Chapter 19
Challenges in the Restoration of Quartzitic and Ironstone Rupestrian Grasslands

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Abstract Actively restoring ecosystems that have "been degraded, damaged or destroyed" became imperative in face of worldwide human impacts on nature. For rupestrian grasslands which are so peculiar and restricted in range, but also subjected to strong impact pressures, this seems to be even more important. Making use of ecological knowledge is fundamental to cope with the many uncertainties inherent to the process of ecological restoration. The overview on the ecology of rupestrian grasslands provided by this book thus is of utmost importance for the progress on this ecosystem's restoration and conservation. We benefit from this by invoking other chapters to base our assumptions and then present extant and possible ways of applying the ecological knowledge gathered. We summarize the academic background on restoration related to rupestrian grasslands, including examples of scientific restoration experiments, plant species with potential for restoration, among other aspects. We then point out potential restoration techniques and potential indicators of functional recovery during the restoration process. The problems imposed by invasive species on the process of restoration are highlighted due to its striking importance for restoration success and sustainability over time. Finally, we outline current gaps and challenges and indicate future directions to the ecological restoration of these ecosystems. This chapter represents the first attempt to review the efforts towards the ecological restoration of rupestrian grasslands at both scientific and technical perspectives.

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19.1 Introduction

Human impacts worldwide have led to the notion that ecosystem restoration is necessary and that it is only possible by intentionally assisting the recovery of ecosystems that have "been degraded, damaged or destroyed" (SER 2004). According to a survey made by Laestadius et al. (2011) more than two billion hectares of degraded land in the world are in need of restoration (but see Veldman et al. 2015a). In spite of the many idiosyncrasies of some ecosystems, along with general scientific and practical challenges, ecological restoration has progressed immensely in the last few decades. However, the restoration of harsh ecosystems, such as rupestrian grasslands, is not an easy task due to their many unique characteristics.

The restoration of any ecosystem inevitably relies on the knowledge of its ecology. This first substantial attempt on gathering knowledge on the ecology of rupestrian grasslands in the form of a book immensely benefits the development of restoration strategies for this ecosystem. Therefore, throughout the present chapter, we frequently reference other chapters in the book that provide the ecological basis for restoration. Here we focus on how this ecological knowledge can be applied to the restoration of rupestrian grasslands, and we urge the reader to consult the referenced chapters for further details on the ecological aspects of this ecosystem.

Some general considerations must be made in order to set the scene for developing strategies for restoration of rupestrian grasslands. Brazilian rupestrian grasslands are primarily restricted to mountaintops, which are often spatially separated (see details and maps in Chaps. 2 and 23). They are characterized by ironstone, quartzite or sandstone rock outcrops with rocky and sandy soils (see Chaps. 2 and 23) and with limited water availability, which can be considered harsh or even extreme conditions for the organisms that live in there (Chap. 4). This setting probably led to the highly diverse and endemic vegetation (see Hopper 2009; Chap. 6), which is often dependent on mutualistic interactions with microorganisms for their existence (Chaps. 8 and 13). The need to cope with the harsh environment has led to a variety of adaptive strategies (see Chaps. 11 and 12). In addition, rupestrian grasslands are subjected to the occurrence of occasional fires (Chap. 18).

A considerable portion of the Rupestrian Grassland ecosystem is under direct and indirect influence by mineral exploitation. Open pit mines, for example, completely alter the terrain to reach minerals. Mining has a profound impact on rupestrian grasslands, altering irreversibly the natural conditions established in ancient times (Veldman et al. 2015a, b; Chap. 23). A recently published article by Fernandes et al. (2014) highlights the compounding threats and the lack of specific conservation goals for the conservation of the Rupestrian Grassland (see also Chap. 23). One thing is clear, that the impacts of mining, roads, and real estate development have left thousands of hectares of the Rupestrian Grassland ecosystem in need of restoration. Once the rupestrian grassland vegetation-environment link collapses, due to the typical dependence of plants on specific site conditions, plant reproductive output is limited and new plant establishment decreases, thereby making natural regeneration difficult (Negreiros et al. 2011; Le Stradic et al. 2014a). To our knowledge, no one has yet provided empirical information on the natural regeneration of degraded rupestrian grasslands. Therefore, active restoration measures are necessary in the recovery of rupestrian grasslands.

This chapter represents the first attempt to review the efforts specifically directed towards the ecological restoration of rupestrian grasslands. We bring to light results from scientific studies on rupestrian grassland restoration, plant species with potential for restoration, and potential indicators of functional recovery during the restoration process. We also highlight the problems posed by invasive species to the process of restoration and illustrate these points with results from field experiments on the restoration of rupestrian grasslands. Finally, we summarize current gaps in knowledge and other emerging challenges and outline future directions for ecological restoration of this ecosystem.

19.2 Why Restore Rupestrian Grasslands?

The restoration of the unique and rare habitats associated with the Rupestrian Grassland ecosystems is a legal obligation, and is supported by Brazilian federal laws (Decree 97.632/1989 and decree 4.339/2002 which focus on the principles of the national policy for biodiversity; law 6.938/1981 that specifies the restoration of areas exploited by mining operations), as well as many state and municipal laws. Hence, restoration is a legal obligation. There are also accessory regulations, such as instruction ABNT 13030/1999, that call for the restoration of mined areas with native species. This norm, however, is already outdated and in need of urgent revision, especially with regard to more precise techniques and the exclusive use of local native species.

A second reason for restoration is that disturbed areas represent serious sources of impact on the Rupestrian Grassland ecosystem, with its low resilience, which results in the loss of biodiverstity and a decrease in the provision of ecosystem services (see Resende et al. 2013; Nunes et al. 2015; Chaps. 21 and 23). Furthermore, degraded areas may impact pristine environments far away from the original site of impact, including the silting of springs and other water bodies.

19.3 Sound Scientific Knowledge for the Development of Restoration Know-How

For long lasting and effective ecological restoration of the Rupestrian Grasslands, sound scientific knowledge is imperative. While restoration of many Brazilian ecosystems focuses on planting of trees—sometimes using non-native species, which critically needs to be discussed—the restoration of the harsh Rupestrian Grassland is much more challenging. Restoration is made difficult by the low survival rate of unassisted plants in the field due to drought and unpredicatable rainfall, which are common in the Rupestrian Grassland. Widely used restoration practices seem not applicable to the Rupestrian Grassland, and creativity in the development of appropriate restoration methods is urgently needed.

There is an urgent need to acquire basic knowledge on soil properties, habitat and microsite conditions, and on vegetation (preferentially from thorough studies on the flora and the definition of a reference ecosystem) to push forward the development of restoration techniques for the Rupestrian Grassland. Although there has been some increase in the study of the basic biology of potential plant species to be used in restoration, restoration technology must benefit from that knowledge and further develop it. Seed germination studies of rupestrian plant species increased over the last decade (see review in Chap. 10). These studies have helped in the development of sound ecological theory to subsidize the conservation of threatened species, but are also useful for the development of ecological restoration strategies (e.g., Gomes and Fernandes 2002; Chap.10). But not all species are suitable for the rigors of initiating restoration in the harsh and nutrient poor Rupestrian Grassland; hence, we ought to increase the number of studies on seed germination as well as stimulate more focused studies on the species best suited for initial restoration.

19.3.1 Reference Ecosystem

Perhaps the first step towards ecological restoration of the Rupestrian Grassland is to establish a reference ecosystem. In general, a reference ecosystem can be defined as “one or more existing, former, or hypothetical ecosystems that serve as a guiding image for ecosystem restoration or mitigation projects” (Miller et al. 2012). A reference ecosystem represents a target, reference, standard model, or mold to which the biological integrity, structure, function, condition or relative health of the ecosystem(s) under restoration can be compared (Jensen et al. 2000). Reference is basically a point of comparison, which can be conceptual, spatial (an environment), conditional (ecological states) or functional. Reference ecosystems are especially important to evaluate restoration success (SER 2004; Steyer et al. 2006; Miller et al. 2012).

Information that could be used for the description of a reference ecosystem in the Rupestrian Grassland includes: ecological descriptions, species lists and maps of the project site prior to degradation; historic and current photographs of the area at ground level; remnants of the site to be restored indicating previous physical conditions and biota; ecological descriptions and species lists from similar intact ecosystems; information from herbariums and museums; palaeoecological data such as fossil pollen, charcoal, history from tree growth rings, among others; and oral stories from people familiar with the project site prior to the damage (SER 2004).

While the theoretical definition of a reference ecosystem is more or less clear, its application in practice is a large problem for Rupestrian Grasslands, given their extremely rich flora and fauna and their high beta-diversity (Chaps. 1, 6 and 23). Local variation in habitats within small areas is very large and dependent on the lithotypes, as nicely demonstrated by the study of Dorr (1969) in the Iron Quadrangule. Carvalho et al. (2012), working on a single small area at a single elevation, recorded the existence of many distinct habitats in the quartzitic rupestrian grassland, each with different soil microorganisms and distinct flora, and consequently different resilience and functioning. The same richness of habitats is also found in the ironstone grasslands in northern Brazil. Although no one has yet attempted to delve into the subject and address this key question, this knowledge is central to both academics and practitioners. The ecological restoration of the Rupestrian Grassland must incorporate the unique local variations that provide the true identity of the ecosystem as a whole. Therefore, urgent work is called for to unravel the environmental signature of the Rupestrian Grassland so that ecological restoration can be acheived at its maximum.

19.3.2 Background Knowledge on Plant Species Propagation

In order propagate a native species for use in restoration basic information on its reproductive mode, germination, growth, performance, natural history and interactions with other organisms in the community is needed. A survey on availability of scientific studies on the propagation of ironstone rupestrian plant species was conducted for plant species reported to occur in the Iron Quadrangule (Table 19.1) and in Carajás (Table 19.2) (Scielo and Web of Science—1945 to 2012). The list of plant species surveyed originated from a compilation of species names reported from publicly available unpublished environmental assessment reports. Although we cannot ascertain with precision the correct taxonomic identification of the plant species of the reports by specialists, these are official documents and important material for consultation. On the other hand, some caution is necessary to interpret such reports. For instance, some native Brazilian species found in both lists are also repeatedly reported as noxious weeds in cultures, as noted in the references listed in the tables.

Table 19.1 presents a list of only 38 out of the 500 species that have been cited for the rupestrian grasslands of the Iron Quadrangule for which information on propagation was found. Plant species known to be non-native to Brazil were removed, as they are mostly invasive species (*Bidens pilosa*, *Solanum americanun*). Scientific information on propagation was found for only 7.6 % of 500 species surveyed. Most species for which some information was found are also recorded in other ecosystems while others are cosmopolitan (based on information at http://floradobrasil.jbrj.gov.br/jabot/listaBrasil). Out of the 38 species, 11 (29 %) are known to be endemic to the Cerrado, Atlantic Forest and Caatinga biomes, which are the biomes with which the Iron Quadrangule ironstone grassland should have the greatest affinity. However, they represent only 2.2 % of the total 500 plant species considered.

For the 541 species listed to occur in the ironstone rupestrian grasslands of Carajás, only 43 (7.9 %) had some information on their propagation. Twelve plant species were removed from this initial list: 6 species were not listed in the Brazilian flora (*Calathea ornata*, *Cyathea delgadii, Gleichenella pectinata, Heliconia birrai, Lycopodiella cernua, Nephrolepis bisserata*); five species are known as exotic invasive species (*Crotalaria juncea, Digitalia horizontalis, Digitalia insularis, Eleucine indica, Urocloa brizantha*). *Mimosa pudica* (Fabaceae) (http://floradobrasil.jbrj.gov.br/jabot/listaBrasil), a native species, was removed because it has been observed invading many areas in Carajás, suppressing the growth of native species (GWF, pers. obs.). Most species listed are also found in other ecosystems while others are cosmopolitan. Information is provided for only 31 species (5.7 %). Out of these, seven species (23 %) are known to be endemic to the Amazon and/or Cerrado biomes, which are the biomes with which the ironstone grassland of Carajás should have the greatest affinity. This represents only 1.3 % of the total 541 plant species considered.

Table 19.1 Native plant species found in unpublished lists of rupestrian grassland plants in the Iron Quadrangule, Brazil, for which some scientific data on propagation is available (Web of Science 1945–2012)

Family	Species	Occurrence	Propagation	Reference (e.g.)
Asteraceae	*Baccharis dracunculifolia*	Ce, Ma, Pm	Seed	Gomes and Fernandes (2002)
	Chresta sphaerocephala	Ce	Seed	Cury et al. (2010)
	Conyza bonariensis	All	Seed	Vidal et al. (2007)
	Eremanthus erythropappus	Ce, Ma	Seed	Rosal et al. (2007)
	Eremanthus incanus	Ca, Ce, Ma	Seed	Velten and Garcia (2005)
	Lychnophora pinaster	Ce	Seed	Melo et al. (2007)
Bignoniaceae	*Pyrostegia venusta*	All	Seed	Rossato and Kolb (2010)
Bromeliae	*Tillandsia gardneri*	Ca, Ce, Ma, Pm	Seed	Scatena et al. (2006)
	Tillandsia geminifolia	Ca, Ce, Ma, Pm	Seed	Stringheta et al. (2005)
	Tillandsia stricta	Ca, Ce, Ma, Pm	Seed	Scatena et al. (2006)
Cactaceae	*Epiphyllum phylanthus*	Az, Ca, Ce, Ma, Pl	Seed	Simão et al. (2010)
	Hylocereus setaceus	Az, Ca, Ce, Ma	Seed	Simão et al. (2010)
Cecropiaceae	*Cecropia glaziouvii*	Ce, Ma	Seed	Godoi and Takaki (2005)
	Cecropia pachystachya	Az, Ca, Ce, Ma Pl	Seed	Valio and Scarpa (2001)
Commelinaceae	*Commelina erecta*	Az, Ca, Ce, Ma Pl	Seed	Nisensohn et al. (2011)
Fabaceae	*Chamaecrista desvauxii*	Az, Ca, Ce, Ma, Pl	Seed	Caldeira et al. (2013)
Fabaceae	*Senna macranthera*	Ca, Ce, Ma	Seed	Cruz et al. (2010)
Fabaceae	*Copaifera langsdorffii*	Az, Ca, Ce, Ma	Seed	Augusto et al. (2003)
Flacourtiaceae	*Casearia sylvestris*	All	Seed	Rosa and Ferreira (2001)
Gesneriaceae	*Sinningia allagophilla*	Ce, Ma, Pm	Seed	Gomes (2006)
Lythraceae	*Cuphea carthagenensis*	All	Seed	Rosa and Ferreira (1998)
Malpighiaceae	*Byrsonima intermedia*	Az, Ce, Ma, Pl	In vitro	Nogueira et al. (2004)
	Byrsonima verbascifolia	Az, Ca, Ce, Ma	Seed	Alberto et al. (2011)
Melastomataceae	*Marcetia taxifolia*	Az, Ca, Ce, Ma	Seed	Silveira et al. (2004)
	Miconia ligustroides	Ca, Ce, Ma	Seed	Chaves et al. (2011)
Myrtaceae	*Blepharocalyx salicifolius*	Ca, Ce, Ma, Pm	Seed	Rego et al. (2009)
Onagraceae	*Ludwigia octovalvis*	Az, Ca, Ce, Ma, Pl	Seed	Wulff and Briceño (1975)
Orchidaceae	*Cattleya bicolor*	Ce, Ma	In vitro	Suzuki et al. (2010)
	Epidendron secundun	Az, Ca, Ce, Ma	Seed	Pereira et al. (2011)
Palmae	*Geonoma schottiana*	Ma	Seed	Aguiar (1990)
Passifloraceae	*Passiflora alata*	Az, Ce, Ma	Seed	Osipi et al. (2011)
Poaceae	*Andropogon bicornis*	All	Seed	Figueiredo et al. (2012)
	Andropogon leucostachyus	All	Seed	Figueiredo et al. (2012)
	Echinolaena inflexa	Az, Ca, Ce, Ma	Seed	Figueiredo et al. (2012)

(continued)

Table 19.1 (continued)

Family	Species	Occurrence	Propagation	Reference (e.g.)
Polygolaceae	*Polygala paniculata*	Az Ca, Ce, Ma, Pm	In vitro	Nogueira et al. (2005)
Smilacaceae	*Smilax campestris*	Ca, Ce, Ma, Pm	Seed	Soares et al. (2011)
Verbenaceae	*Lippia gracilis*	Ca, Ce	Seed	Marinho et al. (2011)
Vochysiaceae	*Vochysia tucanorum*	Ce, Ma	Seed	Pereira et al. (2011)

Occurrence in Brazilian biomes, mode of propagation and the source reference are indicated for each species
Az Amazônia, *Ca* Caatinga, *Ce* Cerrado, *Ma* Mata Atlântica, *Pm* Pampa, *Pl* Pantanal

Table 19.2 Native plant species found in unpublished lists of botanical surveys in the ironstone rupestrian grassland in Carajás, Brazil, for which some scientific data on their propagation was found

Family	Species	Occurrence	Propagation	Reference
Anacardiaceae	*Myracrodruon urundeuva*	Ca, Ce, Ma	Seed	Guedes et al. (2009)
	Tapirira guianensis	All	Seed	Santos-Moura et al. (2012)
Arecaceae	*Euterpe oleracea*	Az, Ce	Seed	Gama et al. (2010)
	Mauritia flexuosa	Az, Ca, Ce	Seed	Spera et al. (2001)
	Socratea exorrhiza	Az	Seed	Potvin et al. (2003)
Bignoniaceae	*Tabebuia impetiginosa*	Az, Ca, Ce, Ma, Pl	Seed	Oliveira et al. (2005)
Bromeliaceae	*Ananas ananassoides*	Az, Ca, Ce, Ma	Seed	Silveira et al. (2010)
	Ananas comosus	Ma	In vitro	Barbosa et al. (2009)
	Tillandsia streptocarpa	Az, Ca, Ce, Ma, Pm	Seed	Scatena et al. (2006)
Cactaceae	*Epiphyllum phylanthus*	Az, Ca, Ce, Ma, Pl	Seed	Simão et al. (2010)
Fabaceae	*Chamaecrista desvauxii*	Az, Ca, Ce, Ma, Pl	Seed	Caldeira et al. (2013)
	Enterolobium schomburgkii	Az, Ce	Seed	Braga et al. (2009)
Leguminosae	*Hymenaea courbaril*	Az, Ca, Ce, Ma, Pl	Seed	Pierezan et al. (2012)
	Sclerolobium paniculatum	Az, Ca, Ce	Seed	Felfili et al. (1999)
Melastomataceae	*Miconia albicans*	Az, Ca, Ce, Ma	Seed	Carreira and Zaidan (2007)
	Miconia Chamissois	Ca, Ce, Ma	Seed	Valio and Scarpa (2001)
Meliaceae	*Cedrela odorata*	Az, Ca, Ce, Ma	Seed	Passos et al. (2008)
Mimosoideae	*Parkia platycephala*	Az, Ca, Ce	Seed	Nascimento et al. (2009)
Myrristicaceae	*Virola surinamensis*	Az, Ca	Seed	Limas et al. (2007)
Orchidaceae	*Encyclia randii*	Az	Seed	Gonçalves et al. (2012)

(continued)

Table 19.2 (continued)

Family	Species	Occurrence	Propagation	Reference
Piperaceae	*Piper aduncum*	All	Seed	Bergo et al. (2010)
	Piper arboreum	Az, Ca, Ce, Ma	Vegetative	Souza et al. (2009)
Rubiaceae	*Alibertia edulis*	Az, Ce	Seed	Silva et al. (2008)
Rutaceae	*Pilocarpus microphyllus*	Az, Ca	Seed	Sabá et al. (2002)
Simaroubaceae	*Simarouba amara*	Az, Ca, Ce, Ma	Seed	Azevedo et al. (2010)
Smilacaceae	*Smilax brasiliensis*	Ce	Seed	Martins et al. (2012)
	Smilax campestris	Ca, Ce, Ma, Pm	Seed	Martins et al. (2012)
Verbenaceae	*Lantana camara*	All	Seed	Affonso et al. (2007)
	Stachytarpheta cayennensis	Az, Ca, Ce, Ma, Pl	Seed	Dias-Filho (1996)
	Swietenia macrophylla	Az, Ce, Ma	Seed	Souza et al. (2010)

Occurrence in Brazilian biomes, mode of propagation and the source reference are indicated for each species
Az Amazônia, *Ca* Caatinga, *Ce* Cerrado, *Ma* Mata Atlântica, *Pm* Pampa, *Pl* Pantanal

This survey shows that the scientific knowledge on the propagation of plant species of ironstone rupestrian grasslands that could help in the development of sustainable restoration strategies is negligible. Even worse is the fact that most studies were performed under laboratory conditions, hence being of limited practical value or still far from field application, where large-scale production of saplings is needed. Studies are biased towards the germination of seeds, with very few studies on other modes of propagation such as in vitro propagation. If it is acknowledged that plant introduction to restored areas is one of the strategies with high potential to restore degraded rupestrian ecosystems, then the lack of information on propagation techniques represents a large void that needs to be closed and strong planning and efforts should be made towards that end. Some development has been underway for the propagation of plant species that occur in the quartzitic rupestrian grasslands (see bellow). While this is of great importance, much more is yet to be done to reach a level of industrial production of plants for restoration of the Rupestrian Grassland (e.g., Wagner et al. 2011).

19.3.3 Nutritional Requirements and Site Preparation

Site preparation represents an important initial step in most restoration activities. Soil amendments are often needed in order to recover the physicochemical conditions of the soil that were lost in the process of degradation. On the other hand, rupestrian grasslands are naturally characterized by nutrient poor soils (e.g., Rodarte et al. 1998; Ribeiro and Fernandes 2000; Medina and Fernandes 2007; Negreiros et al. 2009, 2011; Chap. 3). Fertilization, a practice common in the restoration of forest sites, may rather represent a risk to rupestrian grasslands, as shown by Barbosa et al. (2010) and by Hilário et al. (2011). Enrichment of soil by nutrients through fertilization can instead end up promoting biological invasion by ruderal and exotic species (Negreiros et al. 2011; Chap. 23). Plants native to these ecosystems evolved the ability to survive under severe stresses caused by the lack of nutrients (Negreiros et al. 2011, 2014; Oliveira et al. 2015; Chap. 11). Caution is then needed when preparing the degraded sites for restoration and knowledge is again mandatory.

Although adapted to survive under the extreme environments of rupestrian grasslands, some species are able to exploit additional nutrients, such as the endemic species *Baccharis concinna* and the more widespread *Baccharis dracunculifolia* (Fernandes et al. 2007; Negreiros et al. 2014). Curiously, *B. dracunculifolia* exhibits a growth-survival tradeoff depending on nutrient availability (i.e., having higher growth rates in fertile soils and higher survival rates in nutrient poor soils; Negreiros et al. 2014). The restricted distribution of many plant species may be related to soil nutrient deficiency to which they have adapted, and are now perhaps prisoners of, such as the endemic shrubs *Calliandra fasciculata*, *Chamaecrista ramosa*, *Collaea cipoensis*, and *Coccoloba cereifera,* among others. The studies by Ribeiro and Fernandes (2000), Negreiros et al. (2008), and by Barbosa et al. (2015) provide support for this hypothesis. Studies on the nutritional requirements of plant species used for restoration purposes, or even the overall nutritional quality of the substrate, are of major relevance (see Negreiros et al. 2008, 2009, 2011; Le Stradic et al. 2014a, b; Machado et al. 2013; Messias et al. 2013; Oliveira et al. 2015).

The practical importance of these academic studies to restoration is twofold. First, they show that native species present superior competitive abilities compared to exotic species in the nutrient poor soils of rupestrian grasslands (e.g., Barbosa et al. 2010). Second, they demonstrate that soil fertilization can result in a negative outcome since exotic plants can be favored and outcompete natives, as shown by Hilário et al. (2011) and by Fernandes et al. (2015). Limiting conditions such as the presence of iron can favor native species, but negative outcomes can occur when invasive plants tolerate iron, as reported for *Calotropis procera* grown experimentally in rupestrian grasslands on ironstone (Oliveira et al. 2009). Future efforts to this end could be directed to studies on the acceleration of the growth of plant root systems to capture nutrients in a more effective way, developing more drought resistant species, increased plant associations with microorganisms to promote better field performance, among others.

19.3.4 Scientific Pilot Restoration Experiments

Only five scientific experiments are reported so far on the restoration of rupestrian grasslands: two in quartzitic grasslands degraded by quarrying and three in ironstone grasslands degraded by mining activities (Table 19.3). Although it is disappointing to find so few studies on restoration in the rupestrian grasslands, they are recent and as such indicate that we are moving forward. In this chapter we did not

Table 19.3 Scientific experiments on restoration of rupestrian grasslands published in peer-reviewed journals

Question addressed	Plant/seedling translocation	Substrate testing	Fertilization	Experimental design and treatments	Duration (months)	Main positive results	Main negative results	Type of degradation/outcrop	Source
Translocation viability of the orchid *Oncidium warmingii*	Yes	No	No	Direct and indirect translocation to a pristine area	20	Relatively high tolerance to translocation	Indirect translocation was less efficient	Mining/ironstone	Arruda et al. (2010)
Seedling growth and survival to translocation	Yes	No	NPK 4:14:8[a]	Planting seedlings in two degraded areas	54	High survival rates for 50 % of the species	Intra-specific competition lead to high mortality	Quarrying/quartzitic	Le Stradic et al. (2014a)
Planting of *Eremanthus erythropappus*	Yes	Yes	Likely[a]	Planting in three substrates (topsoil, laterite mowed and exposed)	12	Higher annual growth rates and biomass values for topsoil, followed by mowed laterite; High survival rates for all substrates	Not processing the exposed laterite resulted in lower annual growth and biomass	Mining/ironstone	Machado et al. (2013)
Reintroduction of plants	Yes	Yes	Termalphosphate, $MgSO_4$ and NPK 20:0:8[b]	Planting in two topsoil thicknesses and four fertilizer levels	42	Thicker topsoil layer lead to higher vegetation cover	High mortality rates after 42 months	Mining/ironstone	Rezende et al. (2013)
Resilience through seed bank	No	Yes	No	Hay transfer to degraded areas with 3 types of substrate	14	Indication that seed germination is a potential limitation	No effect observed for hay transfer	Quarrying/quartzitic	Le Stradic et al. (2014b)

[a]greenhouse, [b]four levels (0.00, 0.33, 0.66 and 1.00, see reference for further details on kg/ha)

attempt to locate and analyze private company reports as these are not readily available and because, unfortunately, most of them generally lack scientific rigor (Toy and Griffith 2001). On the other hand, we strongly stress that this knowledge should be rescued and brought to light to aid in the search for better restoration practices and scientific development.

Overall, the available studies covered only the initial stages of restoration, since their maximum duration was of 54 months. All of the studies made use of native plant species. Four out of the five studies tested plant species translocation, either directly from pristine areas or from propagation at greenhouse facilities; while two of them did not include testing with different substrates (Table 19.3).

The translocation of a single orchid species (*Oncidium warmingii*) showed to be quite successful. Arruda et al. (2010) found that all *O. warmingii* orchids translocated directly to the restoration area from the rescue area survived during the 20 month study period, while a smaller number of orchids translocated indirectly from the rescue area survived (70 %). Moreover, plant relative growth was higher for those individuals directly taken to the restoration area.

Another experiment consisted of planting seedlings of a set of woody species (18 species) in degraded areas of quartzitic rupestrian grassland in Serra do Cipó (Le Stradic et al. 2014b). Half of the species exhibited high survival rates (>78 %) 4.5 years after planting, and some were able to reproduce and/or allow the development of an herbaceous understory. The authors suggested the species *Calliandra fasciculata*, *Collaea cipoensis*, *Jacaranda caroba*, *Dasyphyllum reticulatum* and *Diplusodon hirsutus* as potential candidates for restoration of rupestrian grasslands since they presented positive responses to all aspects evaluated. Interestingly, intra-specific competition increased mortality rates in some cases and should be avoided by spreading conspecifics apart in the field (Le Stradic et al. 2014a; Fig. 19.1).

Two experiments consisted of plant species translocation in combination with substrate testing (Table 19.3). Machado et al. (2013) tested planting *Eremanthus erythropappus* seedlings in topsoil and in exposed lower soil layers (laterite) with or without processing to finer grains. The use of topsoil provided the best results for seedling establishment, followed by processed laterite, while unprocessed laterite presented the worst results. The authors argued that this common species of rupestrian grasslands has the potential for planting when there is no topsoil available. Another study by Rezende et al. (2013) tested the planting of seedlings of 15 native species in topsoil with two levels of thickness, in combination with four fertilization treatments. They found that treatments with a thicker topsoil layer presented higher vegetation cover independently of fertilization levels. However, mortality rates after 42 months were higher than 50 % for eight out of the 15 planted species; one species reached 100 % mortality. The authors suggested that practitioners should plant more seedlings per area in order to cope with the high long-term mortality levels.

Le Stradic et al. (2014b) experimentally tested the viability of hay transfer as a technique to restore degraded rupestrian grasslands. Three factors were analyzed: substrate (stony, sandy, and latosol), amendment to the substrate (with or without

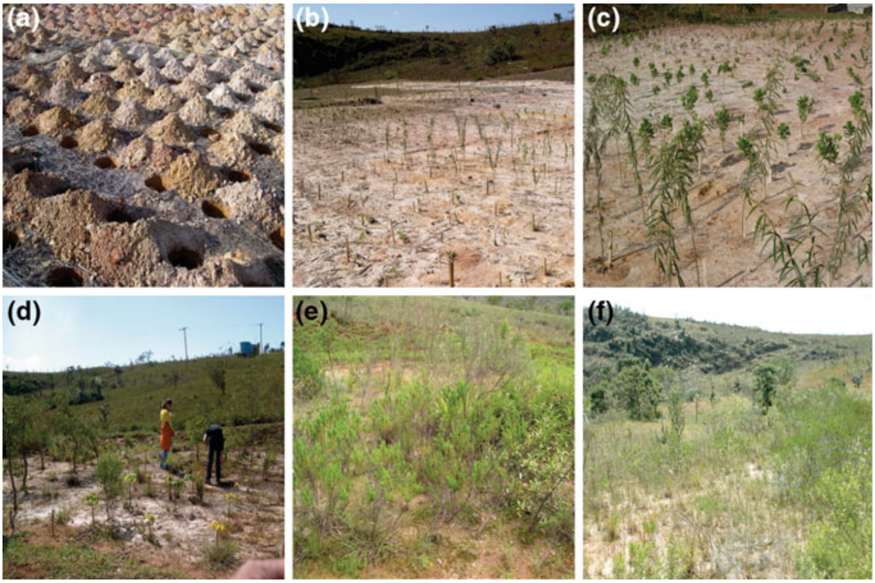
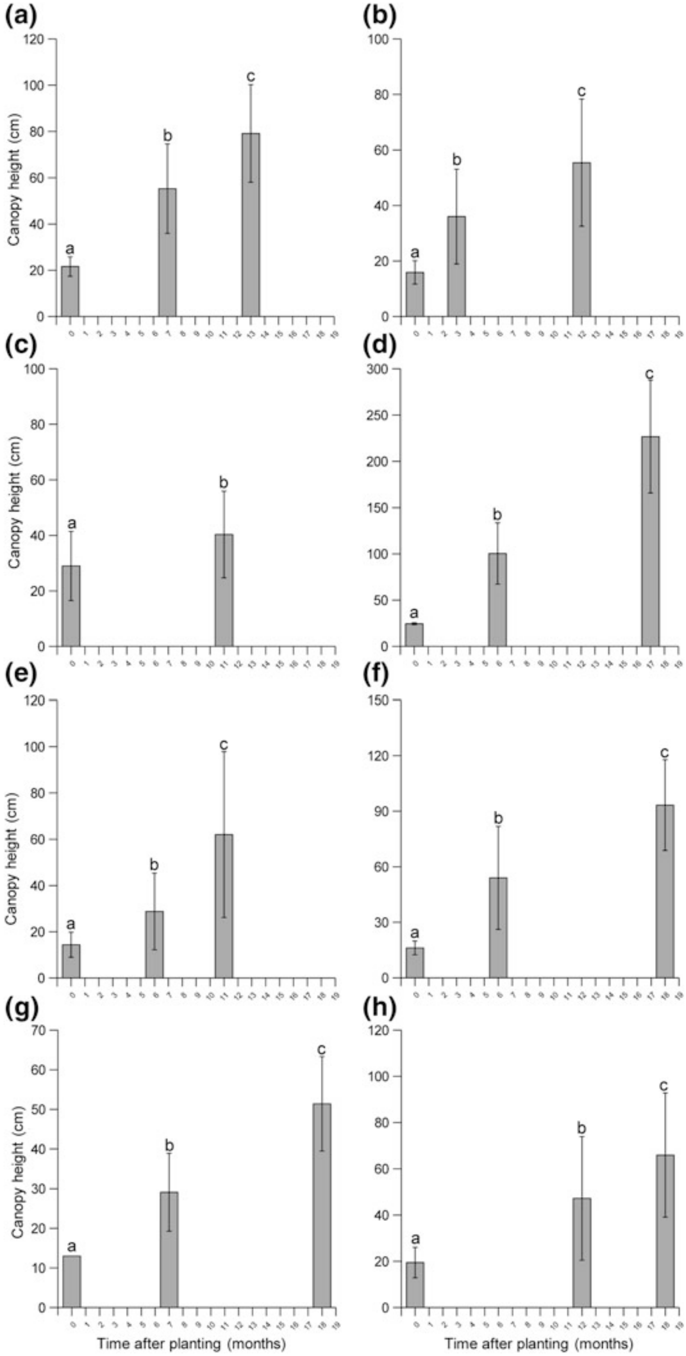


Fig. 19.1 Pilot restoration study on quartzitic rupestrian grasslands in Serra do Cipó. **a** Preparation of the site began with the digging of plant pits (20 × 20 cm). **b** Saplings of native species produced in a nearby greenhouse were introduced in 2002. **c** Site three months after planting. **d** Site after 1 year after planting. **e** Site 2 years after planting. **f** Site 2 years after planting showing the differential response of the various plant species (for details see Le Stradic et al. 2014a)

geotextile), and addition of hay (with or without). Regardless of any factor or combination of factors, only a limited number of seedlings emerged from the seeds contained in the hay; most established species were ruderals probably from other sources (Le Stradic et al. 2014b). The authors suggest that seed germination is a limiting factor for the use of hay transfer as a restoration technique in this ecosystem.

At least one study has addressed the survival of seedlings planted in a restored rupestrian grassland ecosystem (Gomes et al. 2015). The authors experimentally investigated the survival, growth, and reproductive phenology of eight native rupestrian grassland species introduced to restore degraded quartzitic areas. Saplings were monitored for 12–18 months and all species presented high survival (90–100 %) and significant growth in height, indicating their successful establishment in the degraded areas (Fig. 19.2). The endemic and threatened species *Collaea cipoensis* (Fabaceae) had the highest growth, reaching approximately 150 cm in 12 months, six times its initial height; followed by *Mimosa foliolosa* (Fabaceae) and *Baccharis dracunculifolia* (Asteraceae), both with heights of approximately 75 cm in 12 months, around 3.75 times their initial heights. The woody species *Eremanthus incanus* (Asteraceae) and *Dalbergia miscolobium* (Fabaceae) reached ca. three times their initial heights in 12 months (ca. 60 cm).


(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
Canopy height (cm)
Time after planting (months)

◀ **Fig. 19.2** Sapling growth (height) of eight species native to rupestrian grasslands planted in degraded quartzitic areas in Serra do Cipó, MG, Brazil. For each graph, different letters indicate statistical difference between sampling dates ($p < 0.05$). *Vertical lines* show the standard deviation (modified from Gomes et al. 2015). **a** *B. dracunculifolia*. **b** *E. incanus*. **c** *H. ochraceus*. **d** *C. cipoensis*. **e** *D. miscolobium*. **f** *M. foliolosa*. **g** *L. campos-portoana*. **h** *T. heteromalla*

The species *Lavoisiera campos-portoana* (Melastomataceae) grew ca. 2.6 times its initial height in 12 months, reaching ca. 40 cm. In the same timespan, *Tibouchina heteromalla* (Melastomataceae) approximately doubled its initial size, reaching ca. 40 cm. The woody *Handroanthus ochraceus* (Bignoniaceae) grew 10 cm in about 11 months, approximately 1.3 times its initial size. These field data suggest the potential for successful establishment of native species and their ability to adaptat to the harsh conditions found in the degraded areas. Four species completed their reproductive cycle, reaching seed dispersion at an age of approximately two years. These results clearly indicate that planting saplings of native species represents an important tool for the restoration of degraded quartzitic areas in the Rupestrian Grassland.

19.4 Potential Techniques for the Ecological Restoration of Rupestrian Grasslands

A myriad of ecosystem restoration interventions has been suggested and tested for various ecosystems. Regardless of the intervention or set of interventions, implementing restoration is supposed to follow general guidelines as suggested, for example, by the Society for Ecological Restoration in their document "Guidelines for developing and managing ecological restoration projects" (SER 2005). The SER stresses the importance of planning for restoration, from concepts to implementation, going through preliminary and post-implementation tasks. Throughout the process of restoration, interventions should be carefully planned in order to maximize the chances of achieving a successful outcome. For the Rupestrian Grassland, as summarized in Table 19.3, only a few techniques have been scientifically tested. Here we present some potential restoration techniques for the Rupestrian Grassland.

19.4.1 Soil Preparation: Soil Fertility and the Use of Topsoil

Soil preparation is often the first step of a restoration project, consisting mostly of tractable physical and nutritional amendments. However, the peculiarities of Rupestrian Grasslands pose difficulties to this stage of restoration. The shallow and rocky soils characteristic of this ecosystem, with the marked presence of outcrops, constitute a complex mosaic of different soils with distinct successional stages of vegetation resulting from a myriad of ecological and geomorphological filters

(Chaps. 3 and 9). Hence, if superficial layers of soil (topsoil) are lost, it can take several years or even decades until any vegetation cover can be achieved.

Topsoil salvage is a restoration technique widely used worldwide and especially after degradation by mining (Bradshaw and Chadwick 1980) since it has the potential to allow the return of native plant species with lower technical and economic costs (Fowler et al. 2015, see Table 19.3 for two examples in rupestrian grasslands). Species present in the topsoil seed bank are of high importance, especially in such an endemic and diverse ecosystem as the Rupestrian Grassland (Toy and Griffith 2001; Medina and Fernandes 2007). The total knowledge on seed banks of this ecosystem includes only a single study that directly evaluated the seed bank (Medina and Fernandes 2007), and few others that make generealized references to the seed bank (e.g. Matias et al. 2009; Silveira et al. 2013, 2014). However, the often-needed storage of topsoil has not yet been evaluated regarding the viability of seeds (and microbiota) until use. Therefore, the recommendation is to directly transpose topsoil extracted from an active mining site to piles of sterile material or deactivated mining sites in the vicinity. In situations where no topsoil is available for restoring an area, a possibility could be, for instance, to process the available soil to finer grains, as tested for laterite (Machado et al. 2013; Table 19.3).

19.4.2 Seeding and Seedling Planting Techniques

Seeding and the planting of seedlings/saplings are widely used techniques in restoration around the world. On the other hand, the only experimental test of hay by Le Stradic et al. (2014b) was unsuccessful due to limited seed germination (see also Toy and Griffith 2001). More experiments must be performed in order to fully investigate ways of overcoming these limitations since seeding is a technique of great potential for application on a large scale.

Correctly choosing the plant community that will initiate the succession process in a degraded area is one of the most critical decisions in the recovering process (Corrêa 2007; Negreiros et al. 2009). After the appropriate establishment of species used in restoration plantings, success relies on the ability of the planted vegetation to self-regenerate, which requires studies on seedling development, natural regeneration, physiognomy, diversity, and seed rain, among others (Mandetta 2006).

19.4.3 Species Translocation

Translocation of plants from source areas or greenhouses to areas under restoration seems to be another viable option for rupestrian Grasslands. High survival rates of translocated individuals were found in rupestrian grasslands (Table 19.3). One experiment reported high mortality rates after 42 months regardless of substrate thickness or fertilization levels (Rezende et al. 2013). Another experiment on the rescue of almost 4000 individual plants of 43 species reported high survival rates for species belonging to Bromeliaceae, Velloziaceae and Orchidaceae; only six species presented survival bellow 5 % and two species showed 100 % mortality after four months (Mendonça et al. 2008). Le Stradic et al. (2014a) showed that the spatial distribution of plants in a restored area is an important consideration in order to avoid intraspecific competition; this finding is an indication on the importance of the reference ecosystem in the delineation of the restoration process.

Another example of the successes of translocation of species involves restoration attempts on former prospection sites. In planning mining activities, many areas are prospected, which involves the use of machinery that perforates the soils to precisely map the quality and quantity of minerals (Bradshaw and Chadwick 1980). However, not all probed areas are used due to the impurity of the minerals. While the extent and characteristics of these prospection areas has not been mapped, these areas usually are degraded and present risks to biodiversity, as they are generally suitable for the colonization by invasive species, while natural regeneration likely will not occur for decades or even centuries. In a pioneer study performed in an iron mine area of the company Vale in Carajás, dozens of prospection areas (Fig. 19.3a) were placed in the route of successional processes. In just six months after the planting of rescued plant individuals of a few selected species, the prospection areas showed high plant cover (30–70 %), while the control areas (no planting) had no colonization (Fig. 19.3b–d). This ongoing study clearly indicates the potential that

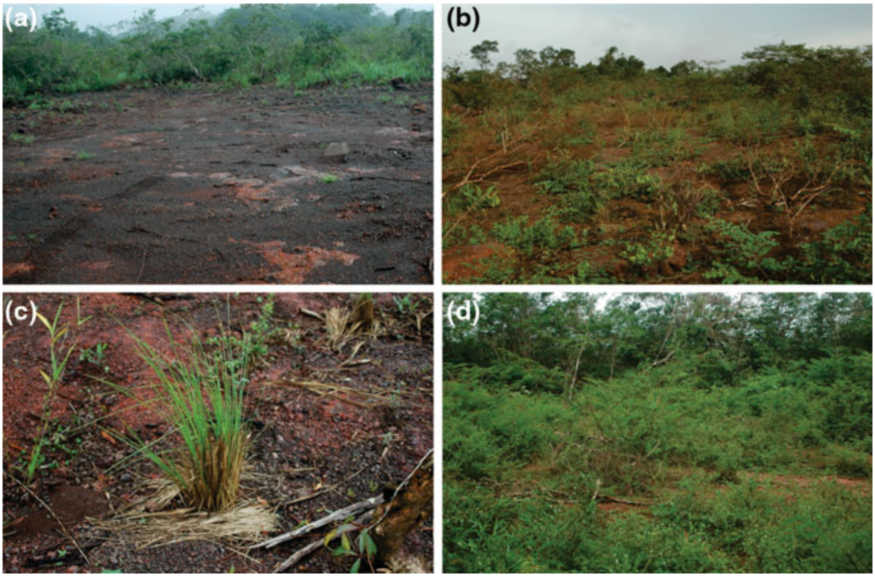


Fig. 19.3 Restoration of prospection areas in an ironstone rupestrian grassland in Carajás by translocation of native species. **a** Prospection areas after abandonement are likely to be uncolonized for decades. **b** and **c** Restored area 30 days after plant translocation. **d** Restored area six months after translocation

the application of scientific knowledge and the political will of mining companies can have on mitigating impacts resulting from prospection and promoting the return of biodiversity and environmental services. Nevertheless, a lot has yet to be done in this regard since prospection areas are often abandoned without any effort at reintegrating them into Rupestrian Grasslands. We still have no idea of the area and impacts of prospection, both direct and as potential sites for the establishment and spread of invasive species.

19.5 Potential Indicators of Restoration Progress

Monitoring ecological restoration is necessary to determine whether restoration interventions were effective. Monitoring constitutes an important part of any restoration initiative and should be considered early in the restoration planning phase (SER 2004, 2005). Restored areas are usually compared to references by using a set of indicators, but monitoring usually is performed for only a limited time (Ruiz-Jaen and Aide 2005; Wortley et al. 2013). However, evaluating restoration success is not an easy task and depends on a number of different aspects. For instance, the SER (2004) listed nine attributes of restored ecosystems in an attempt to provide a general guideline on what should be measured to determine that a restoration project was successful.

To date, very little is known regarding long term monitoring of rupestrian grassland restoration, making it difficult to present a synthesis. Yet some degraded rupestrian grassland areas seem to take a long time to recover even after restoration interventions (Le Stradic et al. 2014b, but see Gomes et al. 2015), and high mortality rates can strongly affect restoration in the midterm (Rezende et al. 2013; but see Gomes et al. 2015). A minimum of ten years after the restoration has begun seems to be a good criterion for monitoring until more research is developed on the subject. This is time period is based on the development of a pilot study done in the rupestrian grasslands (Fernandes and Negreiros, unpub. data). Additionally, we propose monitoring restoration progress rather than success (see Zedler 2007). For the rupestrian grasslands, measuring progress seems applicable and more reasonable since restoration success per se can take longer than the monitoring periods required by law.

We present here potential indicators for a set of aspects, from soil conditions to ecosystem functions, in an attempt to provide a starting point for the evaluation of the progress of rupestrian grasslands restoration. In each case, it is fundamental to perform a careful assessment of which indicators are to be use for determining restoration progress based on the objectives established in the original planning of the restoration. We focused on ecological indicators, but strongly recommend that other indicators, such as social and economic, also be considered (e.g. Wortley et al. 2013).

19.5.1 Soil Conditions

Adequate soil conditions at the restored area are crucial for plant establishment and development. As previously emphasized, rupestrian grassland soils are usually of low fertility and shallow (e.g., Benites et al. 2007). Therefore, even lower fertility soils are found in restored areas. The evolution of soil quality in restored areas must be compared with that of the reference area(s). Soil fertility analysis can then be considered a good indicator. Additionally, monitoring erosion is recommended as an indicator of soil stability in the restored sites. Erosive processes can lead to high rates of soil loss, which is highly detrimental to the restoration initiative of areas that inherently present shallow soils.

Although decomposition rates have been considered to be a good indicator of nutrient dynamics in restored sites (Meyer et al. 2015), studies on nutrient dynamics are rare in rupestrian grasslands. At this moment, it is probably difficult to determine the basic standards for evaluating nutrient dynamics, mostly due to the heterogeneity of rupestrian grasslands. The sole study found on this subject reported that litterfall dynamics varied greatly in time and among physiognomies within the same complex of ironstone rupestrian grassland (Valim et al. 2013). Yet another possible bioindicator of restoration in rupestrian grasslands is soil mycorrhizae. These organisms are highly diverse in rupestrian grasslands and are related to vegetation biodiversity and functioning (Carvalho et al. 2012; Chap. 8).

19.5.2 Plant Development and Performance

Some plant species native to rupestrian grasslands exhibit a growth-survival trade-off due to harsh conditions of water availability and soil fertility that can significantly limit plant growth (Negreiros et al. 2014). Thus, during the early stages of sucession such evaluations must be viewed with caution and can only be compared in relation to the reference ecosystem. Otherwise, plant growth in quartzitic rupestrian grasslands can in fact take place in a short time span (e.g. 12 months, Gomes et al. 2015). Additionally, some invasive species can present considerable growth even in degraded areas with important implications for the process of restoration (see following section). Therefore, monitoring vegetation through plant growth, survival and reproductive stage can provide good basic information on the progress of a restoration initiative.

19.5.3 Succession and Plant Cover

Ecological succession on rupestrian grasslands is limited by a number of factors. For instance, frequent fires in this ecosystem may represent a factor that strongly interferes with the succession process, causing it to regress once in a while and in very unpredictable ways. Furthermore, there is now some evidence that a long time is necessary for vegetation to exhibit clear changes between successional stages (Chap. 9), although the definition of stages for this ecosystem is also a matter of detailed studies. The slow rate of change in vegetation of rupestrian grasslands may be the result of the harsh environment. It is likely that some disturbances, such as fire, may be necessary from time to time to maintain the evolutionary pace of rupestrian grasslands and to achieve a condition of a mosaic of phytophysiognomies. At any rate, the classical successional model of a pioneer community to a climate stage, as commonly applied to forests, does not apply easily to rupestrian grassland, or to grasslands in general, for that matter. Nontheless, the development of vegetation cover—as long as it is composed of native species—is another important practical aspect since it protects soils, provides habitat for other organisms, is involved in many interaction networks between trophic levels, and is an indication of habitat productivity. On the other hand, we are not aware of detailed studies done regarding vegetation cover in rupestrian grasslands (see Le Stradic et al. 2014a, b).

19.5.4 Associated Organisms: Biodiversity

The return of biodiversity and ecosystem functioning to restored ecosystems is highly desirable since it is directly associated with sustainability through time. However, we are unaware of any study looking into this in the Rupestrian Grassland (see Jacobi et al. 2015 for a review of ecological interactions in ironstone rupestrian grasslands). Information on ants, in conjunction with information on the recovery of vegetation, was regarded as a reliable indicator in a restoration project in temperate grasslands by Fagan et al. (2010). In calcareous grasslands, Maccherini et al. (2009) revealed the potential use of different taxa of butterflies and vegetation in restoration evaluation. Galls induced by insects and their host plants have been shown to be good indicators of habitat quality in restored vegetation (Moreira et al. 2007; Fernandes et al. 2010; Toma et al. 2014), but all studies done so far are on forest ecosystems. These highly specific interactions might be even better indicators of habitat quality and health in rupestrian grasslands since galling herbivores are present in these ecosystems in great numbers and on a variety of host plants (Lara and Fernandes 1996; Lara et al. 2002). Pollinators, including bees, butterflies and hummingbirds also represent potential indicators of improvement in habitat quality, as these organisms tend to construct nests in the vicinity of such areas. At least in one example, pollinator behavior and frequency were considered in a restored rupestrian grassland area (Gelvez-Zúñiga et al. 2016).

19.5.5 Ecosystem Functions and Services

Parameters that provide information on ecosystem functions and processes must also be included in the evaluation of vegetation cover and functionality in restored areas of rupestrian grasslands. These include seed dispersal and pollination rates, plant recruitment, and the establishment of trophic structures similar to reference areas. A good starting point regarding seed dispersion and pollination could be the work of Jacobi and Carmo (2011) that lists plant species dispersion and pollination syndromes. Accounting for intra- and interspecific interactions and their associated ecosystem functions are of utmost importance, especially in such a diverse ecosystem. Evaluating ecosystem functions in the early stages of the restoration process of rupestrian grasslands can be a means of assessing the recovery of processes and services provided by the restored area. The recovery of some functions can help guide the management of the restoration process until vegetation is fully established. For the assessment of ecosystem functions, some methods that can be used to indicate restoration success are summarized in Meyer et al. (2015).

Research on ecosystem services has grown exponentially in the last ten years (see Guerry et al. 2015). Ecosystem service valuation was, for the first time, conducted for an area of quartzitic rupestrian grassland by focusing on the service provided by plant diversity storage by Resende et al. (2013). Such studies can help justify conservation and restoration initiatives based on services provided by a preserved or a restored area that are directly related to economic activities in rupestrian grassland areas. The restoration objectives must not just focus on soil protection, but also focus on the recovery of specific services related to biodiversity and ecosystem services (e.g., Bullock et al. 2011). With the increased focus on ecosystem services lately, this is a very promising venue for the advancement of ecological restoration in general.

19.6 The Threat of Invasive Plants to Rupestrian Grassland Restoration

The need to monitor the progress of restoration is not just related to the recovery of native vegetation, but also to the recognition of potential problems. One of the major problems in restored areas is that of invasive species. In addition to the fact that they represent a great threat to the identity of rupestrian grasslands (see Barbosa et al. 2010; Hilário et al. 2011; Fernandes and Barbosa 2013; Fernandes et al. 2014; Chap. 23), biological invasions are of major concern to the success of ecological restoration, and they may present a risk for adjacent well-conserved areas as well.

Fernandes et al. (2015) listed the non-native species invasions in restored quartzitic rupestrian grassland areas in Serra do Cipó and called attention to the aggressive behavior of some species. Among the highly competitive species that can come to dominate plant communities are the exotic African grasses *Urochloa* *brizantha* and *Melinis minutiflora*. These grasses have been spreading over huge areas and, consequently, have replaced native species in many areas of the Cerrado, as clearly shown by Pivello et al. (1999). Other non-native species of the rupestrian grasslands include *Cajanus cajan*, *Mimosa pigra*, *Crotalaria pallida*, *Crotalaria spectabilis*, *Achyrocline satureioides,* and *Ageratum fastigiatum,* among others. Furthermore, the native species *Stylosanthes guianensis* is also among those that might represent a threat to restoration of rupestrian grasslands. Therefore, wide and detailed evaluation of invasive species and their impact on restoration processes are urgently needed.

19.7 Summary of Current Gaps in Knowledge and Challenges for the Restoration of Rupestrian Grasslands

The acknowledged idiosyncrasies inherent to the Rupestrian Grassland call for a combination of techniques to restore degraded sites and, most importantly, long term monitoring. Success of ecological restoration of rupestriam grasslands must evolve under a sound scientific basis, as we cannot risk to follow wrong strategies in the field because of the serious impact they might cause. Negative results could promote biological invasions and the silting of springs and water basins. While we acknowledge an increase in scientific developments in the restoration efforts of some mining companies (some results have been presented above), the initiatives are very timid given the magnitude and importance of the area to be properly restored. The scenario is challenging because it involves governance, law enforcement, management, knowledge development, economic investments, know-how, well-trained human resources, and long term monitoring. Rupestrian grasslands must be restored as close as possible to reference ecosystems, as society will end up paying the costs of producing unsuitable habitats of low or zero ecosystem value. We must be able to figure out what does not work in the rupestrian grassland restoration and start working on alternatives. We must redirect restoration efforts towards being sustainable and ecologically oriented.

The accumulation of knowledge on the ecology of rupestrian grasslands is a good starting point from which practitioners can gain an appreciation of the complexity of this ecosystem. A true guide through the paths of restoring such complex ecosystems is still unavailable, mainly due to historical reasons. Neither were policies enacted to push conservation forward, nor were stakeholders made responsible for the ecological restoration of degraded areas. With very few exceptions, academia has for too long stayed away from this discussion, which has prevented advances. Rather, studies on conservation and restoration were developed in other ecosystems, such as the rainforests, traditionally in the focus of Brazilian conservation policy and research. The result was a profound gap in the knowledge on how to restore the harsh Rupestrian Grassland, or other open-type ecosystems in Brazil, for that matter (e.g. Overbeck et al. 2013). Therefore, a great effort must be made to equalize such knowledge and effectively develop some basal knowledge regarding the restoration of this old-growth grassland.

To achieve such know-how, we need to make use of the valuable knowledge of practitioners regarding their experience with restoration of rupestrian grasslands. We also need to overcome the unavailability of propagules in the market (i.e. seeds and seedlings) in order to apply large-scale restoration. However, this requires the will and action of stakeholders, and the constant inspection and pressure from governmental agencies. Only concerted efforts from all institutions involved can make true advances in restoration possible. Furthermore, more detailed and broadened research is needed on the ecology of seeds, and in the determination of key species to be used and directly managed in order to increase restoration success. Specific knowledge and technologies must also be developed for plant propagation, such as in vitro propagation, germination rates of the selected species, plant performance in the field, long-term survival of plants at restored sites, protection from invasions or severe disturbances, etc. Based on specific site conditions we ought to establish a variety of plant types including trees, shrubs, grasses and wildflowers that work together as a plant community, that hold the soil in place by slowing water runoff and facilitating its absorption, and that represent habitat for many other species and bring biodiversity back—and with that ecosystems services. Knowledge must be developed on species with deep, fibrous roots that solidly anchor each plant and help it withstand drought. Also, we must select tough, low-maintenance plants that need low staking, fertilizing and disease-control. In other words, resilient native plants need to be selected. Species that can naturally spread by underground suckering can quickly form thickets that protect a restored site and provide microsites for wildlife colonization. Similarly, herbs, shrubs and trees that regenerate easily by self-sowing, such as early and fruiting species, are also important for filling and stabilizing degraded space. Clearly, an important aspect is high survival.

More research on invasive species control is also necessary. Worldwide efforts are being made to advance this topic, but our knowledge for rupestrian grasslands is anectodal at best. For ecosystems that are complex and limited in range, such as the Rupestrian Grassland, the threat of invasive species is very substantial.

Restoration of the Rupestrian Grassland should also consider ecosystem functioning and the provision of services. It is essential to go beyond planting and monitoring vegetation structure in order to achieve some level of ecosystem sustainability and integration. Here we have presented some ways of achieving this, and we believe there is more yet to come. After filling these gaps in our knowledge, the expectation is that the exploitation of natural resources will be as sustainable as possible, allowing some of the Rupestrian Grassland to persist over time.

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