Forum

Controversies and hidden risks in biodiversity offsets in critically threatened Canga (ironstone) ecosystems in Brazil

Flavio Fonseca Carmo and Luciana Hiromi Yoshino Kamino

Abstract Canga, or ironstone, ecosystems are hotspots of old-growth plant diversity and highly specialized cave invertebrates. These ancient metalliferous habitats are amongst the most threatened ecosystems because of the destruction caused by large-scale iron ore mining. International debate on biodiversity offsets is increasing because these mechanisms are seen as tools for potentially balancing economic development with conservation biodiversity. Leading mining companies worldwide, including some of the largest iron ore producers in Brazil, are signatories to offset principles and best practices that aim to achieve no net loss of habitats, species or ecosystem functions. We aimed to analyse whether Brazilian legal requirements for biodiversity offsets result in the achievement of conservation outcomes or in elevated threat of extinction in canga ecosystems. We evaluated technical reports that support decision-making related to environmental licensing for iron ore mining and specific offset proposals linked to the Atlantic Forest Act. We found a relevant net loss in canga ecosystems and observed shortcomings related to the equivalency and transparency of offset principles. These deficiencies are mainly related to lax norms and regulations and the absence of an integrated database for accessing information on environmental licensing processes. We argue that both policy flaws and low engagement by the Brazilian mining industry in implementing offset principles have increased the threat of extinction in canga ecosystems.

Keywords Brazil, canga ecosystem, critical habitats, environmental licensing, governance, iron mining, risk of extinction

Introduction

Ironstone ranges are island-like lateritic duricrusts that occur on the oldest iron rocks and landforms, mainly in Australia and Brazil (in the latter they are known as canga). These ecosystems are hotspots of endemic, high-diversity and threatened plant and animal communities (Gibson et al., 2010; Vasconcelos et al., 2019). The Brazilian canga features a variety of habitats including cliffs, caves, crevices and high-altitude bogs and ponds that are acidic and contain high concentrations of metals, especially iron and manganese (Gibson et al., 2010; Jacobi et al., 2015; Gagen et al., 2019). In open areas where the rock substratum is exposed, temperatures can exceed 60 °C (Jacobi et al., 2015). The canga ecosystems in south-eastern Brazil host > 2,900 vascular plant species, including 148 species present on official lists of threatened flora, 50 species that are microendemic or whose distributions are concentrated in iron-rich rock outcrops and 15 species known only from their type localities, including seven species that are probably extinct (Oliveira et al., 2014; Carmo et al., 2018; Bitencourt et al., 2020). In addition, canga ecosystems shelter specialized animal communities such as troglobitic invertebrates in caves (Gibson et al., 2010; Vasconcelos et al., 2019).

The canga ecosystem is a federal and state priority area for the conservation of biodiversity and speleological heritage and is associated with the Brazilian Atlantic Forest, recognized by science and by governments as one of the most threatened tropical rainforests (Myers et al., 2000; Brasil, 2006). In the Quadrilátero Ferrífero (Iron Quadrangle), south-eastern Brazil, priority conservation areas contain one of the greatest expanses of these unique ecosystems. These areas have been classified as of maximum importance because they contain canga ecosystems, endemic fauna and flora and important public water sources (Drummond et al., 2005; MMA, 2007; ICMBio, 2018). In addition, the canga ecosystems are within the boundaries of two United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserves, the Espinhaço Range and the Atlantic Forest, that represent a model of participatory management of cultural and environmental heritage recognized by the intergovernmental programme Man and the Biosphere (UNESCO, 2021).

However, these ancient habitats are highly threatened because of the ongoing destruction caused by the mining of iron ore deposits to supply the global demand for commodities (Sonter et al., 2014; Tibbett, 2015; Villén-Pérez et al., 2018). This problem is pronounced at large-scale mining sites, where there are significant impacts on landscapes, pollution of air, rivers and streams, and loss of biodiversity (Jacobi et al., 2011; Carmo et al., 2020; Kamino et al., 2020).

Flavio Fonseca Carmo (orcid.org/0000-0002-5423-7957, corresponding author, flavio@institutopristino.org.br) and Luciana Hiromi Yoshino Kamino (orcid.org/0000-0003-2624-0128) Instituto Pristino, Belo Horizonte, Minas Gerais, 30642180, Brazil

Received 20 November 2020. Revision requested 2 March 2021.
Accepted 28 February 2022. First published online 9 November 2022.

One mechanism that has been implemented to reduce the conflicts between the implementation of development projects and biodiversity conservation is the use of biodiversity offsets (BBOP, 2009a). Offsetting mechanisms are applied when it is not possible to avoid, mitigate or rehabilitate biodiversity impacts (ten Kate et al., 2004). Unlike other environmental compensation mechanisms, biodiversity offsets assume that the outcomes of conservation actions will achieve no net loss of habitats, species compositions or ecosystem functions and services (BBOP, 2009b). International debate on biodiversity offsets is increasing in the scientific literature and amongst the mining industry, developers, financial institutions, governments and civil society organizations. The main driver of these debates is the potential these offsets have for balancing economic development and biodiversity conservation (McKenney & Kiesecker, 2010; Virah-Sawmy et al., 2014).

Reviews of biodiversity offsets have discussed the implementation risks and practical challenges of achieving conservation objectives, identifying failures, and controversial results (Gonçalves et al., 2015; Apostolopoulou & Adams, 2017; Bull & Strange, 2018; Simmonds et al., 2020). These risks and challenges are more significant when impacts lead to irreplaceable losses in sensitive natural areas, such as unprotected regions of high conservation value, priority conservation areas and unique ecosystems characterized by endemic and/or restricted-range species or those categorized as threatened on Red Lists, as with the Brazilian canga ecosystems. These sensitive natural areas can be considered critical habitats, which encompass both natural and modified habitats, that deserve particular attention in the planning and implementation of biodiversity offsets (BBOP, 2009b; Watkins et al., 2015; IFC, 2019). Therefore, metalliferous regions are useful locations in which to evaluate offset outcomes because there is overlap between sensitive ecosystems and large-scale mining.

Brazilian federal and state legal requirements regulate five categories of compensation related to environmental licensing, following the mitigation hierarchy approach (Barros et al., 2015; IEF, 2021a). These environmental compensations for impacts on biological diversity predominantly allocate financial resources for land-tenure regularization in previously established protected areas that are in the public domain (i.e. they represent protected areas similar to IUCN categories Ia, II and III sensu Dudley, 2013) and/or for restoration actions. In Brazil, private properties in public areas must be expropriated by the government through an administrative process that determines the market value of the property and any improvements to it. In addition, there are mechanisms associated with land donation for creating new protected areas. Several authors consider this form of environmental compensation in Brazil to fall under the definition of biodiversity offsets (Darbi et al., 2009; Bull & Strange, 2018; Silveira et al., 2020) because the offsets are realized through conservation outcomes whose premise is the protection of natural areas where biodiversity loss is imminent (BBOP, 2009a). Additionally, some rules and metrics in the Brazilian legal requirements for environmental compensation resemble concepts used in the design of the offset process. One of these rules (a state regulation) refers to the obligation to establish offset sites in the same ecosystem and to follow the biodiversity offset equivalency principle (ICMM & IUCN, 2013). This principle requires that conservation outcomes involve the same type of biodiversity (same species, habitats or ecosystems) as those affected by the project. Mechanisms applying this principle are also referred to as like-for-like or in-kind offsets (BBOP, 2009b).

We investigate a specific mechanism in Brazilian offsetting that occurs when enterprises, including in the mining industry, are located in the Atlantic Forest biome and cause substantial natural habitat loss (unavoidable adverse impacts). A federal law known as the Atlantic Forest Act (Brasil, 2006) sets forth in Article 17 that the offsets must allocate an area equivalent to the extent of the impacted site (a 1:1 ratio), with the same ecological characteristics and, whenever possible, in the same micro-watershed. As all of the canga ecosystems associated with the Atlantic Forest are located in the state of Minas Gerais, there are also state legal requirements. The State Normative Resolution number 73 of 2004 established that any enterprise or project that causes the loss of natural areas (unavoidable adverse impacts) in ecosystems associated with the Atlantic Forest is required to offset an area at least twice the size (≥ 2:1 ratio) of the impacted area and in the same ecosystem (Minas Gerais, 2004). This rule relates to the offset ratio (BBOP, 2009b): the ratio between an area occupied by an offset and the area affected by a project.

We aimed to assess whether biodiversity offsets result in conservation outcomes or increased extinction threats in canga ecosystems associated with the Atlantic Forest Act. To this end, we determined (1) the background level of natural habitat loss, which is the total area of canga ecosystems irreversibly converted into mining sites, and (2) the offset ratio. We aimed to clarify the degree to which compensation procedures follow basic principles and international best practices such as no net loss, equivalency and transparency.

Methods

To assess biodiversity offset outcomes in canga ecosystems, we examined the environmental licensing technical reports on iron mining activities published during 2008–2020 in the state of Minas Gerais, south-east Brazil. These technical reports support the decision-making advisers at the Specialized Technical Chambers of the State Council for Environmental Policy (Conselho Estadual de Política

Ambiental) in their decisions regarding the environmental intervention requests and compensation proposals presented by companies and entrepreneurs.

We built a database from the technical reports of mining projects in the Atlantic Forest. Firstly, we identified the municipalities with iron ore deposits and mining sites using the Minas Gerais Mineral Resources web map (CODEMGE, 2018). Secondly, we consulted the official public database on environmental licensing procedures and searched for the technical reports associated with the municipalities identified in the first step. The searches were conducted on the websites of the Specialized Technical Chambers of the State Council for Environmental Policy: the Regional Collegiate Units (COPAM, 1999), the Chamber of Mining Activities (SEMAD, 1999b) and the Biodiversity Protection and Protected Areas Chamber (SEMAD, 1999a). Thirdly, we examined each technical report regarding the municipalities, mining sites and projects that provided information on irreversible impacts (habitat loss) in canga ecosystems and indicated the locations and areas of proposed offset sites. For each mining site or project we verified the following information: (1) the locations and total areas of canga ecosystems lost irreversibly because of the installation or expansion of mining sites and whether these areas are located in priority conservation areas or UNESCO Biosphere Reserves, and (2) the locations and total areas of proposed offset sites for canga ecosystems and whether these are located in protected areas.

Results

We found 50 technical reports published during 2008–2020 on iron ore mining sites in the Atlantic Forest. These technical reports are related to 31 projects involving the conversion of canga ecosystems into industrial sites for the installation or expansion of open-pit mines, waste piles and mining infrastructure such as access roads. These 31 mining projects were in 15 municipalities and along a 180 km north–south axis in the state of Minas Gerais. Sites for 29 (93%) of these projects were located in UNESCO Biosphere Reserves and were priority areas for the conservation of biodiversity and speleological heritage.

These 31 mining projects resulted in the irreversible loss of 1,953 ha of canga ecosystems (Table 1). We found a total of 1,186 ha to be occupied by like-for-like offsets designated to compensate for canga habitat loss, corresponding to an offset ratio of only 0.6:1.

We also found that of the 1,186 ha occupied by offsets, only 375 ha (32%) of unprotected canga ecosystems had been converted into new protected areas. The remaining 68% (811 ha) corresponded to land-tenure regularization in previously established protected areas. Furthermore, we observed that 767 ha of the offset sites were designated for other ecosystem types (out-of-kind offsets) such as vegetation in monodominant broad-leaved dwarf forests composed of *Eremanthus* spp. (candeia), grassland vegetation associated with quartzite substrates (quartzitic *campos rupestres*) and granitic and gneissic inselbergs and cerrado grasslands. We also found that c. 30 ha of the offset sites were designated for the recovery of degraded canga ecosystems (Table 1).

Discussion

The biodiversity offset policy for canga ecosystems associated with the Atlantic Forest Act did not promote conservation outcomes for these threatened ecosystems. We found a total of 1,186 ha occupied by offsets in canga ecosystems, whereas we observed an irreversible loss of 1,953 ha. The state legal requirements are for a 2:1 offset ratio and for offsets in the same ecosystem; thus, we expected to identify at least 3,906 ha occupied by offsets for canga sites. However, our findings indicate that there is an offset debt represented by the offset ratio of 0.6:1.

We also observed shortcomings related to the high proportion of canga ecosystems occupied by offsets for land-tenure regularization (68% of 1,186 ha) in previously established protected areas. Land regularization issues pose one of the greatest challenges for managing protected areas in Brazil (Pacheco et al., 2017), but the key point we highlight here is that there are at least four other categories of monetary compensation (Barros et al., 2015; IEF, 2021a) for allocating resources to address this problem. Choosing to allocate most of the offset area to land-tenure regularization results in no net benefit (Virah-Sawmy et al., 2014) because canga ecosystems in protected areas are already under no threat of habitat loss, unlike those in unprotected areas.

We documented a net loss of canga ecosystems of 767 ha (39% of 1,953 ha of irreversible loss) because offsets were designated in other ecosystem types (out-of-kind offsets). In these cases, the equivalent losses of specific habitats in canga, cliffs and iron caves, for example, or the impacts on populations of endemic plants and troglobitic fauna, were not reported in the biodiversity outcomes because the offsets in other ecosystems did not contribute to the reduction of extinction risks and failed to contribute to achieving no net loss.

In the Quadrilátero Ferrífero, the loss of canga habitat has reached 50% of its total area and most remnants are within a degraded matrix comprising many large-scale open-pit mines (Jacobi et al., 2011; Salles et al., 2019). Biodiversity offsets can generate conservation outcomes through restoration as long as there are no major restrictions on the ability to restore environments to levels of biological and structural ecosystem complexity similar to before degradation (BBOP, 2009a). However, this scenario is not expected for canga

TABLE 1 The 50 technical reports published during 2008–2020 regarding 31 iron mining projects in the Atlantic Forest, Minas Gerais State, south-east Brazil. These reports are made available for public consultation by the State Council for Environmental Policy, the Chamber of Mining Activities and the Biodiversity Protection and Protected Areas Chamber.

			Mining site		Offset site	
Publication year	ID number	Municipality	Located in priority conservation area?	Area of canga loss (ha)	Area in canga (ha)	Area in other ecosystems (ha)
2008	46883/2008; 011/2017	Catas Altas	Yes	82.9	Not found	
2008	05/2008; 096/2013	Itabirito	Yes	388.0	Not found	
2009	SN/2009; 160/2018	Catas Altas	Yes	34.5	0.0	37.2
2009	002/2009; 014/2014	Conceição do Mato Dentro	Yes	15.9	0.0	28.8
2009	506914/2009; 151/2012	Mariana	Yes	74.1	Not found	
2010	757545/2010; 014/2014	Conceição do Mato Dentro	Yes	34.9	69.8 (land regularization in Serra da Ferrugem Natural Monument)	0.0
2010	668286/2010; 007/2017	Mariana	Yes	4.1	Not found	
2010	006/2018	Mariana, Ouro Preto	Yes	17.4	17.8 (land regularization in Serra do Gandarela National Park)	29.0
2010	078/2018	Santa Bárbara	Yes	12.2	24.4 (land regularization in Serra do Gandarela National Park)	0.0
2010	186/2018	Itatiaiuçu	No	13.4	0.0	26.8
2011	ZM17/03/2011; 98/2018	Mariana	Yes	30.5	30.5 (for restoration/recovery)	25.1
2011	400/2011; 198/2013	Itabirito	Yes	41.5	Not found	
2012	478/2012; 061/2016	Ouro Preto, Mariana	Yes	79.2	Not found	
2014	98/2017	Ouro Preto	Yes	20.7	0.0	42.0
2014	23/2017	Nova Lima	Yes	2.2	Not found	
2015	921818/2015; 004/2015	Conceição do Mato Dentro	Yes	17.7	35.4 (land regularization in Serra da Ferrugem Natural Monument)	0.0
2017	666964/2017; 179/2017	Barão de Cocais	Yes	281.0	282.3 (land regularization in Serra do Gandarela National Park)	110.0
2017	1375747/2017; 146/2017	Conceição do Mato Dentro	Yes	281.0	301.4 (creation of private nature reserve)	260.8
2017	209/2017	Itatiaiuçu	No	4.7	10.6 (creation of private nature reserve)	0.0
2017	09/2018	Mariana, Ouro Preto	Yes	25.8	52.4 (creation of private nature reserve)	0.0
2018	007/2018; 719895/2019	Itabirito	Yes	52.7	52.7 (land regularization in Serra da Moeda Natural Monument)	40.7
2018	786382/2018; 13367/2018	Brumadinho, Sarzedo	Yes	0.7	0.7 (creation of private nature reserve)	0.0
2018	414607/2018; 005/2018	Nova Lima, Rio Acima	Yes	156.2	155.6 (land regularization in Serra da Calçada Natural Monument)	130.6

Table 1 (*Cont.*)

Publication year	ID number	Municipality	Mining site: Located in priority conservation area?	Mining site: Area of canga loss (ha)	Offset site: Area in canga (ha)	Offset site: Area in other ecosystems (ha)
2018	0829572/2018; 591702/2019	Barão de Cocais	Yes	79.8	87.4 (land regularization in Serra do Gandarela National Park)	0.0
2019	002/2019; 063607/2020	São Joaquim de Bicas, Igarapé, Brumadinho	Yes	3.4	3.6 (land regularization in Serra da Moeda Natural Monument)	0.0
2019	0350182/2019; 016/2020	Mariana	Yes	68.5	68.5 (land regularization in Serra do Gandarela National Park)	0.0
2020	004/2020	Nova Lima	Yes	7.5	0.0	6.8
2020	07/2020	Sarzedo	Yes	82.0[1]	Not found	
2020	0154647/2020	Mariana	Yes	2.2	2.2 (creation of private nature reserve)	2.2
2020	345998/2020	Itabirito	Yes	6.3	13.9 (land regularization in Serra da Moeda Natural Monument)	0.0
2020	0226650/2020	Itabirito, Ouro Preto	Yes	31.7	7.4 (creation of private nature reserve)	26.9
Total area (ha)				1,952.7	1,216.6	766.9

[1]Estimated using a geographical information system.

ecosystems given the lack of evidence that these island-like lateritic duricrusts can be recovered at the landscape level. Canga ecosystems are the result of millions of years of weathering in banded iron rock formations and are hotspots for old-growth scrublands and grasslands, rare plants and troglobitic invertebrates (Jacobi et al., 2015; Ferreira et al., 2018). Additionally, some studies have reported that once the canga substrate is degraded, rehabilitation or restoration actions result in the emergence of different ecosystems. There are several challenges that need to be overcome to restore canga ecosystems, especially those associated with age, edaphic specificity/high concentrations of metallic minerals, oligotrophism and restricted endemic species (Gagen et al., 2019; Gastauer et al., 2019; Guedes et al., 2020).

All of these challenges contributed to only 30 ha of the offset sites being designated for the recovery of canga ecosystems. A state environmental agency has recognized the lack of restoration and recovery methodologies (SEMAD, 2017) capable of offsetting the hundreds or thousands of hectares of canga ecosystems destroyed by mining activities. Failed attempts to achieve no net loss provide evidence of the inappropriate use of restoration offsets in biodiversity conservation actions, especially when these impacts occur in old-growth plant communities (Curran et al., 2014; Coralie et al., 2015).

Degradation and loss are intense and relatively rapid in canga habitats. During 1985–2011 there was a 213% increase in total mining area in the Quadrilátero Ferrífero (de Diniz et al., 2014) and this vulnerability was recognized by federal and state biodiversity policies (Brasil, 2002; IEF, 2021a,b), which acknowledged that canga ecosystems are special and fragile environments that are threatened significantly by mining activity. Furthermore, we found that sites for 93% of all mining projects developed during 2008–2020 were located in UNESCO Biosphere Reserves and were priority areas for the conservation of biodiversity and speleological heritage.

Some studies have related metalliferous substrates to patterns of genetic plant population structure, suggesting that degradation of canga areas could lead to significant losses in the gene pools of some species (Butcher et al., 2009; Lousada et al., 2013). Other studies have reported that iron-ore mining activities are related to the extinction of local populations of rare plants such as *Minaria monocoronata* and *Stachytarpheta confertifolia* (Rapini, 2012; Cardoso et al., 2020). Biodiversity offset policies and good environmental practices also outline situations in which it is not possible to establish offsets, as expressed in the principle that there are limits to what can be offset (BBOP, 2012; ICMM & IUCN, 2013; IFC, 2019). The leading mining companies, including the largest iron ore producers in Brazil, are signatories of these principles (ICMM, 2022).

We propose that state environmental agencies adopt strategies and metrics based on Business and Biodiversity Offsets Programme Principle 2 (BBOP, 2012), to evaluate cases in which offset practices are inappropriate or inviable.

These strategies and metrics could be implemented at the landscape level and applied to situations in which the impacts cannot be compensated adequately because of the vulnerability or irreplaceability of canga biodiversity. In addition, it is important to consider the international engagement of the mining industry in adopting actions that generate biodiversity outcomes such as extinctions avoided and improved condition of impacted community types (BBOP, 2012; ICMM & IUCN, 2013). State environmental policy provides governmental forums to catalyse these discussions, which should involve the participation of researchers, environmental technicians from the State Forest Institute (Instituto Estadual de Florestas) and advisers at the State Council for Environmental Policy and the Biodiversity Protection and Protected Areas Chamber (Câmara de Proteção à Biodiversidade e de Áreas Protegidas).

We argue that the failures in achieving conservation outcomes in canga ecosystems are related to at least two non-exclusive situations. Firstly, inadequacies in public consultation systems could hinder the search for and access to existing data on environmental licensing processes, especially for 2008 and 2012, for which we could not identify offset reports linked to the Atlantic Forest Act and for which only technical reports of other compensation categories were available. Currently, information on offset processes is made available to the public only in unstructured files, usually as PDFs, and without a search system. Secondly, successive reinterpretations of norms and regulations (Freudenburg & Gramling, 1994) could favour lax fulfilment requirements of the original legal premises. In turn, this laxity could lead to neglect of the protection of canga ecosystem biodiversity in decision-making processes.

To overcome the inadequacies in public consultation systems, we suggest the creation of an integrated database to facilitate access to data such as the name of the business and owner, Biodiversity Protection and Protected Areas Chamber decision date, size and georeferenced location of the target area of significant impacts (habitat loss and degradation) and the area designated (offset sites) for the conservation of canga ecosystems. Additionally, files in structured formats (tables/matrices) and geospatial data in vector formats could be provided for use in geographical information systems. The creation of such an instrument would also improve the participation of society, especially local communities, in biodiversity offset planning and the monitoring of conversation outcomes, and therefore improve the governance of natural resources and biodiversity (ICMM & IUCN, 2013; Zu Ermgassen et al., 2020), and adherence to the transparency principle (BBOP, 2012). It has been suggested that biodiversity offset policies can provide ecological outcomes only if there is a strengthening of commitment to biodiversity conservation amongst stakeholders, including local communities (Guillet & Semal, 2018; Zu Ermgassen et al., 2020).

A more difficult challenge to overcome is that of successive reinterpretations and manipulation of rules and regulations, which can exert a strong negative impact on biodiversity offset decisions (Clare & Krogman, 2013). For example, a state environmental agency recently published an administrative procedure, IS 02/2017 (SEMAD, 2017), which accepted an exception that half of the offset sites be allocated to other ecosystem types provided that the environmental gain was proven. This exception for out-of-kind offsetting was linked to the difficulty of entrepreneurs in locating offset sites in the same type of ecosystem impacted by a project. A priori, this situation does not apply to canga ecosystems because almost all unprotected natural remnants are on properties owned by the mining industry (Jacobi et al., 2011). Nevertheless, we observed that in practice this exception was widely adopted by mining companies in most offsetting cases in canga ecosystems, a situation that prevents no net loss from being attained because its premise requires avoiding equivalent losses in biodiversity and habitats.

Another example of such laxity was observed recently in State Council for Environmental Policy Normative Deliberation 236/2019 (Minas Gerais, 2019), which revoked Normative Deliberation 73/2004 that had obliged mining operations to offset an area at least twice the size of the impacted area and in the same ecosystem. Similarly, State Decree 47749/2019 (Minas Gerais, 2019) retains the 2:1 offset ratio but allows the entrepreneur to choose, separately or jointly, between two types of offsetting: offset sites with the same ecosystem type or the allocation of all of the offsetting to land-tenure regularization of previously established protected areas, even in areas where there are no canga ecosystems (a 0:1 ratio).

We have observed an expansion of out-of-kind offsets as a counterpart to the loss and degradation of canga habitats in Brazil and Australia, countries where mining lobbies hold disproportionate influence over environmental regulations and are also principal advocates for increasing the laxity of offsetting policies (Milanez et al., 2019; Zu Ermgassen et al., 2020). In contrast, mining companies are the main stakeholders involved in the development of biodiversity offsets and in engagement with some of the main conservation strategies, such as like-for-like conservation and the avoidance of net biodiversity loss (ICMM & IUCN, 2013; Virah-Sawmy et al., 2014). This international engagement of the mining industry in offsetting has the same aim of implementing good environmental practices, such as those related to the requirement that mining companies adequately assess their development projects in terms of the risks and impacts to natural areas and ecosystem services, with the goal of achieving no net loss of biodiversity (ICMM, 2015).

However, in Brazil, this failure to implement international good practices and mining principles has resulted in destruction of canga ecosystems during their conversion into mining sites. One of the consequences of this failure is the local extinction of some populations of rare species, such as the cactus *Arthrocereus glaziovii*, which is categorized as Endangered on the IUCN Red List (Taylor & Braun, 2013), and some recently described new species, such as *Ditassa cangae*, *Ditassa ferricola* and *Pleroma ferricola* (Oliveira et al., 2014; Carmo et al., 2018; Bitencourt et al., 2020), along with degradation of the habitats of the rare troglobitic planthopper *Ferricixius davidi* (Hoch & Ferreira, 2012).

Previous studies have also discussed inadequacies in regulating and implementing biodiversity offsets linked to the Atlantic Forest Act (Miola et al., 2019; Silveira et al., 2020). These studies identified the use of erroneous ecological concepts and vegetation misclassification in resolutions, administrative standards and technical reports, and noted the need to establish evidence-based decision-making during the analysis of environmental compensation processes. All of the decisions that have resulted in this inadequate scenario for the conservation of canga ecosystems were made by the State Biodiversity Protection Technical Chamber. This situation is favourable to the mining industry in that it exempts companies from the responsibility of identifying conservation solutions for canga habitats degraded by their mining operations (Apostolopoulou & Adams, 2017).

In this scenario of expansion of out-of-kind offsetting, each opportunity lost by not allocating the offset site to create new protected areas for canga ecosystems presents the potential for implementing more mining projects, which will result in new irreversible impacts on these critical habitats. This cycle of degradation resembles a distorted ouroboros, an Ancient Greek symbol depicting a serpent eating its own tail. A similar situation was also observed by Apostolopoulou & Adams (2017, p. 28), who noted that 'offsetting can be the response to biodiversity loss only if we accept a society where all ecosystems and places are open for trading, and nature will be restricted only to "what is left over after every other demand has been satisfied"'.

Acknowledgements This research received no specific grant from any funding agency or commercial or not-for-profit sector. We thank two anonymous reviewers for their comments.

Author contributions The authors contributed equally to the development of this article.

Conflicts of interest None.

Ethical standards This research abided by the *Oryx* guidelines on ethical standards.

References

Apostolopoulou, E. & Adams, W.M. (2017) Biodiversity offsetting and conservation: reframing nature to save it. *Oryx*, 51, 23–31.

Barros, E.C., Borges, L.A.C., das Graças Paula, M. & Mafra, F.L.N. (2015) The instrument of environmental compensation in Brazil and in the State of Minas Gerais. *Cerne*, 21, 449–455.

BBOP (2009a) *Biodiversity Offset Design Handbook*. Business and Biodiversity Offsets Programme, Washington, DC, USA.

BBOP (2009b) *Glossary*. Business and Biodiversity Offsets Programme, Washington, DC, USA.

BBOP (2012) *Resource Paper: Limits to What Can Be Offset*. Business and Biodiversity Offsets Programme, Washington, DC, USA.

Bitencourt, C., Fernandes, M.F., do Espírito Santo, F. & Rapini, A. (2020) Two new Critically Endangered species of Ditassa (Apocynaceae) from the threatened cangas of the iron quadrangle, Minas Gerais, Brazil. *Plant Ecology and Evolution*, 153, 246–256.

Brasil (2002) *Federal Decree 4339, 22/08/2002*. Institutes principles and guidelines for the implementation of the National Biodiversity Policy, Brazil. planalto.gov.br/ccivil_03/decreto/2002 [accessed 13 April 2022].

Brasil (2006) *Federal Law 11428, 22/12/2006*. Provides for the use and protection of native vegetation in the Atlantic Forest Biome, and provides other measures, Brazil. planalto.gov.br/ccivil_03/_ato2004-2006/2006/lei/l11428.htm [accessed 13 April 2022].

Bull, J.W. & Strange, N. (2018) The global extent of biodiversity offset implementation under no net loss policies. *Nature Sustainability*, 1, 790–798.

Butcher, P.A., McNee, S.A. & Krauss, S.L. (2009) Genetic impacts of habitat loss on the rare ironstone endemic Tetratheca paynterae subsp. paynterae. *Conservation Genetics*, 10, 1735–1746.

Cardoso, P.H., Menini Neto, L. & Salimena, F.R.G. (2020) Taxonomic notes on Stachytarpheta (Verbenaceae) from Brazil. *Kew Bulletin*, 75, 17.

Carmo, F.F., Lanchotti, A.O. & Kamino, L.H.Y. (2020) Mining waste challenges: environmental risks of gigatons of mud, dust and sediment in megadiverse regions in Brazil. *Sustainability*, 12, 8466.

Carmo, F.F., Mota, R., Kamino, L.H.Y. & Jacobi, C.M. (2018) Check-list of vascular plant communities on ironstone ranges of south-eastern Brazil: dataset for conservation. *Biodiversity Data Journal*, 6, e27032.

Clare, S. & Krogman, N. (2013) Bureaucratic slippage and environmental offset policies: the case of wetland management in Alberta. *Society & Natural Resources*, 26, 672–687.

CODEMGE (2018) *Mineral Resources of Minas Gerais On-Line: Synthesis of Knowledge about Mineral Wealth, Geological History, Environment and Mining in Minas Gerais*. recursomineralmg.codemge.com.br [accessed 18 November 2020].

COPAM (1999) *The Regional Collegiate Units*. meioambiente.mg.gov.br/copam/camaras-tematicas-do-copam [accessed 18 November 2020].

Coralie, C., Guillaume, O. & Claude, N. (2015) Tracking the origins and development of biodiversity offsetting in academic research and its implications for conservation: a review. *Biological Conservation*, 192, 492–503.

Curran, M., Hellweg, S. & Beck, J. (2014) Is there any empirical support for biodiversity offset policy? *Ecological Applications*, 24, 617–632.

Darbi, M., Ohlenburg, H., Herberg, A., Wende, W., Skambracks, D. & Herbert, M. (2009) *International Approaches to Compensation for Impacts on Biological Diversity*. Final Report. Forest-Trends, Dresden, Germany.

de Diniz, J.M.F.S., dos Reis, A.A., Acerbi Junior, F.W. & Gomide, L.R. (2014) Detection of mining area expansion in the Ferriferous Quadrangle, Minas Gerais, from 1985 to 2011 by means of remote sensing techniques. *Boletim de Ciências Geodésicas*, 20, 683–700.

Drummond, G.M., Martins, C.S., Machado, A.M., Sebaio, F.A. & Antonini, Y. (2005) *Biodiversity in Minas Gerais: An Atlas for Its*

Conservation, 2nd edition. Fundação Biodiversitas, Belo Horizonte, Brazil.

Dudley, N. (2013) *Guidelines for Applying Protected Area Management Categories Including IUCN WCPA Best Practice Guidance on Recognising Protected Areas and Assigning Management Categories and Governance Types*. IUCN, Gland, Switzerland.

Ferreira, R.L., Oliveira, M.P.A. & Silva, M.S. (2018) Subterranean biodiversity in ferruginous landscapes. In *Cave Ecology* (eds O.T. Moldovan, L. Kováč & S. Halse), pp. 435–447. Springer, Berlin, Germany.

Freudenburg, W.R. & Gramling, R. (1994) Bureaucratic slippage and failures of agency vigilance: the case of the environmental studies program. *Social Problems*, 41, 214–239.

Gagen, E.J., Levett, A., Paz, A., Gastauer, M., Caldeira, C.F., da Valadares, R.B.S. et al. (2019) Biogeochemical processes in canga ecosystems: armoring of iron ore against erosion and importance in iron duricrust restoration in Brazil. *Ore Geology Reviews*, 107, 573–586.

Gastauer, M., Vera, M.P.O., de Souza, K.P., Pires, E.S., Alves, R., Caldeira, C.F. et al. (2019) A metagenomic survey of soil microbial communities along a rehabilitation chronosequence after iron ore mining. *Scientific Data*, 6, 190008.

Gibson, N., Yates, C.J. & Dillon, R. (2010) Plant communities of the ironstone ranges of South Western Australia: hotspots for plant diversity and mineral deposits. *Biodiversity and Conservation*, 19, 3951–3962.

Gonçalves, B., Marques, A., Soares, A.M.V.D.M. & Pereira, H.M. (2015) Biodiversity offsets: from current challenges to harmonized metrics. *Current Opinion in Environmental Sustainability*, 14, 61–67.

Guedes, R.S., Ramos, S.J., Gastauer, M., Fernandes, A.R., Caldeira, C.F., do Amarante, C.B. & Siqueira, J.O. (2020) Phosphorus lability increases with the rehabilitation advance of iron mine land in the eastern Amazon. *Environmental Monitoring and Assessment*, 192, 390.

Guillet, F. & Semal, L. (2018) Policy flaws of biodiversity offsetting as a conservation strategy. *Biological Conservation*, 221, 86–90.

Hoch, H. & Ferreira, R.L. (2012) Ferricixius davidi gen. n., sp. n. – the first cavernicolous planthopper from Brazil (Hemiptera, Fulgoromorpha. Cixiidae). *Deutsche Entomologische Zeitschrift*, 59, 201–206.

ICMBio (2018) *Priority Areas for the Conservation of Speleological Heritage*. icmbio.gov.br/cecav/images/stories/Areas_Prioritarias_Patrimonio_Espeleologico_2018.pdf [accessed 1 June 2020].

ICMM & IUCN (2013) *Independent Report on Biodiversity Offsets. The Biodiversity Consultancy for the International Council on Mining and Metals and the International Union for Conservation of Nature*. icmm.com/website/publications/pdfs/environmental-stewardship/2013/research_biodiversity-offsets.pdf [accessed 1 June 2020].

ICMM (2015) *Mining Principles*. icmm.com/mining-principles [accessed 1 June 2020].

ICMM (2022) *Our Members*. icmm.com/en-gb/our-story/our-members [accessed 27 October 2022].

IEF (2021a) *Environmental Compensation*. ief.mg.gov.br/unidades-de-conservacao/compensacao-ambiental [accessed 5 April 2021].

IEF (2021b) *State Biodiversity Protection Plan*. ief.mg.gov.br/biodiversidade/plano-estadual-de-protecao-a-biodiversidade [accessed 4 April 2021].

IFC (2019) *International Finance Corporation's Guidance Note 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources*. International Finance Corporation, Washington, DC, USA.

Jacobi, C.M., Carmo, F.F. & Campos, I.C. (2011) Soaring extinction threats to endemic plants in Brazilian metal-rich regions. *Ambio*, 40, 540–543.

Jacobi, C.M., Carmo, F.F., Carmo, F.F. & Campos, I.C. (2015) Iron geosystems: priority areas for conservation in Brazil. In *Mining in Ecologically Sensitive Landscapes*, 1st edition (ed. M. Tibbett), pp. 55–78. CSIRO Publishing, CRC Press, Boca Raton, USA.

Kamino, L.H.Y., Pereira, E.O. & Carmo, F.F. (2020) Conservation paradox: large-scale mining waste in protected areas in two global hotspots, southeastern Brazil. *Ambio*, 49, 1629–1638.

Lousada, J.M., Lovato, M.B. & Borba, E.L. (2013) High genetic divergence and low genetic variability in disjunct populations of the endemic Vellozia compacta (Velloziaceae) occurring in two edaphic environments of Brazilian Campos rupestres. *Brazilian Journal of Botany*, 36, 45–53.

McKenney, B.A. & Kiesecker, J.M. (2010) Policy development for biodiversity offsets: a review of offset frameworks. *Environmental Management*, 45, 165–176.

Milanez, B., Magno, L. & Pinto, R.G. (2019) From weak politics to private policies: the role of the mining sector in the transformations of environmental policy in Minas Gerais State, Brazil. *Cadernos de Saúde Pública*, 35, e00051219.

Minas Gerais (2004) *Normative Resolution Copam 73 08/09/2004*. Minas Gerais, Brazil. siam.mg.gov.br/sla/download.pdf?idNorma=164 [accessed 14 pril 2021].

Minas Gerais (2019) *Decree 47.749 11/11/2019*. Minas Gerais, Brazil. jornal.iof.mg.gov.br/xmlui/handle/123456789/226377 [accessed 13 April 2022].

Miola, D.T.B., Marinho, A.P., Dayrell, R.L.C. & Silveira, F.A.O. (2019) Silent loss: misapplication of an environmental law compromises conservation in a Brazilian biodiversity hotspot. *Perspectives in Ecology and Conservation*, 17, 84–89.

MMA (2007) *Fichas Técnicas das Áreas Prioritárias para Conservação, Uso Sustentável e Repartição dos Benefícios da Biodiversidade Brasileira*. MMA, Brasília, Brazil.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. *Nature*, 403, 853–858.

Oliveira, A.L.F., Romero, R. & Guimarães, P.J.F. (2014) A new Brazilian species and some synonyms in Pleroma (Melastomataceae). *Brittonia*, 66, 353–357.

Pacheco, R., Rajão, R., Soares-Filho, B. & van der Hoff, R. (2017) Regularization of legal reserve debts: perceptions of rural producers in the State of Pará and Mato Grosso in Brazil. *Ambiente & Sociedade*, 20, 181–200.

Rapini, A. (2012) Apocynaceae. In *Diversidade Florística nas Cangas do Quadrilátero Ferrífero*, 1st edition (eds C.M. Jacobi & F.F. Carmo), pp. 72–75. Código Editora, Belo Horizonte, Brazil.

Salles, D.M., Carmo, F.F. & Jacobi, C.M. (2019) Habitat loss challenges the conservation of endemic plants in mining-targeted Brazilian mountains. *Environmental Conservation*, 46, 140–146.

SEMAD (2017) *Service Instruction 02/2017. Compensation for Cutting or Removing Primary or Secondary Vegetation in the Middle or Advanced Stages of Regeneration in the Atlantic Forest Biome*. Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável, Belo Horizonte, Brazil. meioambiente.mg.gov.br/images/stories/2017/ASNOP/Instrução_de_Serviço_Sisema_no_02-2017_2017.04.07-novo.pdf [accessed 18 November 2020].

SEMAD (1999a) *Biodiversity Protection and Protected Areas Chamber*. Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável, Belo Horizonte, Brazil. meioambiente.mg.gov.br/component/content/article/4241 [accessed 18 November 2020].

SEMAD (1999b) *Chamber of Mining Activities*. Secretaria de Estado de Meio Ambiente e Desenvolvimento Sustentável, Belo Horizonte, Brazil. meioambiente.mg.gov.br/component/content/article/4235 [accessed 18 November 2020].

Silveira, F.A.O., Perillo, L.N., Carmo, F.F., Kamino, L.H.Y., Mota, N.F.O., Viana, P.L. et al. (2020) Vegetation misclassification compromises conservation of biodiversity and ecosystem services in Atlantic Forest ironstone outcrops. *Perspectives in Ecology and Conservation*, 18, 238–242.

Simmonds, J.S., Sonter, L.J., Watson, J.E.M., Bennun, L., Costa, H.M., Dutson, G. et al. (2020) Moving from biodiversity offsets to a target-based approach for ecological compensation. *Conservation Letters*, 13, e12695.

Sonter, L.J., Barrett, D.J., Soares-Filho, B.S. & Moran, C.J. (2014) Global demand for steel drives extensive land-use change in Brazil's Iron Quadrangle. *Global Environmental Change*, 26, 63–72.

Taylor, N.P. & Braun, P. (2013) *Arthrocereus glaziovii*. In *The IUCN Red List of Threatened Species* 2013. dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T40939A2945254.en.

ten Kate, K., Bishop, J. & Bayon, R. (2004) *Biodiversity Offsets: Views, Experience, and the Business Case*. IUCN, Gland, Switzerland, Cambridge, UK, and Insight Investment, London, UK.

Tibbett, M. (2015) Mining in ecologically sensitive landscapes: concepts and challenges. In *Mining in Ecologically Sensitive Landscapes* (ed. M. Tibbett), pp. 3–6. CSIRO Publishing, Leiden, Netherlands.

UNESCO (2021) Biosphere Reserves in Latin America and the Caribbean. en.unesco.org/biosphere/lac [accessed 3 April 2021].

Vasconcelos, P.M., Farley, K.A., Stone, J., Piacentini, T. & Fifield, L.K. (2019) Stranded landscapes in the humid tropics: Earth's oldest land surfaces. *Earth and Planetary Science Letters*, 519, 152–164.

Villén-Pérez, S., Mendes, P., Nóbrega, C., Gomes Córtes, L. & De Marco, P. (2018) Mining code changes undermine biodiversity conservation in Brazil. *Environmental Conservation*, 45, 96–99.

Virah-Sawmy, M., Ebeling, J. & Taplin, R. (2014) Mining and biodiversity offsets: a transparent and science-based approach to measure 'no-net-loss'. *Journal of Environmental Management*, 143, 61–70.

Watkins, G., Atkinson, R., Canfield, E., Corrales, D., Dixon, J., Factor, S. et al. (2015) *Guidance for Assessing and Managing Biodiversity Impacts and Risks in Inter-American Development Bank Supported Operations*. Inter-American Development Bank Technical Note n° IDB-TN-932. publications.iadb.org/publications/english/document/Guidance-for-Assessing-and-Managing-Biodiversity-Impacts-and-Risks-in-Inter-American-Development-Bank-Supported-Operations.pdf [accessed 3 November 2020].

Zu Ermgassen, S.O.S.E., Maron, M., Corlet Walker, C.M., Gordon, A., Simmonds, J.S., Strange, N. et al. (2020) The hidden biodiversity risks of increasing flexibility in biodiversity offset trades. *Biological Conservation*, 252, 108861.