Perspectives in Ecology and Conservation 15 (2017) 172–178

ABECO ASSOCIAÇÃO BRASILEIRA DE CIÊNCIA ECOLÓGICA E CONSERVAÇÃO

Perspectives in ecology and conservation

Supported by Boticário Group Foundation for Nature Protection

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Research Letters

Impacts of mining activities on the potential geographic distribution of eastern Brazil mountaintop endemic species

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ARTICLE INFO

Article history:
Received 4 November 2016
Accepted 27 July 2017
Available online 1 September 2017

Keywords:
Anurans
Birds
Conservation
Ecological Niche Models
Extinction Risk
Mineral exploitation
Rupestrian grasslands

ABSTRACT

Mining causes profound impacts on biodiversity. In Brazil, mining pressure is intense, especially in highly biodiverse regions such as the Espinhaço range. We analyzed the direct and indirect effects of mining on the potential geographic range of 32 anuran and eight bird species endemic to the eastern Brazil mountaintops. We also assessed the mining impacts on the local biodiversity rate of both species groups. Currently, 36.44% and 28.80% of the median potential distribution of the anuran and bird species, respectively, are affected directly or indirectly by mining. More than half of the range for eight anuran species and more than 40% of two birds species's ranges are influenced by this anthropogenic activity. Regions with suitable environmental characteristics for more than one species are highly affected by mining: 67% of the pixels that are suitable for 16 species (2109 km^2) are currently impacted by mining. These results indicate that mining activities present a considerable threat to both anurans and birds endemic of the eastern Brazil mountaintops. We discuss many aspects related to the loss of potential habitat for these species, and call for management strategies to avert the ongoing wave of mining impacts.

Introduction

The depletion of mineral reserves and consumption are the drivers of the rush for mineral extraction. The mining pressure is especially intense in developing countries, such as Brazil, whose economy is largely based on commodity exports. Being the second world's largest mineral producer (IBRAM, 2012), the mining sector has considerable economic and political influence in Brazil (Garcia et al., 2017). Although recent environmental disasters have demonstrated the vulnerability of the Brazilian environmental impact assessments and mineral extraction licensing processes, proposed changes in Brazilian mining legislation aim to facilitate mineral extraction (El Bizri et al., 2016; Fernandes et al., 2016). It has been argued that the development of widespread mining and dams in Brazil risks damaging its environmental conservation credentials (Ferreira et al., 2014). Moreover, Brazilian Government expects an increase of mineral production by 2030 (Brasil, 2010) which might further increase environmental impacts on biodiversity and ecosystem services provision.

We focus attention on the impacts of mining activities on species in a region where mineral extraction is one of the most important Brazilian economic activities: the eastern Brazil mountaintops.

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http://dx.doi.org/10.1016/j.pecon.2017.07.005
1679-0073/

This region encompasses the Espinhaço range, a rich and diverse mountain range dominated by the rupestrian grasslands, an ecosystem that occurs on quartzitic or ferruginous soils and suffers high mining pressure (Fernandes, 2016). Mining has a direct effect on local habitat degradation through the removal of native vegetation and soil, as well as indirect effects by promoting changes at the landscape level, such as the opening of roads and secondary accesses, urbanization, deforestation for charcoal production, and intentional introduction of exotic species in rehabilitation projects (Fernandes, 2016; Sonter et al., 2014).

The Espinhaço range has the highest rates of plant endemism in South America (Fernandes, 2016) and high levels of endemism and diversity of amphibians (Leite et al., 2008). Recent descriptions of new anuran (Leite et al., 2012) and bird (Freitas et al., 2012) species in the Espinhaço indicate that many species, not yet known to science, might already be threatened. The Iron Quadrangle situated in the southernmost Espinhaço is also one of the world's largest gold and iron deposits (Lobato et al., 2001), accounting for 70% of the current Brazilian iron production (IBRAM, 2012). This region is also of utmost conservation concern (Silva et al., 2008) within the biologically rich Espinhaço, and has the highest anuran species richness level across the mountain range (Leite et al., 2008). More than 300 years of mineral extraction in the Iron Quadrangle have led to environmental contamination (Matschulla et al., 2007), with known impacts upon many endemic plant species (Jacobi et al., 2011). However, the impact of mining on the distribution range of the fauna in the Iron Quadrangle, and throughout the whole Espinhaço range, is still unknown.

Mountain species often have small and disjunct distributions, which may increase their vulnerability to ecological disturbances and increase their extinction risk (Harris and Pimm, 2008; Sobral-Souza et al., 2015). Small geographic range size has been found to be the best single predictor of extinction risk (Harris and Pimm, 2008). Mining activities in areas of high endemism and diversity are known to pose a considerable threat to local species (Jacobi et al., 2011), and may have a disproportionately high impact in high altitude ecosystems. These drivers may have wide-ranging consequences as highland species might not have the chance to colonize similar habitats due to limited dispersion capability, large distances between suitable habitats, hostile intervening terrain, or even non-existence of similar habitats (see Fernandes, 2016).

In this study, we aimed to assess the direct and indirect impacts of mining activities on anuran and bird species endemic to the eastern Brazil mountaintops, based on ecological niche models (ENM). ENM have been used to model species potential distributions by associating occurrence records and environmental variables, enabling the identification of potential habitat areas even when sampling is incomplete (Pearson, 2007; Peterson et al., 2011). Potential distribution maps can be used to evaluate the spread of potential threats within a species geographical distribution (Pena et al., 2014). We also measured the local biodiversity rate to assess the impacts of mining activities on regions that are suitable for a high richness of bird and anuran species. We hypothesized that a high proportion of the potential habitat available for both anuran and bird species endemic to the eastern Brazil mountaintops will overlap with areas that are currently directly and especially indirectly affected by mining.

Methods

Study area and mining maps

We defined as our study area all Brazilian states that contain the occurrence points for the 41 anuran and 8 bird species endemic to the eastern Brazil mountaintops (S1 Table, S2 Table). Polygons of current mining activities for Bahia, Espírito Santo, Minas Gerais, Rio de Janeiro and São Paulo were acquired from the National Department of Mineral Resources (DNPM) website (http://sigmine.dnpm.gov.br/webmap/, accessed May 2016). These maps hold all records for mining extraction, licensed mines and

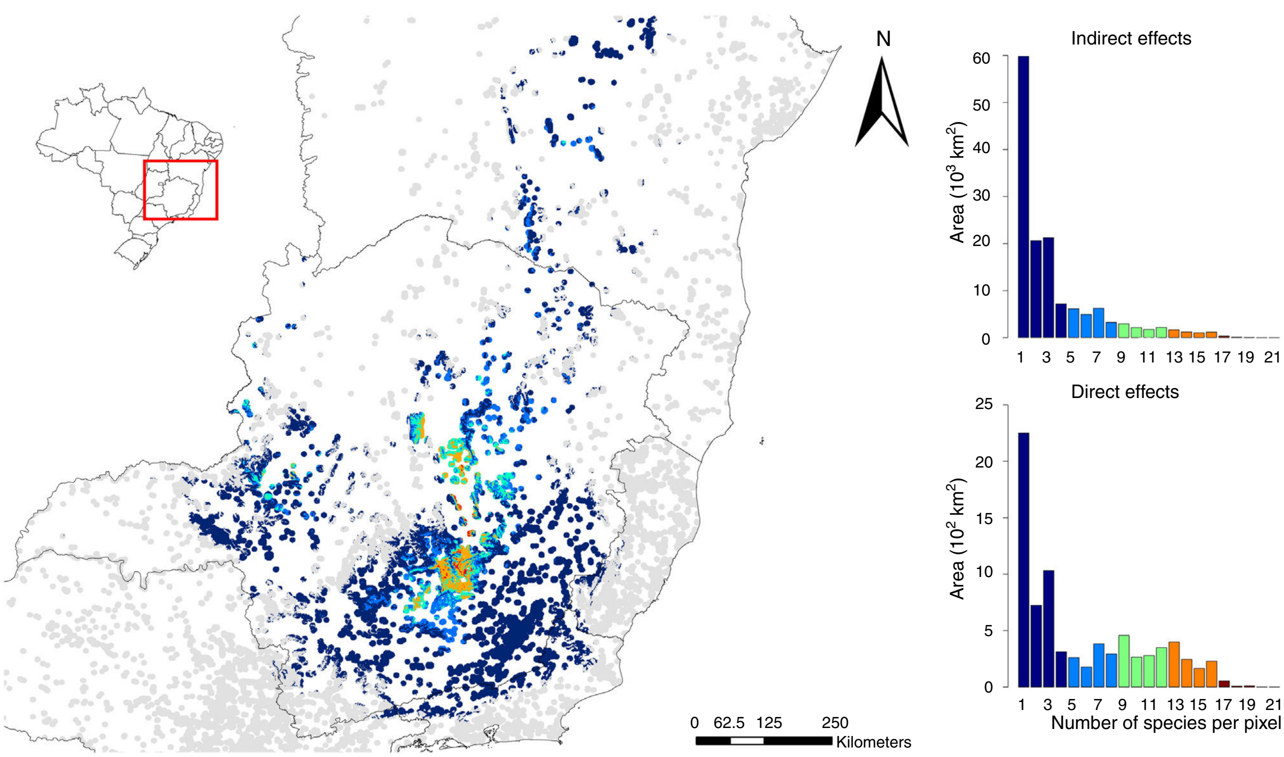

Fig. 1. The effects of mining activities on the estimated biodiversity rate for 41 anuran species, endemic to the eastern Brazil mountaintops. Polygons highlighted in gray represent mines officially approved and licensed for mining activity and their respective 5 km radius buffer, which did not overlap areas estimated as suitable for anuran species. Histograms highlight the area directly and indirectly affected by mining in each richness class identified by the biodiversity rate estimate.

mineral surveys. We followed the same procedure adopted by Ferreira et al. (2014) and considered mines officially approved and licensed for mining activity, which fall under the categories of mining concession, extraction record, licensing and artisanal mining (*lavra garimpeira*), which together represent the direct influence of mining on the suitable habitat of species. The indirect influence of mining was assumed to be the area within a 5 km buffer around the extent of the mine itself. This buffer radius value is at the lower end of the suggested 5–10 km range of indirect effects of mining activities (Durán et al., 2013), and was selected partly because of variation in different species' responses to mining activities. Therefore, the adopted range represents a solid and very conservative approach to the range of mining impacts on species.

Species potential-distribution maps using ENM

We used museum records and field surveys to gather a georeferenced database of the distribution of the 41 endemic anurans in the Espinhaço range. The identities of museum specimens were established using physical examination (Leite, 2012). To fill some sampling gaps, field surveys were carried out in 14 localities during 140 days of fieldwork between 2007 and 2011. The database consists of 2785 independent records of the 41 endemic species. Occurrence records for the eight mountaintop endemic bird species were compiled from the literature, field observations and specimens from museum when their geographic coordinates were available (Vasconcelos and Rodrigues, 2010). All museum records were revisited in this study. A total of 206 unique records were compiled for the eight species (S1 Table).

Ecological niche model (ENM) techniques are based on known occurrences of species to infer the suitability values in regions where species are currently not known to occur (Peterson et al., 2011). Currently there are ENMs techniques that are able to model species with few known occurrence points (see Pearson et al., 2007). In this study one of our aims was to infer the spatial richness pattern of birds and anuran species endemic to the eastern Brazil mountaintops. Thus, we decided to model the potential distribution only for the anuran species that have more than 10 occurrence points (30 species, S3 Table) and modeled the distribution for all birds, since only eight species are considered endemic to the eastern Brazil mountaintops. Three bird species, *Scytalopus diamantinensis*, *Asthenes moreirae* and *Formicivora grantsaui*, have only 9, 9 and 5 occurrence points, respectively (S1 Table). Eleven anuran species have less than 10 known occurrence points (S2 Table). We used the same ENM procedure for both species groups.

To measure the effect of climate conditions on the studied species distribution and estimate their geographic range, we downloaded 19 environmental variables from CHELSA database (http://chelsa-climate.org/), with approximately 1 km^2 resolution (in Equator region). These 19 variables are correlated to each other and require a selection procedure to decrease the collinearity. Thus, we used a factorial analysis with *Varimax* rotation (similar to the variable selection procedure adopted by Sobral-Souza et al., 2015) within our study area. We used this background because this area comprises the historical and current species dispersion, two criteria of ENM background selection proposed by Barve et al. (2011). We then selected five environmental variables that explain 95.3% of the background climate variation: BIO03 (Isothermality), BIO05 (Max Temperature of Warmest Month), BIO07 (Temperature Annual Range), BIO16 (Precipitation of Wettest Quarter), BIO17 (Precipitation of Driest Quarter) (Hijmans et al., 2005).

There are different mathematical algorithms able to infer species distributions. These algorithms vary in premises, however the combined use leads to more reliable predictions (Araújo and New, 2007; Diniz-Filho et al., 2009). We used a forecast ensemble approach (Araújo and New, 2007) based on four different algorithms. The first two are presence-only methods: envelope score

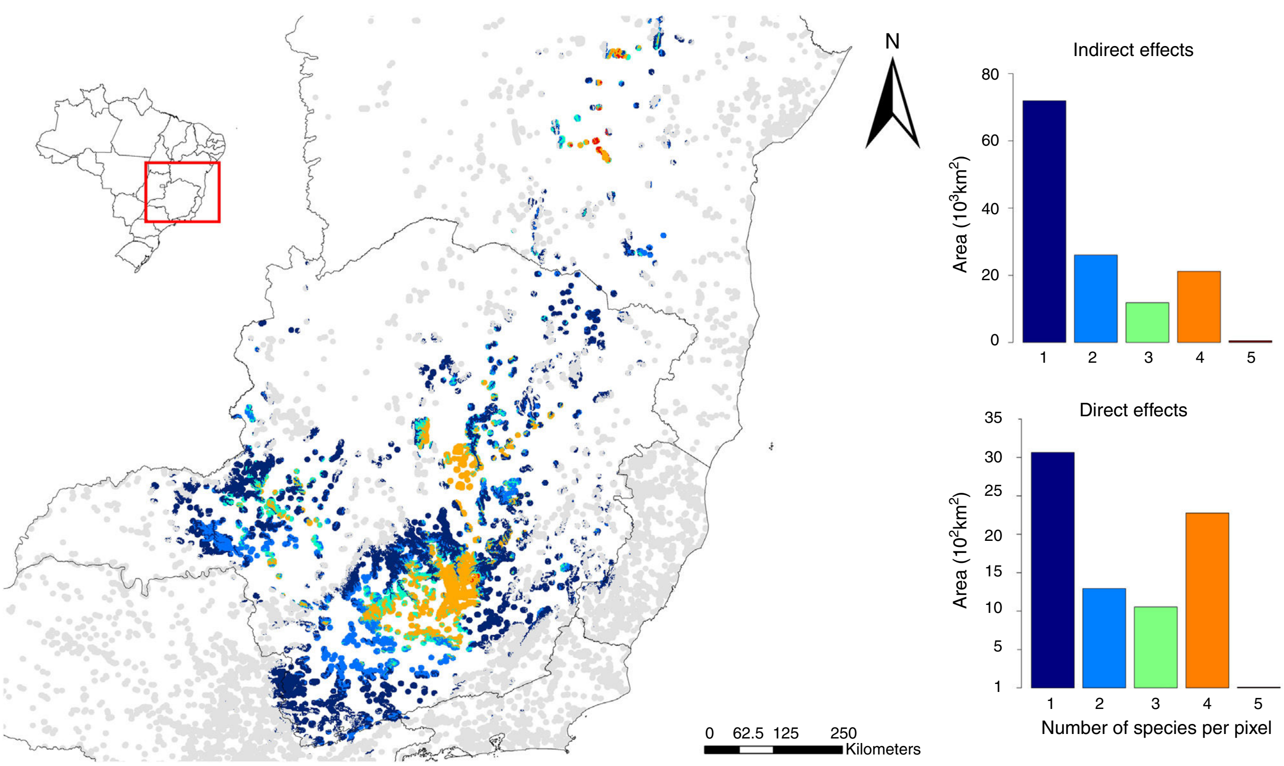

Fig. 2. The effects of mining activities on the estimated biodiversity rate for eight bird species, endemic from the eastern Brazil mountaintops. Polygons highlighted in gray represent mines officially approved and licensed for mining activity and their respective 5 km radius buffer, which did not overlap areas estimated as suitable for bird species. Histograms highlight the area directly and indirectly affected by mining in each richness class identified by the biodiversity rate estimate.

– Bioclim (Nix, 1986) – and distance method – Domain (Gower distance; Carpenter et al., 1993). The other two are machine-learning methods based on presence-background records: Support Vector Machines (SVM) (Tax and Duin, 2004) and Maximum Entropy – MaxEnt (Phillips and Dudík, 2008). The algorithms were modeled using "dismo" and "kernlab" R-packages (Hijmans et al., 2015; Karatzoglou et al., 2004). We modeled each species individually using two-fold partition approach with 75% and 25% of train and test, respectively. This occurrence partitioned approach was used to calculate the evaluation values (True Skill Statistics – TSS) of each model (Allouche et al., 2006). We randomized this procedure 10 times for each algorithm and for each species using a bootstrap analysis. Thus, we obtained 40 maps (4 algorithms × 10 times) for each species, and used the maximum *sensitivity* and *specificity* threshold to transform the continuous maps into binary maps. We used this threshold because it is recommended when presence-only data are available in the niche modeling analysis (Liu et al., 2013, 2016). Then, we overlapped the maps of the same algorithms and the maps between algorithms to predict the final species distribution maps. Thus, the cell values of the final maps vary from 0 to 40, representing the frequency in which each cell was predicted as suitable for each species.

To measure the local biodiversity rate, we generated potential species richness maps for bird and anuran species based on ENMs. We extracted the LPT value (Pearson et al., 2007) of each species and transformed each species map into binary maps (1 – occurrence, 0 absence). We overlapped all maps for birds and for anuran species and obtained the final map, in which the pixels indicate the number of species of anurans or birds for which the environmental characteristics are suitable, varying from 0 to 21 for anuran and from 0 to 6 for birds (maximum richness values). The occurrence records of the anuran species with <10 occurrence points were used to generate the final richness map for the endemic mountaintop anuran species.

To assess the potential impacts of mining on the mountaintop anuran and bird species, we adjusted the potential distribution maps of all species to the polygons related to the direct and indirect effects and the area not affected by mining. Then, we built bar-plots with the proportional area of each class (direct, indirect and not affected) for each species. The same procedure was adopted to assess the effects of mining on the biodiversity rate of both bird and anuran species.

Results

The ENMs for all studied species predicted reliable and good distributions (the majority of TSS values were above 0.5). The anuran and bird species potential biodiversity maps showed a high richness rate in the central region of Minas Gerais State for both species groups, areas highly impacted by mining activities (Figs. 1 and 2).

As we predicted, mining causes a profound effect on the potential habitat for mountaintop endemic anuran and bird species. More than 470 thousand square kilometers were estimated as suitable for

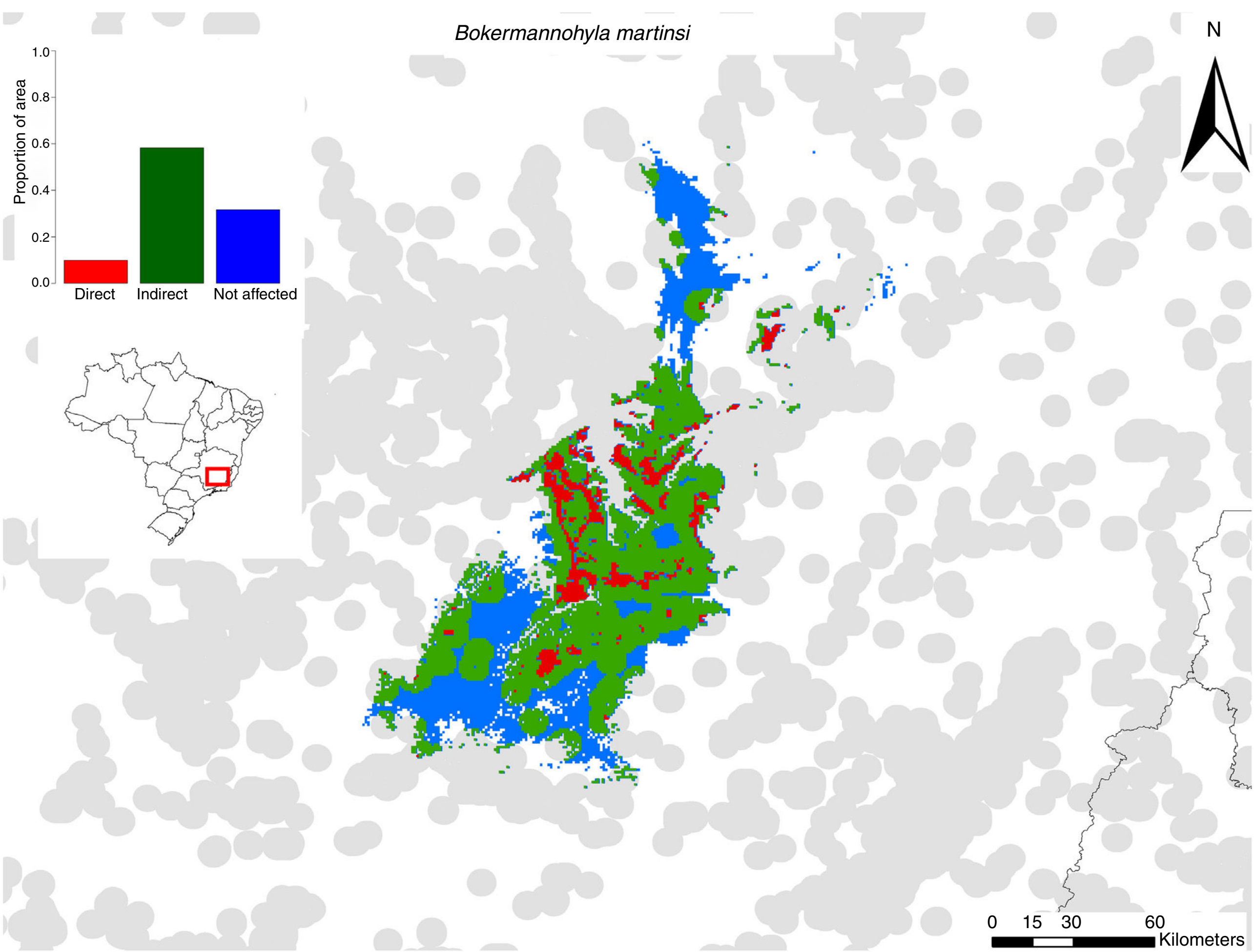

Fig. 3. The direct and indirect effects of mining on the potential distribution of *Bokermannohyla martinsi*. The histogram highlights the proportion of estimated suitable habitat area that are directly, indirectly and not affected by mining activities.

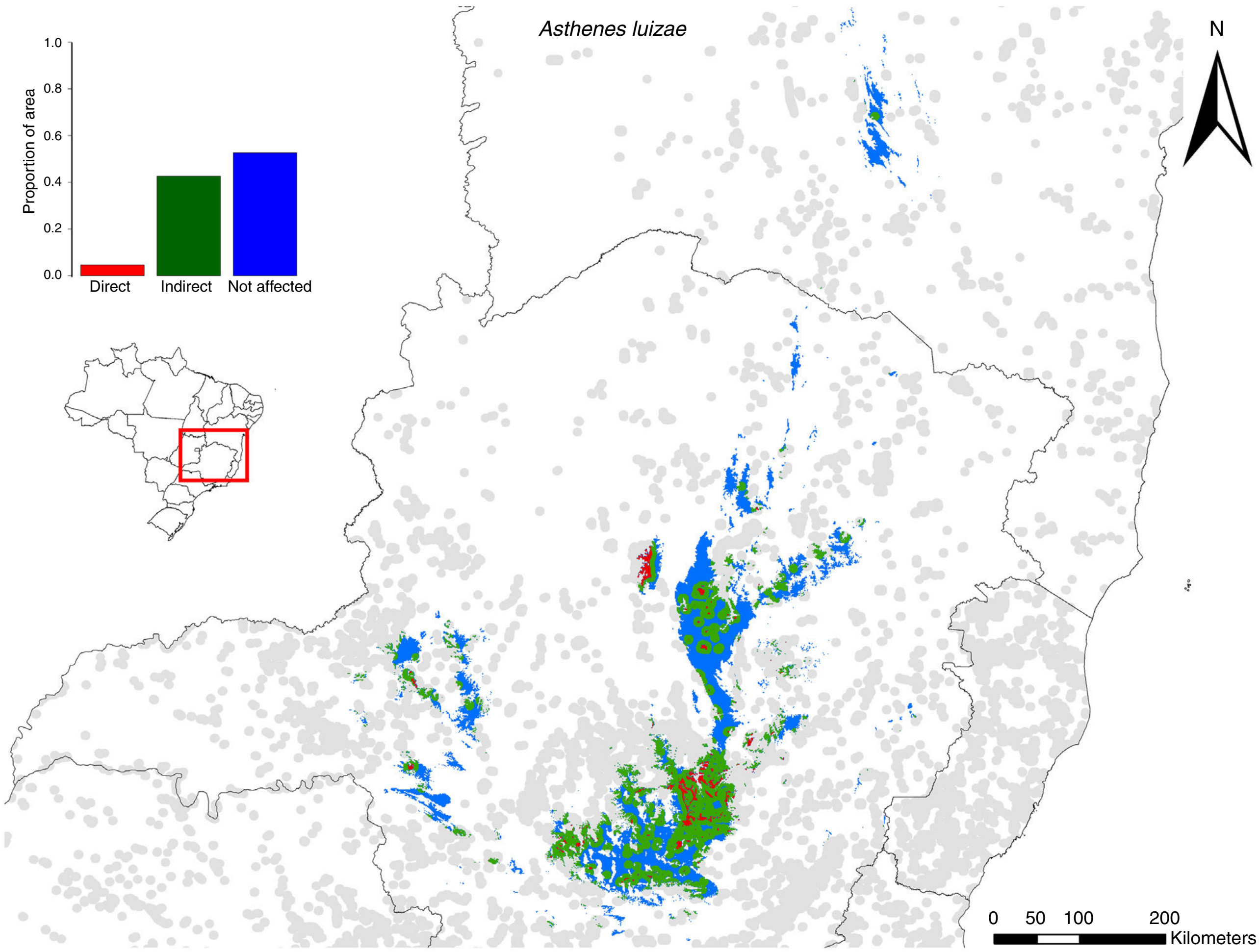

Fig. 4. The direct and indirect effects of mining on the potential distribution of *Asthenes luizae*. The histogram highlights the proportion of estimated suitable habitat area that are directly, indirectly and not affected by mining activities.

anuran species, 32.33% of which are currently directly or indirectly affected by mining (S4 Table, Fig. 1).

The median proportions of anuran species potential range affected directly and indirectly by mining are 5.75% and 30.69%, respectively. Two anuran species (*Scinax cabralensis* and *Bokermannohyla sagarana*) have more than 35% of their ranges directly affected by mining, while eight species have more than half of their ranges impacted by the combined direct and indirect effects of mining (S3 Table). *Bokermannohyla martinsi* was the most affected anuran species, with 68.29% of the estimated habitat being directly and indirectly influenced by mining (Fig. 3). Considering the biodiversity rate estimated for all anuran species, we observed that 67% of the pixels with environmental characteristics suitable for 16 species (2109 km^2) are currently either directly or indirectly affected by mining (S4 Table, Fig. 1). The area estimated suitable for more than one anuran species is currently more directly and indirectly affected by mining (89,894 km^2 of overlapped area), than the area estimated suitable for only one species (64,324 km^2 of overlapped area) (S4 Table, Fig. 1).

Between the eleven rare anuran species (<10 occurrence points), all occurrence points of *Aplastodiscus* aff. *cavicola* (4), *Corythomantis galeata* (1) and *Proceratophys redacta* (2) are within the 5 km buffer radius. *Sphaenorhynchus canga* has five of its six occurrence points being directly influenced by mining activities, and the remaining occurrence point is currently indirectly affected by mining. *Pleurodema alium* (2) and *P. minuta* (2) have half of their occurrence points within the indirect effects range of mining activities (S3 Table).

All assessed bird species are less directly affected by mining than the anuran species. However, all species are currently being directly and indirectly affected by mining (S5 Table). The median proportions of bird species potential range affected directly and indirectly by mining are 2.04% and 26.76%, respectively. More than 40% of the suitable habitat for *Asthenes luizae* (Fig. 4) and *Augastes scutatus* are currently either directly or indirectly affected by mining (S5 Table). When assessing the biodiversity rate for bird species, from more than 436 thousand square kilometers estimated as suitable for all bird species, 31% are currently indirectly or directly affected by mining (S6 Table, Fig. 2). 39% of pixels with environmental characteristics suitable for four species (53,541 km^2) are currently being affected by mining activities (Fig. 2, S6 Table).

Discussion

All the endemic mountaintop bird and anuran species assessed in this study are affected by mining, at least indirectly. Eight anuran species have already had more than 50% of their ranges affected at some degree by mining, and *B. martinsi* was estimated to have almost 70% of its range affected at some degree by mining. More than 40% of the suitable habitat for *A. luizae* and *A. scutatus* are currently being influenced by mining activities. If other threats to the rupestrian grasslands are considered, such as climate change, habitat degradation by fire, livestock, tourism, road construction, agriculture and *Eucalyptus* plantations (Fernandes, 2016), the situation of the endemic anuran and bird species is even more worrisome.

The estimated suitable habitat area for 17 anuran and one bird species is less than 20,000 km^2. Considering the Criteria B from IUCN Red List (IUCN, 2016) alone, these species can be classified as Vulnerable (<20,000 km^2) or Endangered (<2000 km^2). More than 60% of the estimated suitable habitat for *S. cabralensis* (1654 km^2) and *B. sagarana* (2458 km^2) is currently being influenced by mining. Further, all the occurrence points of three rare anuran species are within the 5 km range of influence of mining activities, and almost all occurrence points of *Sphaenorhynchus canga* are currently directly affected by mining. Between the assessed bird species, 33.25% of the 2233 km^2 estimated as suitable for *Asthenes moreirae* are currently under the influence of mining activities. As mountaintop species are already known to be more prone to extinction events due to habitat loss (Stuart, 2004) and climate change (Şekercioğlu et al., 2008), small range mountaintop species may be at major risk of extinction over the coming decades. Furthermore, some of the anuran species in this study have only recently been described (e.g.: Leite et al., 2012). Therefore, it is urgent a detailed assessment of the conservation status of bird and anuran species endemic to the eastern Brazil mountaintops, considering mining expansion as a major threat for these species.

More than 30% of the area considered as suitable for bird or anuran species are currently under pressure by mining activities. When assessing the biodiversity rate maps for both species groups, pixels estimated suitable for more than 2 bird and anuran species are highly affected by mining. 2897 km^2 have suitable environmental characteristics for four bird species, only 0.66% of the suitable habitat area for all bird species. However, more than 43% of this area is currently being either directly or indirectly affected by mining. Considering anuran species, the area estimated suitable for more than one species is currently more directly and indirectly affected by mining than the area estimated suitable for only one species. 2109 km^2 (only 0.45% of the suitable area estimated for all anuran species) have suitable environmental characteristics for 16 different anuran species, 67.47% of which are under pressure of mining activities. Those areas, which can be considered as biodiversity hotspots of endemic mountaintop bird and anuran species, should be considered priority areas for conservation.

Mining affects species by destroying, fragmenting, and degrading natural habitats, releasing toxic wastes (Gentes et al., 2007) and altering land-use dynamics in mined regions (Sonter et al., 2014). Geomorphological aspects, which attract mining to mountain areas, spatially overlap with the areas of high endemism associated to high elevations. Because of the political and economic power of the mining sector, decision makers have often prioritize mining over conservation. While in other biomes the proposals of biodiversity offsetting may be a good conservation compromise, these offsetting initiatives are more difficult to implement in mountainous areas, because these habitats are naturally patchy (Sonter et al., 2014).

Mineral exportation is one of Brazil's economic cornerstones, and it is expected to further expand by 2030 to meet global demands for iron, gold, copper and other minerals. This will place more pressure for exploiting mineral reserves, and if current policies are adopted this shall overlook the impact of mining on biodiversity. Considering anuran and bird species endemic to the eastern Brazil mountaintops, mining already impacts more than 40% of the suitable habitat for 13 species. If other threats are considered such as fire, pasture development, agriculture, forest plantations and climate change, it is very likely that many species will become extinct in a near future. As all species studied here are endemic, local extinction means global extinction. Currently, there are thousands of square kilometers of areas within Brazilian conservation units with approved mines or being considered for mineral extraction (Ferreira et al., 2014). Therefore, to avoid or mitigate the impacts of mining activities on mountaintop endemic species, it is essential to undertake a task force aimed at mapping ecological and conservation attributes in mountaintops, especially in mining regions. This will help design management practices in order to reconcile socio-economic and environmental needs.

Acknowledgments

This work was supported by the Brazilian National Research Council (CNPq) [MR (grant number 503168/2012-2), TSS (grant number 150319/2017-7), DH (grant number 500995/2011-7 PDJ) and GWF]; the Fundo de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) (MR and GWF); the Coordenação de Aperfeiçoamento de Pessoal de Nível Superiorfor (CAPES) (GWF, JCCP, MHV). We also thank the Vellozia Reserve. TSS thanks Unimes for the logistic support. We thank A. Mastin, U. Oliveira, G. Ziv and L. Budello for the important contributions to the manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.pecon.2017.07.005.

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