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Policy Forums

Vegetation misclassification compromises conservation of biodiversity and ecosystem services in Atlantic Forest ironstone outcrops

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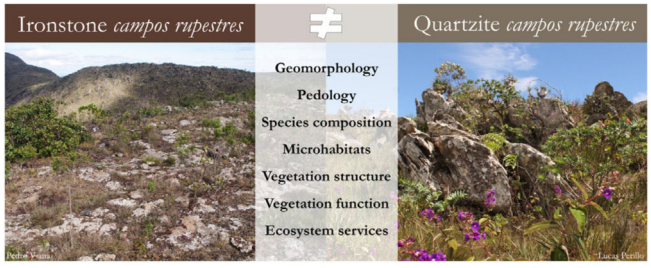
HIGHLIGHTS

- Changes in Brazil's legislation threaten conservation of ironstone *campos rupestres*.
- There is no ecological equivalence between ironstone and quartzite *campos rupestres*.
- Specific offset methods are needed to avoid the destruction of ironstone ecosystems.

GRAPHICAL ABSTRACT



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ABSTRACT

A recent state provision allows quarzitic *campo rupestre* (QCR) set-asides as in-kind compensation for ironstone *campo rupestre* (ICR) suppression in the Atlantic Forest, which induces out-of-kind compensation. However, the recently published state provision defines no clear parameters to demonstrate "ecological equivalence" as an in-kind compensation. We evaluated whether there is ecological equivalence between and ICR and QCR in the Brazilian Atlantic Forest. We show marked geological, pedological, floristic, structural, and functional differences between ICR and QCR. There is evidence that the new compensation rules only partially offset loss of biodiversity and ecosystem services hosted by ICR, determining limited effectiveness of the legislation for ICR conservation in the Atlantic Forest. We conclude that the development of clear compensation parameters based on scientific evidence and quantitative indicators is a priority gap for the conservation of ICR under increasing mining pressure.

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Introduction

Brazil is recently experiencing a series of changes in environmental legislation and de-regulation processes that threaten the protection of its biodiversity, geodiversity and cultural heritage (Bernard et al., 2014; Silveira et al., 2018; Carvalho et al., 2019; Metzger et al., 2019; Ferreira et al., 2020; Salvador et al., 2020). Such changes reflect a gap between ecological knowledge and conservation policy (Azevedo-Santos et al., 2017). A critical assessment of assumptions of changes in conservation legislation, and their potential environmental setbacks is urgently needed to both inform and support public policy.

A 2017 change in the interpretation of environmental compensation legislation threatens a key ecosystem within the Atlantic Forest domain in Minas Gerais State as the assumptions of these changes have not been properly addressed. The Atlantic Forest is a vegetation mosaic comprising dense evergreen and semideciduous rainforest, and open ecosystems such as coastal dunes and rocky outcrop montane grasslands (Joly et al., 2014; Neves et al., 2017). The Atlantic Forest was declared a "national heritage" by the Constitution of the Republic of Brazil (Brasil, 1988) and is protected by the federal Law 11.428/2006 (Brasil, 2006). The federal Atlantic Forest Law mandates environmental compensation of suppressed vegetation in a like-for-like basis, i.e. vegetation with ecological equivalence (as expressed by its article 17). In-kind offsets refer to compensatory mitigation that provides habitat, functions, values, or other attributes like those affected, whereas out-of-kind offsets allow for different forms of compensation (McKenney and Kiesecker, 2010).

Recently, in Minas Gerais state, the *Provision* n° 02/2017 (SISEMA, 2017) (hereafter IS02/2017) gave a new interpretation to this matter. It has allowed out-of-kind compensation (in a different vegetation type) in half of the offsetting area, as long as there is "ecological equivalence" between the suppressed vegetation and the vegetation type to be set-site for offsetting. More recently, State Decree 47.749/2019 (Minas Gerais, 2019) allowed setting-aside areas for compensation of Atlantic Forest with the same ecological characteristics, including the following criteria: similar vegetation structure, phytophysiognomy, successional stage, species richness and endemism. Nevertheless, when areas with these similar characteristics are unavailable, compensation may be carried-out under the assumption of an "environmental gain", broadly defined in Art. 50 as "the set of conservation or recovery actions that promote the reduction of habitat fragmentation and increase connectivity between areas". Here, we address the loosely defined issue of ecological equivalence in Atlantic Forest ironstone outcrops, a key ecosystem under anthropogenic pressure, especially iron-ore mining.

Ironstone *campo rupestre* (ICR, or *canga* vegetation) occurs on substrates of ferruginous and banded iron formations (i.e. ironstone geosystems) which have been severely and rapidly degraded owing to iron-ore mining. In the Atlantic Forest, ironstone *campo rupestre* occurs mostly in the so-called Iron Quadrangle region in Minas Gerais, the largest mineral province in Brazil. The estimated original area of ironstone geosystems in Minas Gerais is 1580 km^2, harboring 2933 known vascular plant species (Carmo et al., 2018), mostly within the Atlantic Forest domain. ICR hosts geographically rare micro-habitats that harbor a threatened and endemic biota that experience significant pressure from iron-ore mining (Jacobi et al., 2007; Viana et al., 2016; Mota et al., 2018; Monteiro et al., 2018), driven by the global demand for iron ore and steel (Sonter et al., 2014a; Carmo and Kamino, 2015). Up to 2014, the *canga* ecosystem at the Iron Quadrangle lost an overall 50% of its habitats (Jacobi et al., 2011; Salles et al., 2018; Souza-Filho et al., 2019). Nonetheless, information on potential offsetting in such threatened ecosystem is unclear (Sonter et al., 2014b; Carmo, F.F. personal communication).

Our goal was to critically examine the scientific evidence for the ecological equivalence concept in the new Minas Gerais State legislation (State Decree 47.749/2019) encompassing the plant communities in ironstone and quartzite *campo rupestre*. We compare ICR with QCR because areas in the latter have been used to compensate for the suppression of the former. First, we examine the extent of similarities between ICR and QCR in terms of geomorphology, pedology, floristic composition, vegetation structure and function, and biogeographical patterns. Second, we argue that the out-of-kind compensation alternative seriously compromises the persistence of endemic biodiversity and key ecosystem services provided by ironstone outcrop geosystem. Finally, we discuss legal issues concerning IS02/2017 and State Decree 47.749/2019 and propose actions to steer legislation that would secure biodiversity and ecosystem services.

Geomorphological and pedological differences between rocky outcrop types

Rocky outcrop vegetation is typically characterized by a heterogeneous mosaic of grassland micro-habitats, marked by seasonal water stress and an acidic condition of its neo-soils (Monteiro et al., 2018), with low water-holding capacity (Silveira et al., 2016) and low fertility (Ranieri et al., 2012). However, geology and mineralogy drive significant differences between QCR and ICR in relation to soil physical and chemical properties. These differences are specifically related to higher concentrations of metallic minerals such as iron and manganese, and clayey/silty textures in ICR; and the sandy texture with greater exchangeable aluminum levels in QCR (Silveira et al., 2016). The strong pedological differences indicate little ecological equivalence between the ICR and QCR ecosystems (Benites et al., 2007; Messias et al., 2013; Carmo and Jacobi, 2016; Schaefer et al., 2016; Mucina, 2018).

Differences in vegetation ecology and functioning between ICR and QCR

Local and regional floristic surveys comparing QCR and ICR have found clear differences in species composition between the two ecosystems (Jacobi and Carmo, 2009; Messias et al., 2013; Carmo et al., 2016). Zappi et al. (2017) recently compiled a nationwide database comparing the floristic species of QCR and ICR. Their comprehensive and updated database comprises 2920 species of 789 genera from 10,668 occurrences across 47 sampling sites. The authoritative study by Zappi et al. (2017) shows unequivocal results indicating strong floristic differentiation between QCR and ICR. Differences in species composition between ICR and QCR are also reflected in phylogenetic structure of plant communities (Zappi et al., 2017, 2019), meaning that different evolutionary processes drove community assembly between QCR and ICR. In the Espinhaço Range context, the levels of plant endemism support recognition of a distinct biogeographic district for the Iron Quadrangle (Colli-Silva et al., 2019).

QCR and ICR are not only different in terms of species composition, evolutionary history, functional identity, and biogeography but also in lithostratigraphic and geomorphologic features. ICR hosts one of the most rare and threatened habitats: the subterranean iron cave system (Ruchkys et al., 2015). These formations, composed by macro, meso and micro-caves, are common subterranean components of ICR, but are extremely rare in QCR. The presence of iron cave networks provides underground connectivity for endemic and threatened species, i.e. troglobites harbored by the ICR (Ferreira et al., 2015). Some singular ecosystem processes occur on the iron substrates of ICR. The micro-topographic heterogeneity favors the development of root system through cracks, pores,

crevices, and small channels on ironstones (Carmo et al., 2016) and rarely form rhizothemes and root tussocks structures. Such underground plant biomass forms a specific trophic base to resident fauna, including endemic ICR cave invertebrates (Ferreira et al., 2015). Furthermore, the underground root systems and microorganisms are directly associated with the iron biogeochemical cycle as part of reduction and oxidation cycles, which contribute to the geomorphological evolvement of ironstones and its subterranean heterogeneity (Levett et al., 2016). Given such unique properties of ICR, attempts to offset its loss through QCR set asides will inevitably result in biodiversity loss, especially of troglobite fauna (Ruchkys et al., 2015).

Disruption of ecosystem services–water security

To apply ecological equivalence between ecosystems, we must examine whether there is equivalence in ecosystem services provided by each. Due to outstanding lithostratigraphic differences, QCR and ICR strongly differ in quality and quantity of water recharge capacity and provision of underground water. The geological formation composed by banded iron formation (i.e. itabirites) covers only 13% (90.800 ha) of the total 700.000 ha of the Iron Quadrangle region (Vasconcelos, 2014; Schaefer et al., 2016). This geological formation is the most important aquifer of Metropolitan Belo Horizonte Region (the third largest Brazilian city) and contains 80% (4×10^9 m^3) of subterranean water reserves of the region (IBRAM, 2004). The ICR are associated with *cangas* that have higher water-recharge potential than quartzites in QCR due to their porosity, microfractures and permeability (IBRAM, 2004; Carmo et al., 2016). Compensating lost ICR with QCR areas will likely fail to secure water recharge and provision.

Legal issues of IS02/2017 and State Decree 47.749/2019

ICRs in the Atlantic Forest biome are protected by both Federal Law N°11.428/06 (the Atlantic Forest Law) and Article 225, §4, of the Brazilian Constitution (Brasil, 1988). In cases where legislation allows vegetation suppression of the biome, its art.17 establishes the obligation to compensate an equivalent extension of area with ecological equivalence. However, the publication of IS02/2017 and Decree 47.749/2019 clearly violates the provision of the aforementioned Federal standard.

When trying to define the meaning of "same ecological characteristics", state regulations create a new criterion called "environmental gain", which has nothing to do ecological equivalence. According to art. 50 of the Decree, the environmental gain would be *the set of conservation or recovery actions that promote the reduction of habitat fragmentation and the increase of connectivity between systems, with the purpose of reinforcing the ecological importance of the area, through creation or increasing ecological corridors and recovery of anthropized areas.* The Decree allows that, once the unavailability of areas with the same ecological characteristics is determined, the compensation is made 100% considering only the criterion of environmental gain, that is, without minimally guaranteeing ecological similarity between the areas suppressed and the one intended for conservation.

Nonetheless, the Brazilian constitution and the requirement for compensation by the Atlantic Forest Law are clearly intended to protect and ensure that the use of any ecosystems associated with this hotspot biome does not increase the risks of species extinction. IS02/2017 and the Decree clearly aim at addressing this principle. Considering the species richness, endemism, and restricted distribution in the Brazilian territory, compensating ICR areas by complying with strict equivalence criteria, which can guarantee the ecosystem's long-term survival, has become increasingly difficult in Minas Gerais. This difficulty explains the flexibilization of state norms conflicting with federal law and scientific criteria.

ICR conservation should be prioritized due to irreplaceable geological and biological characteristics (Carmo and Jacobi, 2013; Zappi et al., 2017). Degradation or loss of ICR habitats may be irreversible in geological and ecological terms. Hence, out-of-kind compensation is unlikely to guarantee no-net-loss of relevant environmental attributes let alone result in net-positive outcomes, as proposed by IS02/2017. Out-of-kind compensation is unlikely to decrease the extinction risk of endemic species from the suppressed ICR ecosystem. Furthermore, Decree 47.749/2019 does not make the assessment ecosystem services mandatory in the process of ecological characterization, nor provides clear or evidence-based metrics to guide compensation (Miola et al., 2019). Therefore, there is a clear possibility that "residual impacts" in ICR may have exceeded limits to what can be set-aside for offsetting, despite the lack of systematic assessments of threshold criteria. The international standards for conservation best practices recommend the application of the precautionary principle in scenarios of uncertainty (BBOP, 2012).

IS02/2017 regulates administrative procedures concerning compensation for vegetation suppression permits in the Atlantic Forest in Minas Gerais. ICRs do not have a specific standard for their characterization. Due to the absence of a specific norm for ICR, CONAMA Resolution 423/2010, which regulates compensation of a different ecosystem, is being adopted, resulting in serious errors during the process of vegetation suppression permitting and environmental compensation in ICR (Miola et al., 2019). Therefore, ICR are vulnerable to compensation mechanisms that may lead to extinction of its rare natural habitats, ecological processes, and biodiversity.

Additionally, the protection and compensation of Atlantic Forest ecosystems should not be dealt with by the Executive Branch through a state policy (i.e., State Decree and *Provisions*) in contraction to Federal legislation. In legal terms, this matter has a constitutional importance and should be treated only after a judicious democratic engagement process involving all stakeholders, considering researchers' scientific evidence and citizens' opinions. Any regulation allowing suppression of Atlantic Forest remnants without compulsory like-for-like compensation violates the principles of the Brazilian Constitution.

Conclusions

By scrutinizing the scientific literature, we conclude that there is no empirical evidence to support the notion of generalized ecological equivalence between ICR and QCR habitats, and that the flexibilization in environmental compensation within Atlantic Forest biome does not guarantee proper protection of biodiversity and ecosystem services. The out-of-kind compensation proposed by the IS 02/2017 and the State Decree 47.749/2019 lacks consideration of solid geological and ecological scientific knowledge about these habitats, as well as a juridical foundation to accept the compensation equivalences between the distinct types of rock outcrops.

The overall area covered by ICR is decreasing steeply at local and national scales (Salles et al., 2018; Souza-Filho et al., 2019). Therefore, promotion of no-net loss of its biodiversity is urgently needed (Sonter et al., 2014b). Unfortunately, there are only a few protected areas that provide full legal protection status to ICR habitats. If the mining development trends continue in its current pace, significant biodiversity loss is expected given the high levels of endemism in both fauna and flora of ICR (Jacobi et al., 2007). Marked decreases in delivery of key ecosystem services will also follow the loss of ICR, especially compromising water recharge provision. Owing to a critical lack of knowledge on restoration of ICR (Silveira et al., 2016; Miola et al., 2019), and the steep loss of the original area covered by

Box 1

Suggestions to improve the compensation analysis for Atlantic Forest Ironstone *campo rupestre*.

1. To develop clear and specific policy guidelines and indicators on how to implement the ecological equivalence in compensation for the ICR based on international best practices of mitigation hierarchy and biodiversity offsetting, and no-net-loss concept.
2. To implement a discussion of compensation limits for restricted habitats within the biome (risk vs. irreplaceability) with different multipliers for compensation.
3. To allow free public access to a registry that describes how compensated actions are achieving their promised results.

ironstone outcrops (Salles et al., 2018), we may be rapidly coming to a point-of-no-return, in which the remaining ICR areas will no longer hold the ecological processes for biodiversity and ecosystem services.

There is a pressing need for the establishment of reliable ecological equivalence metrics to better support offsetting of Atlantic Forest ICR. Evidence-based compensation is likely to improve our ability to promote no net loss of biodiversity and to effectively secure ecosystem services provided by ICR. Evidence-based indicators and metrics should consider that multiple floristic groups may be recognized in ICR based on distinct species composition and environmental conditions, primarily related to substrate and climate (Neves et al., 2018). Discussions between the scientific community, legislators, and decision-makers are urged to develop effective indicators (see suggestions in Box 1). We call for an inclusive debate to reassess the assumptions of IS02/2017 and State Decree 47.749/2019 to reconcile economic activities with conservation of biodiversity and ecosystem services for people and nature.

Conflict of interest

The authors declare no conflict of interest.

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