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Silent loss: Misapplication of an environmental law compromises conservation in a Brazilian biodiversity hotspot

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ABSTRACT

We examine scientific evidence underpinning the application of the Atlantic Forest Act (AFA) to licensing and compensation in *campo rupestre*, a megadiverse grassland strongly affected by mining but lacking specific legislation. We found no empirical support to the assumptions of the current legislation. First, lists of indicators species are not appropriate to indicate successional stages in *campo rupestre*. Second, the reliance on successional stages of regeneration in this ecosystem as recommended by legislation has no empirical support. Using the AFA instead of a specific policy to *campo rupestre* has led to significant area loss of this vegetation type. We conclude that inadequate legislation enforcement poses a threat to biodiversity and conservation of the *campo rupestre*. We recommend the environmental agencies to immediately stop using current legislation (CONAMA Resolution 423/2010) in environmental licensing processes and provide suggestions for the elaboration of specific legislation that addresses the peculiarities and importance of *campo rupestre*.

Introduction

The legal protection of the Brazilian Atlantic Forest, a biodiversity hotspot (Myers et al., 2000), is defined by the Federal Law 11,428/2006, regulated by the Decree 6660/2008. The Atlantic Forest Act (hereafter AFA) defines guidelines for the use and conservation of native vegetation of the Atlantic Forest, the only Brazilian biome protected by specific legislation. The AFA establishes that the suppression of vegetation at advanced and intermediate stages of regeneration is allowed only in cases of public utility and social interest (Araujo, 2010). In both cases, suppression is authorized after an environmental compensation proposal is issued, which consists in the protection of a like-to-like area in the same river basin. Secondary vegetation classified at initial regeneration stages is not protected by the AFA and can be deforested without compensation (Ribeiro et al., 2009).

The AFA encompasses the Atlantic Forest *sensu stricto* and associated ecosystems, including open vegetation types such as the *campo de altitude* (altitudinal grassland) and the *campo rupestre* (Scarano, 2002; Neves et al., 2017, 2018). To improve the applicability of the AFA, the Brazilian National Environment Council (CONAMA) published the Resolution 423/2010 (hereafter CR423; see Supplementary Material I) defining the specific parameters and criteria for seral classification of *campo de altitude* vegetation, including lists of indicator plant species in each regeneration stage. Based on the principle of analogy (Kelsen, 2006), environmental agencies have been employing the CR423 for environmental licensing in *campo rupestre* areas, despite strong geological and floristic differences with the *campo de altitude* (Alves and Kolbek, 2010; Vasconcelos, 2011). There is vast literature discussing features of these two vegetation types (Scarano, 2002; Benites et al., 2007; Alves and Kolbek, 2010; Vasconcelos, 2011), and therefore we do not address this subject here.

Campo rupestre is an ancient, heterogeneous vegetation mosaic established on quartzite and ferruginous rocks in the highlands of Brazil. Despite harboring the highest levels of plant diversity and endemism in the country (Giulietti et al., 1997; Silveira et al., 2016),

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hard-policies to protect this ecosystem are inexistent. We aimed to investigate the effectiveness of the current legal protection of this environment by scrutinizing scientific evidence that underpins the application of the CR423 for *campo rupestre.* We investigated if the criteria used for *campo de altitude* is applicable for *campo rupestre* by answering the following: (1) What is the degree of similarity between the *campo de altitude* indicator species listed in CR423 and the *campo rupestre* flora? (2) Does the seral classification for *campo rupestre* fit similar assumptions as established by CR423 for *campo de altitude*? and (3) How has environmental compensation been carried out by projects legally licensed in areas of *campo rupestre* under AFA?

Materials and methods

Study system

We examined environmental licensing processes for mining activities, which have a major economic and ecological impact in this ecosystem (Fernandes et al., 2018; Sonter et al., 2014). According to the AFA application map (Brasil, 2008), *campo rupestre* in Minas Gerais occurs interspersed in the Cerrado and Atlantic Forest (Fig. 1a–c), mainly associated to the Espinhaço Range. Mineral extraction directly and strongly affects this ecosystem by completely removing the soil and vegetation, causing significant changes in the landscape by promoting the opening of accesses, urbanization and the cover of the soil explored with exotic species (Fernandes et al., 2018, Pena et al., 2017). Because of extensive impacts and public utility character, authorization of mining activities must be preceded by compensatory measures (Araujo, 2010).

Data analyses

We analyzed the floristic overlap between *campo rupestre* (5011 species; Silveira et al., 2016) and the indicator species list in CR423, used to classify successional stages in *campo de altitude*. To evaluate if the CR423 classification of successional stages for *campo de altitude* is appropriate to classify *campo rupestre*, we surveyed the literature in the Web of Science (1945–May 2018), SciELO (1997–May 2018) and Scopus (1960–May 2018) databases to review the state-of-art on ecological succession in *campo rupestre* (Supplementary Material II), and retrieved all available information on succession.

To investigate legal compensation in *campo rupestre*, we examined all environmental licensing processes of mining activities in Minas Gerais from April 2010, when CR423 came into effect, to December 2016. We analyzed technical reports issued by the Regional Superintendence for Environmental Regularization of Minas Gerais of the State Council for Environmental Policy (http://www.meioambiente.mg.gov.br/copam/urcs) and collected information on the process, the project and the total area required for exploration. To evaluate how the compensation for suppressed *campo rupestre* areas was carried out, we analyzed all documents of processes that authorized *campo rupestre* suppression, whenever available (http://www.siam.mg.gov.br). Finally, we examined the meeting guidelines and technical reports of COPAM's Biodiversity Protection Chamber (http://www.meioambiente.mg.gov.br/copam/camaras-tematicas-do-copam). Thirteen out of the 37 processes on compensatory areas (about 203.9 ha) were unavailable in the database even after several communication attempts (Fig. S1).

Results

Floristic similarity

Nearly 29.4% of *campo rupestre* in Minas Gerais is within the AFA application area, while most of its area is in the *Cerrado* biome (Fig. 1a). Only 145 (23.6%) out of the 614 species in the CR423 list of indicator species occur in *campo rupestre*. The CR423 list of indicator species contains just 2.9% of *campo rupestre* species (Fig. 1d). Only 22.2 and 24.8% of indicators species of initial and intermediate succession stages in CR423, respectively, occur in *campo rupestre* (Fig. 1e). Considering the rare and endemic species included in the list of the CR423, the floristic overlap is 12.7%.

Succession in campo rupestre

From all 1476 articles, 93 articles were related to the topic of interest (Supplementary Material III) but only five articles directly addressed ecological succession in *campo rupestre* (i.e., Alves and Kolbek, 2000; Conceição et al., 2007; Amaral et al., 2013, 2015; Conceição and Pirani, 2016). Three articles (Alves and Kolbek, 2000; Conceição et al., 2007; Conceição and Pirani, 2016) addressed primary succession in *campo rupestre*, whereas the others evaluated floristic, phytosociology and dynamics of colonizing vegetation in an area degraded by gold mining without delving deeper into the topic. Nonetheless, these studies aimed to define parameters for chronosequences of secondary succession in *campo rupestre,* similarly to what is defined by the CR423 for *campo de altitude*.

Environmental licensing and compensation

Despite the inadequate knowledge on ecological succession, almost half of the environmental licensing processes (46%, 620.8 ha) classified *campo rupestre* areas into some stage of secondary succession. Of these, 47% did not present any criteria for the classification. The remaining 53% provided lists of indicator species of the CR423 as a basis for sere classification. Other criteria used to support sere classification were the presence of invasive African grass species, fire incidence and the presence of garbage.

We evaluated 730 documents of environmental licensing, resulting in 225 documents that met the search criteria. The clear majority of analyzed documents mentioned indirect damage to *campo rupestre* due to their proximity to area. Only 37 processes pledged direct suppression of these environments. About 65% of these processes were between the two largest classes, defined according to their size and pollution potential.

The total *campo rupestre* area suppressed was 809.47 ha. All suppressed sites were inserted in areas protected by the AFA, and 24% of them occurred in ecological transition areas with the Cerrado biome. Nearly 19% of the processes classified areas of *campo rupestre* in the initial successional stage (78.11 ha) which require no compensation. Compensation was made based on environmental similarity (like-to-like) in 27% of the processes, corresponding to 427 ha of suppressed area and 854 ha of protected area through the implementation of private conservation units or donation of properties in conservation units of integral protection pending land regularization. In 19% of the processes, however, compensation for suppressed *campo rupestre* was made through conservation of forests (out-of-kind compensation; Fig. S1 – Supplementary Material IV).

Discussion

We found that the application of the AFA to environmental licensing in *campo rupestre* lacks a scientific basis. First, there is little overlap between the list of indicator species in CR423 and the

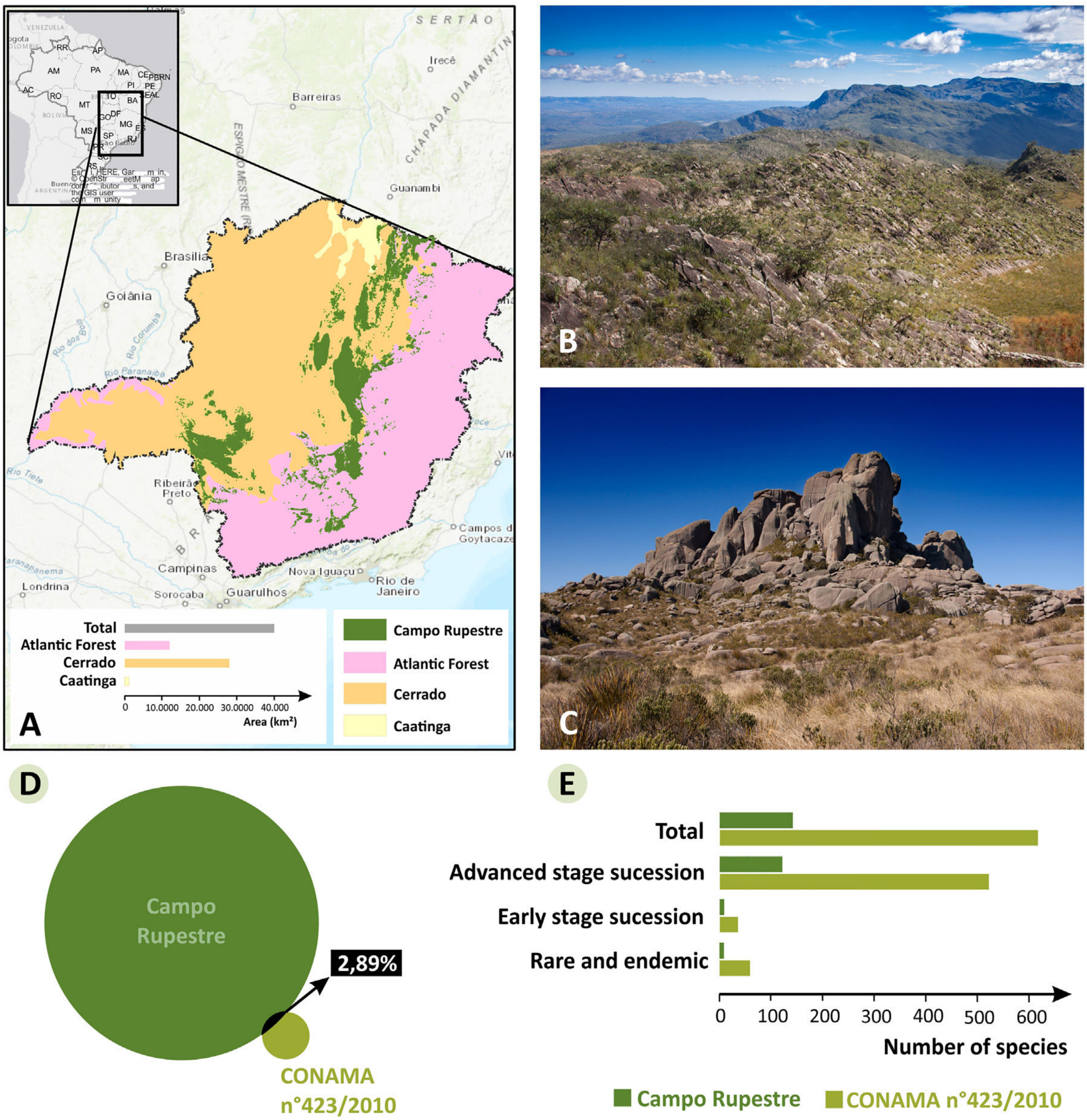

Fig. 1. A. Geographic distribution of *campo rupestre* (*sensu* Silveira et al., 2016) and the other biomes (IBGE 2018) in Minas Gerais; B. Typical landscape of *campo rupestre* at Serra do Cipó and *campo de altitude* (C) at the Parque Nacional do Itatiaia; D. Overlap of plant species between *campo rupestre* and the list of indicator species from the Resolution CONAMA 423/2010. Circle size refers to number of species; E. Total number of species in the Resolution CONAMA and total number of species in the Resolution and that occurs in *campo rupestre*. Photos in B and C by Augusto M. Gomes.

campo rupestre flora. Second, empirical evidence to support vegetation classification into successional stages is lacking. Therefore, the current guidelines and parameters established by legislation are inappropriate for *campo rupestre* conservation and management. We suggest that legislation misapplication in the environmental licensing process is resulting in biodiversity loss.

Indicator species in CR423 poorly represents the *campo rupestre* flora. Due to the low floristic similarity between *campo de altitude* and *campo rupestre* (Alves and Kolbek, 2010), the use of this legal instrument as a criterion for suppression and compensation in *campo rupestre* is technically impracticable. Despite its small geographic extent, *campo rupestre* is a highly heterogeneous ecosystem driven by edaphoclimatic factors (Abrahão et al., 2019). The resulting plant communities have dissimilar composition, and geographically structured endemism (Echternacht et al., 2011; Messias et al., 2011, 2012; Carmo and Jacobi, 2016; Neves et al., 2018). Therefore, the strong species turnover among *campo rupestre* sites poses a challenging task to establish lists of indicator species (Neves et al., 2018).

The process of ecological succession established by the CR423 has proven inappropriate to guide licensing and compensation in *campo rupestre*. Our data showed that no study investigated chronosequences of secondary succession in *campo rupestre*, and this lack of scientific knowledge hampers the development of practical criteria and parameters to classify seres. In the well-known process of forest regeneration, early stages of succession are characterized by low species and functional diversity, low biomass, habitat complexity, canopy cover and high environmental stress (Chazdon, 2008). During succession, as ecosystem development occurs, the structure, function and composition of regenerating forests become more similar to pre-disturbance, old-growth forests (Guariguata and Ostertag, 2001). This textbook mode of succession

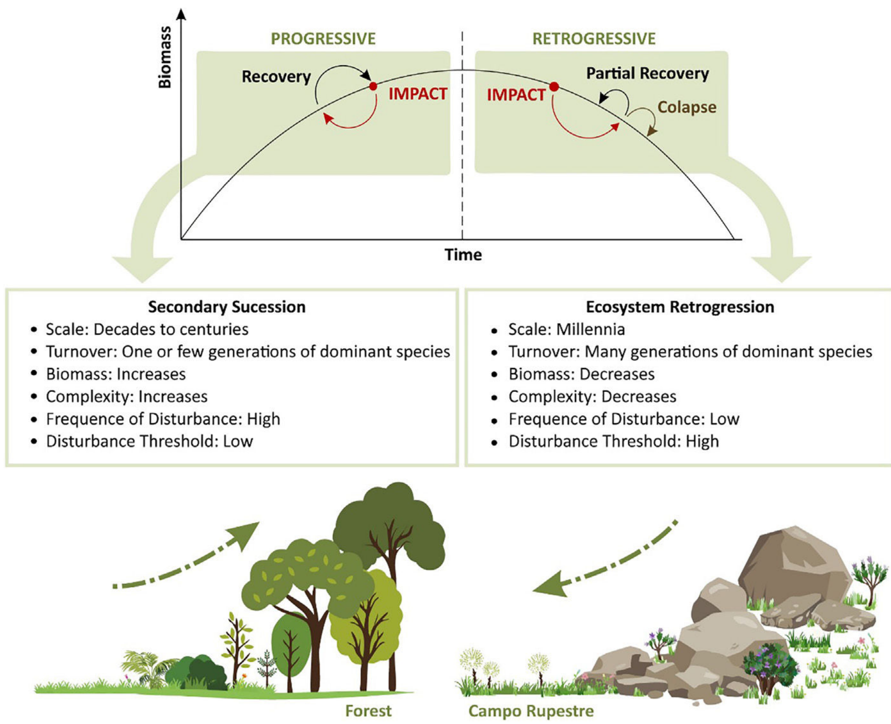

Fig. 2. Theory of ecosystem retrogression (modified from Walker and Reddell, 2007). Secondary succession is applied to forests whereas the retrogressive phase best characterize succession in *campo rupestre*. The fundamental differences in secondary and retrogressive succession are shown in the boxes above the draws, but the Y-axis depicts changes in aboveground biomass as an example to illustrate different properties between the two processes. The green arrows indicate the trajectory of succession with time.

is called progressive succession, which culminates in the phase of maximal biomass accumulation (until further disturbances or soil limitation takes place; Wardle et al., 2004; Fig. 2).

Progressive succession strongly contrasts with less-known retrogressive succession (Walker and Reddell, 2007). The retrogressive phase of succession is common in ecosystems establishing on old and extremely-impoverished soils (Walker and Reddell, 2007). Conversely to secondary succession, ecosystem retrogression is characterized by a decline in soil nutrient availability, reduction in biomass and plant productivity, and increasing predominance of slow-growth and stress-tolerant species (Gaxiola et al., 2010; Coomes et al., 2013). Differently from the progressive succession, retrogression is a phenomenon that occurs on a scale of (tens or hundreds of) millennia (Walker and Reddell, 2007; Peltzer et al., 2010; Fig. 2). Anthropogenic disturbances including soil removal, nutrient inputs or changing fire regimes do not take ecosystems in the retrogressive phase to an earlier stage that tends to recover toward the previous state (such as occurs in the progressive succession). Instead, these processes accelerate the retrogression leading to ecosystems with lower biomass and complexity, further reducing resilience (Walker and Reddell, 2007; Peltzer et al., 2010). Ecosystems in the retrogressive phase do not seem to recover to their previous states not even with the help of restoration efforts (Peltzer et al., 2010). In addition, there is theoretical and empirical evidence on the low resilience and the lack of regeneration in *campo rupestre* following degradation (Buisson et al., 2019; Le Stradic et al., 2018), as expected for an ecosystem in retrogression.

The model of retrogressive succession applies to *campo rupestre* (Abrahão et al., 2019), and therefore, the application of successional stages in AFA is inappropriate to license projects in *campo rupestre* areas. Nevertheless, almost half of the environmental licensing processes analyzed classified *campo rupestre* areas in some stage, despite the lack of scientific criteria underpinning such classification. Unfortunately, the criteria used to define the successional stage were predominantly that related to the degree of human impact in the area, which has no strict relation to ecological succession (Prach and Walker, 2019).

Finally, all licensing processes that requested permission to suppress *campo rupestre* areas were located within the limits of the Atlantic Forest. Hence, the environmental agencies required environmental compensation as recommended by AFA. Although the data referring to 35% of the compensation proposals were unavailable, our results show that extensive *campo rupestre* areas were legally lost by mining through out-of-kind, rather than a like-to-like compensation (Sonter et al., 2014). In view of the impossibility to recover *campo rupestre* areas (Le Stradic et al., 2018), the like-to-like compensation becomes important strategy to conciliate exploration and conservation.

Given the silent biodiversity loss in areas with irreplaceable ecosystem services (e.g. water supply, Rodrigues et al., 2019), we suggest the formulation of specific legislation to improve environmental licensing in *campo rupestre* is needed to reconcile natural resource exploration and conservation (Box 1). We acknowledge that, in the absence of specific legislation, the use of the AFA in project licensing is better than no regulation at all (see Vasconcelos, 2014). However, laws inappropriate to meet the need for conservation and sustainability should be adjusted (Howes et al., 2017; Singh et al., 2018). We argue for a broad, comprehensive, evidence-based discussion in order to produce sound legislation that will recognize the need for sustainable use of natural resources in *campo rupestre*. Such initiative will bridge the gap between science and practice, and will likely advance our ability to prioritize areas for exploration and better target sites for conservation of biodiversity and ecosystem services, benefiting society, people and nature.

Declarations of interest

None.

Box 1: Recommendations for the *campo rupestre* conservation

The *campo rupestre* has not received a legal treatment consistent with scientific evidence, despite its unique biodiversity and endemism. We propose that the regulatory environmental agencies should adopt the following:

- Stop applying the CONAMA Resolution 423/2010 to the *campo rupestre* sites due to low ecological similarity between *campo rupestre* and *campo de altitude*;
- Stop relying on concepts of ecological succession and definitions of successional seres to classify *campo rupestre* sites targets of licensing;
- Compensate *campo rupestre* areas by establishing protected areas with high floristic similarity;
- Discuss and create a specific legislation for *campo rupestre*, with the engagement of all stakeholders, society, academics and mining companies;
- Require immediate detailed floristic studies in all environmental licensing processes that affect areas of *campo rupestre*, until a specific law is created.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.pecon.2019.04.001.

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