of individuals in each layer of the community and are the most important species in the layer because these species have the largest ecological role and determine the basic characteristics of the layer. The edificatory plant is the dominant species in the upper layer of a plant community, and it is usually the community constructor. The constructive species determines the appearance of the community and restricts other components of the community (including plants, animals, and microorganisms). Therefore, the species included in the restoration of ecological systems must be considered, and constructor species are important in the evaluation of the restoration scheme.

The purpose of the restoration project should be to restore the most dominant species in the primary functional groups, rather than a specific number of species [58]. This method is practical and can achieve the most important goal, which is achievable in most recovery projects. Pioneer species are species in the early stages or in the mid-stage of the succession of ecological communities. Pioneer species appear earlier and survive relatively easily, and they play a constructive role in the ecological restoration of communities in the ecological restoration framework. However, the maximum biological diversity method can be used to conduct artificial restorations, which eliminates the need to introduce pioneer species. However, in areas where recovery is relatively difficult or where the habitat conditions are not sufficient, the emergence of pioneer species plays an important role in community construction. The vegetation structure indicator represents the community ecosystem productivity, the energy storage and conversion capacity, and the ecological niche diversity and its complicated functions in the community ecosystem. The restoration of vegetation communities is a prerequisite for the restoration of animal communities and ecological processes. Therefore, vegetation communities can be considered evaluation indicators, and they are easy to measure with low processing time.

Among the ecological function indicators, soil organisms regulate ecological processes, such as decomposition, nutrient mineralization, etc., and microorganisms play an important role in the ecosystem by participating in nutrient cycling, organic matter degradation, and energy flow. The generation cycle of arthropods is short; therefore, these organisms can reflect inter-annual variations in the recovered plots. Small arthropod species can effectively monitor subtle but important diversification factors that may affect the habitat quality. The flora community impacts
the arthropods’ food structure, habitat, natural enemy species, population dynamics, and fecundity, which then affects the diversity and richness of the plant communities. However, the diversity of the arthropod community also influences the structure, function, stability, and ecological processes of the ecosystem [59]. Arthropods directly or indirectly use the vegetation as food and habitat; therefore, they are sensitive to disturbances in the composition of the plant community. Changes in the diversity and complexity of the arthropod community could reflect habitat degradation; therefore, these organisms could play a role as a large-scale ecosystem biodiversity indicator in the evaluation of ecological restoration projects.

5. Conclusions

Quarry mining devastates vegetation and the related ecosystem functions; thus, vegetation restoration may be severely restricted by site conditions. In addition, plant recovery is usually slow and the remaining plants may persist in the grass and shrub stages for a long time. For natural restoration and long-term ecological restoration, the “plant community characteristics” are more suitable for use as the recovery evaluation indicator, and the proportion of native species is suitable for characterizing the degree of degradation of the ecosystem because such restorations tend to correspond to the succession of the original habitat.

In a quarry, the surface soil may be stripped, which destroys the local vegetation community and greatly reduces the number of species. Due to the lack of soil and nutrients, low soil activity and serious soil erosion are key factors limiting ecological restorations of quarries. Soil is the foundation for the ecological restoration of the vegetation community. For areas where the soil has been stripped off the surface, the soil layer thickness is the most important recovery factor. The soil physical and chemical properties, structure, and nutrient indicators in the current recovery assessment indicator can be directly referenced to select the quarry soil recovery evaluation index, and soil microbes, including the soil macrofauna and soil bacteria, provide important ecological functions for the recovery of the plant-soil system. Soil microorganisms can help community reconstruction and increase feedback in the material circulation and energy flows in the ecosystem processes on the ground or underground, and their behavior is indicative of soil dynamic recovery, which is conducive to promoting the recovery and cohesion of all ecological processes.

The restoration of the ecological system of the abandoned quarry represents the restoration of self-maintaining and self-regulating functions within a complex “human-natural-economic” ecosystem, which is influenced by human disturbances and natural factors. The ecosystem management of quarries focuses on the recovery of the ecosystem “structure-process-function” integration, which can stimulate the self-repair function of the ecosystem and eventually generate an ecosystem that exhibits a dynamic balance and the relative stability of self-maintenance. The preliminary evaluation indicators described above were selected for the evaluation of degraded ecosystem restorations. However, to improve and test the indicators to determine their usefulness in restoration evaluations and monitoring system construction, the indicators must move beyond a theoretical discussion and be implemented in practical investigations to determine whether they can promote research on the evaluation, monitoring, early warning, and restoration of degraded ecosystems caused by human interference.

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References

1. Li, Q.; Chen, Y.L.; Zhou, X.Y.; Bei, R.T.; Yin, L.H.; Xiong, Z.P. Assessment of ecological restoration of degraded ecosystem and its biodiversity. *J. Northwest For. Univ.* **2008**, *23*, 69–73.
2. Wang, J.; Li, Z.; Hu, X.; Wang, J.; Wang, D.; Qin, P. The ecological potential of a restored abandoned quarry ecosystem in Mt. Mufu, Nanjing, China. *Ecol. Eng.* **2011**, *37*, 833–841. [CrossRef]
3. Simón-Torres, M.; del Moral-Torres, F.; de Haro-Lozano, S.; Gómez-Mercado, F. Restoration of dump deposits from quarries in a Mediterranean climate using marble industry waste. *Ecol. Eng.* **2014**, *71*, 94–100. [CrossRef]

4. El-Taher, A.; García-Tenorio, R.; Khater, A.E.M. Ecological impacts of Al-Jalamid phosphate mining, Saudi Arabia: Soil elemental characterization and spatial distribution with INAA. *Appl. Radiat. Isot.* **2016**, *107*, 382–390. [CrossRef] [PubMed]

5. Corbett, E.A.; Anderson, R.C.; Rodgers, C.S. Prairie revegetation of a strip mine in Illinois: Fifteen years after establishment. *Restor. Ecol.* **1996**, *4*, 346–354. [CrossRef]

6. Milgrom, T. Environmental aspects of rehabilitating abandoned quarries: Israel as a case study. *Landsc. Urban Plan.* **2008**, *87*, 172–179. [CrossRef]

7. Mouflis, G.D.; Gitas, I.Z.; Iliadou, S.; Mitri, G.H. Assessment of the visual impact of marble quarry expansion (1984–2000) on the landscape of Thasosisland, NE Greece. *Landsc. Urban Plan.* **2008**, *86*, 92–102. [CrossRef]

8. Pinto, V.; Font, X.; Salgot, M.; Tapias, J.; Mañá, T. Image analysis applied to quantitative evaluation of chromatic impact generated by open-pit quarries and mines. *Environ. Geol.* **2001**, *41*, 495–503. [CrossRef]

9. Boscutti, F.; Vianello, A.; Bozzato, F.; Casolo, V. Vegetation structure, species life span, and exotic status elucidate plant succession in a limestone quarry reclamation. *Restor. Ecol.* **2017**, *25*, 595–604. [CrossRef]

10. Carrick, P.J.; Krüger, R. Restoring degraded landscapes in lowland Namaqualand: Lessons from the mining experience and from regionalecological dynamics. *J. Arid Environ.* **2007**, *70*, 767–781. [CrossRef]

11. Damigos, D.; Kaliampakos, D. Assessing the benefits of reclaiming urbanquarries: A CVM analysis. *Landsc. Urban Plan.* **2003**, *64*, 249–258. [CrossRef]

12. Chenot, J.; Jaunatre, R.; Buisson, E.; Dutoit, T. Long-term effects of topsoil transfer assessed thirty years after rehabilitation of dry alluvial quarries in Southeastern France. *Ecol. Eng.* **2017**, *99*, 1–12. [CrossRef]

13. Society for Ecological Restoration International Science and Policy Working Group (SER). The SER International Primer on Ecological Restoration. 2004. Available online: http://www.ser.org (accessed on 1 January 2018).

14. Liu, X.F.; Wang, W.J.; Li, J.; Wang, W.; Gao, Z. Research advances and prospects of post-disaster ecological restoration assessment. *Acta Ecol. Sin.* **2014**, *34*, 527–536.

15. Bradshaw, A.D. Restoration ecology as a science. *Restor. Ecol.* **1993**, *1*, 71–73. [CrossRef]

16. Hobbs, R.J.; Norton, D.A. Towards a conceptual framework for restoration ecology. *Restor. Ecol.* **1996**, *4*, 93–110. [CrossRef]

17. Lake, P.S. On the maturing of restoration: Linking ecological research and restoration. *Ecol. Manag. Restor.* **2001**, *2*, 110–115. [CrossRef]

18. Alexander, G.G.; Allan, J.D. Ecological success in stream restoration: Case studies from the Midwestern United States. *Environ. Manag.* **2007**, *40*, 245–255. [CrossRef] [PubMed]

19. Yang, Z.P.; Gao, J.X.; Zhou, K.X.; Zheng, H.; Wang, Y.; Li, H.M. Evaluation of ecological restoration: Research progress. *Chin. J. Ecol.* **2013**, *32*, 2494–2501.

20. Ding, J.Y.; Zhao, W.W. Progress and Prospects on Evaluation of Ecological Restoration: A Review of the 5th World Conference on Ecological Restoration. *J. Appl. Ecol.* **2014**, *25*, 2716–2722.

21. Peng, S. *Restoration Ecology*: China Meteorological Press: Beijing, China, 2007.

22. Li, Z.C.S. *Synecolgy*: Meteorological Press: Beijing, China, 2011.

23. Zhang, H. Study on the Technology of Ecological Restoration in Huangyuan Village Quarry Loose Deposits of Beijing Fangshan Region. Ph.D. Thesis, Beijing Forest University, Beijing, China, 2013.

24. Horney, J.; Dwyer, C.; Aminto, M.; Berke, P.; Smith, G. Developing indicators to measure post-disaster community recovery in the United States. *Disasters* **2017**, *41*, 124–149. [CrossRef] [PubMed]

25. Fei, Y.; Ke, L.; Wang, Q. Study on evaluation system of quality in artificial vegetation restoration of abandoned quarry. In Proceedings of the Symposium of National Seminar on Soil and Water Conservation and Ecological Restoration, Xian, China, September 2009; pp. 221–226.

26. Wang, Q. Study on the Characteristics of Natural Restoration and Artificial Ecological Restoration of Quarry in East China. Ph.D. Thesis, Beijing Forest University, Beijing, China, 2009.

27. Rivera, D.; Mejías, V.; Jäuregui, B.M.; Costa-Tenorio, M.; López-Archilla, A.I.; Peco, B. Spreading topsoil encourages ecological restoration on embankments: Soil fertility, microbial activity and vegetation cover. *PLoS ONE* **2014**, *9*, e101413. [CrossRef] [PubMed]

28. Redente, E.F.; Mcendon, T.; Agnew, W. Influence of topsoil depth on plantcommunity dynamics of a seeded site in northwest Colorado. *Arid Soil Res. Rehabil.* **1997**, *11*, 139–149. [CrossRef]
29. Holmes, P.M. Shrubland restoration following woody alien invasion and mining: Effects of topsoil depth, seed source, and fertilizer addition. *Restor. Ecol.* **2001**, *9*, 71–84. [CrossRef]

30. Song, B.M. The Studies on the Ecological Restoration in Abandoned Quarry in Xishan Mountain in Beijing: Process, Characters and Mechanism of Natural Restoration. Ph.D. Thesis, Shandong University, Jinan, China, 2008.

31. Chen, J. Study on plant diversity at an early ecological restoration stage on an abandoned quarry. *Chin. Agric. Sci. Bull.* **2009**, *25*, 210–214.

32. Li, J.F. Study on Quality Assessment of Ecological Restoration in Mine Derelict Land in Beijing. Ph.D. Thesis, Beijing Forest University, Beijing, China, 2010.

33. Xu, L.S.; Chen, L.D. Progresses of evaluation on ecological restoration environmental effect. In Proceedings of the Fifth Conference on Chinese Youth Ecology Workers, Guangzhou, China, 15–16 November 2008; Volume 11, pp. 7–13.

34. Hao, J.; Guo, D.; Shangguan, T. Ecological performance assessment on early plant reclamation in coal gangue yard. *Acta Ecol. Sin.* **2016**, *36*, 1946–1958.

35. Zhang, H. Study on the evaluation index and restoration of Karst degraded ecosystems based on the structure-process-function integration. *Ecol. Sci.* **2015**, *34*, 205–210.

36. Ruiz-Jaén, M.C.; Aide, T.M. Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. *For. Ecol. Manag.* **2005**, *218*, 159–173. [CrossRef]

37. Liu, Y.G. Evaluation of Artificial Restoration Effect of the Abandoned Mines in Beijing. Ph.D. Thesis, Beijing Forest University, Beijing, China, 2011.

38. Zhang, Y.; Zhao, T.; Shi, C.; Wu, H.; Li, D. Dynamic research on vegetation recovering in abandoned mine slopes in Beijing mountainous areas. *J. Arid Land Resour. Environ.* **2013**, *27*, 61–66.

39. Ning, F.S.; You, X.; Yang, H.L. Countermeasures for ecological and landscape restoration of abandoned quarries in urban district of Chongqing City. *Bull. Soil Water Conserv.* **2005**, *3*, 77–80.

40. Yang, H.J.; Bi, Q.; Zhao, Y.N.; Feng, F.J. Vegetation restoration technology in freeway slope and quarry of Shenzhen. *Chin. J. Ecol.* **2004**, *23*, 120–124.

41. Yin, J.Z.; Zhu, K.H.; Shi, X.Y.; Han, C.; Gu, B. Vegetation restoration and soil properties on rocky slope in Qingfeng Quarry. *Bull. Soil Water Conserv.* **2012**, *1*, 144–149.

42. Tang, Z.; Li, J.G.; Hui, L.I. Rapid responses of soil microbes and active organic carbon to eco-restoration in karst region. *Ecol. Environ. Sci.* **2014**, *23*, 1130–1135.

43. Wang, X.H.; Zhu, X.D.; Li, Y.F. Landscape pollution assessment and ecological restoration technology on quarries in the Tai Lake District of Changzhou City. *Bull. Soil Water Conserv.* **2006**, *26*, 89–93.

44. Yu, L. Ecological restoration and sustainable utilization of abandoned quarry. *China Constr. Inf.* **2012**, *7*, 110–112.

45. Berke, P.; Cooper, J.; Aminto, M.; Grabich, S.; Horney, J.A. Adaptive planning for disaster recovery and resiliency: An evaluation of 87 local recovery plans in eight states. *J. Am. Plan. Assoc.* **2014**, *80*, 310–323. [CrossRef]

46. Chang, Z.; Wang, Q. Study on the soil and plant community characteristics at an early ecological restoration stage in an abandoned quarry. In Proceedings of the International Conference on Agricultural and Natural Resources Engineering Advances in Biomedical Engineering, Hannover, Germany, November 2011; Volumes 3–5.

47. Han, F.; Li, C.R.; Sun, M.G.; Fan, Y.X.; Zhao, F.; Lu, S.S.; Fu, Y. Plant community structure at an early ecological restoration stage on an abandoned quarry in Sibao Mount. *J. Cent. South Univ. For. Technol.* **2008**, *2*, 35–49.

48. Shao, Y.R.; Xu, J.X.; Xue, L. Soil characteristics changes during ecological restoration of abandoned quarries in Huangshi, Hubei. *J. Cent. South Univ. For. Technol.* **2014**, *34*, 82–89.

49. Shi, L. Effects and Evaluation of Vegetation Recovery for Limestone Quarry Wasteland in Western Beijing. Ph.D. Thesis, Beijing Forest University, Beijing, China, 2014.

50. Hong, P. Research for the Distribution of Vegetation Restorated Naturally oMentougou Quarries Wasteland. Master’s Thesis, Beijing Forest University, Beijing, China, 2008.

51. Trueman, M.; Hobbs, R.J.; Van Niel, K. Interdisciplinary historical vegetation mapping for ecological restoration in Galapagos. *Landsc. Ecol.* **2013**, *28*, 519–532. [CrossRef]
52. Dutoit, T.; Buisson, E.; Fadda, S.; Henry, F.; Coiffait-Gombault, C.; Jaunatre, R.; Alignan, J.-F.; Masson, S.; Bulot, A. The pseudo-steppe of La Crau (South-Eastern France): Origin, management and restoration of a Mediterranean rangeland. In *Steppe Ecosystems: Biological Diversity, Management and Restoration*; Morales Prieto, M.B., Traba Diaz, J., Eds.; Nova Publishers: New York, NY, USA, 2013; p. 347.

53. Liu, F.; Lu, L. Progress in the study of ecological restoration of coal mining subsidence areas. *J. Nat. Res.* **2009**, *4*, 612–620.

54. Zhong, S. *Study on the Theoretical System and Evaluation Method of Ecological Restoration of Abandoned Mine*; Liaoning Engineering and Technical University: Fuxin, China, 2006.

55. Simpson, R.L. *Ecology of Soil Seed Bank*; Academic Press: San Diego, CA, USA, 1989.

56. Li, F.R.; Zhao, L.Y.; Wang, S.F. Effects of enclosure management on the structure of soil seed bank and standing vegetation in degraded sandy grasslands of eastern Inner Mongolia. *Acta Pratac. Sin.* **2003**, *12*, 90–99.

57. Yang, Y.J.; Sun, X.Y.; Wang, B.P. Forest soil seed bank and natural regeneration. *J. Appl. Ecol.* **2001**, *12*, 304–308.

58. Montoya, D.; Rogers, L.; Memmott, J. Emerging perspectives in the restoration of biodiversity-based ecosystem services. *Trends Ecol. Evol.* **2012**, *27*, 666–672. [CrossRef] [PubMed]

59. Dimond, J. Reflections on goals and on the relationship between theory and practice. In *Restorations Ecology: A Synthetic Approach to Ecological Research*; Jordan, W.R., III, Gilpin, N., Aber, J., Eds.; Cambridge University Press: Cambridge, UK, 1987; pp. 329–336.

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