

Using birds in environmental impact assessment of quarrying activities: a case study in the Atlantic forest of Southern Brazil

Uso de aves em estudos de impacto ambiental de atividades minerárias: um estudo de caso na floresta atlântica do Sul do Brasil

Cleiton D. **TEIXEIRA**¹; Marcéli D. S. **LOPES**²; Douglas D. **TEIXEIRA**³ & Caio J. **CARLOS**^{1,4}

ABSTRACT

The use of environmental indicators in Environmental Impact Assessments (EIA) is a common approach to evaluate the ecological quality of a given area. Birds are particularly valuable as bioindicators in the Atlantic forest, especially in the context of mining activities such as quarrying. This study aimed to (1) estimate the magnitude of environmental impacts; (2) provide data to assess their significance; (3) predict future environmental conditions under the proposed project; and (4) support the comparison of alternatives and the development of mitigation strategies. A systematic literature review was conducted using the Web of Science and Google Scholar platforms. When refined to focus on birds, 25 impacts across 14 environmental aspects were identified, of which four were considered positive and the remainder negative. The impact-aspect matrix revealed that most negative effects on bird communities are associated with the installation and extraction phases of quarry operations. In contrast, positive impacts were linked to the recovery of degraded areas, which can promote the establishment of new habitats. These findings highlight the importance of integrating avian data into EIA processes to inform decision-making and enhance the ecological sustainability of mining projects.

Keywords: avifauna, Conservation Biology, Environmental Impact Assessment.

RESUMO

O uso de indicadores ambientais em Estudos de Impacto Ambiental (EIA) é uma abordagem amplamente empregada para avaliar a qualidade ecológica de uma determinada área. As aves destacam-se como bioindicadores particularmente eficazes na mata atlântica, especialmente diante de atividades minerárias, como as pedreiras. Este estudo teve como objetivos: (1) estimar a magnitude dos impactos ambientais; (2) fornecer dados para avaliação de sua significância; (3) prever as condições futuras do ambiente sob influência do projeto; e (4) subsidiar a comparação de alternativas e a formulação de estratégias de mitigação. Realizou-se uma revisão sistemática da literatura nas plataformas Web of Science e Google Scholar. Após o refinamento para o grupo das aves, foram selecionados 25 impactos relacionados a 14 aspectos ambientais, dos quais quatro foram considerados positivos e os demais negativos. A matriz de aspectos e impactos revelou que os efeitos negativos mais frequentes sobre as comunidades de aves estão associados às fases de instalação e extração da pedra. Em contrapartida, os impactos positivos relacionam-se à recuperação de áreas degradadas, favorecendo a criação de habitats. Os resultados destacam a importância de integrar dados sobre avifauna nos EIA, promovendo decisões mais sustentáveis em projetos minerários.

Palavras-chave: avifauna, Biologia da Conservação, Estudo de Impacto Ambiental.

Recebido em: 30 maio 2025

Aceito em: 19 out. 2025

¹ Universidade Federal do Rio Grande do Sul (UFRGS), Programa de Pós-Graduação em Biologia Animal, Laboratório de Comportamento, Ecologia e Filogenia de Aves Aquáticas (Cefalab), Av. Bento Gonçalves, n. 9500, Agronomia – CEP 91509-900, Porto Alegre, RS, Brasil.

² Universidade do Extremo Sul de Santa Catarina (Unesc), Programa de Pós-Graduação em Ciências Ambientais, Laboratório de Pesquisa Florística, Ecologia de Florestas, Etnobiologia, Restauração Ecológica, Criciúma, SC, Brasil.

³ Unesc, Engenharia Ambiental e Sanitária, Criciúma, SC, Brasil.

⁴ Corresponding author: macronectes1@yahoo.com.uk.

INTRODUCTION

Currently, approximately 84% of the Brazilian population resides within the Atlantic Forest domain (IBGE, 2020). This represents over 180 million people, contributing 80% of the country's Gross Domestic Product (GDP) (PINTO & VOIVODIC, 2021). Over recent decades, there has been a marked increase in the production, trade, and consumption of non-renewable resources. These shifts, which significantly impact Brazil, are associated with biodiversity loss and the decline of ecosystem services in the Atlantic Forest. Major factors affecting the biodiversity of the remaining Atlantic Forest include deforestation, pollution, agribusiness, mining, and urban expansion (GAIO, 2018). Presently, only about 26% of the original forest cover remains, predominantly as fragments smaller than 100 hectares (REZENDE *et al.*, 2018; PINTO *et al.*, 2021).

Among industrial activities, quarrying is employed for the extraction of materials for civil construction, such as crushed stone, pebbles, sand, quartz, and ornamental rocks. These products contribute to urban development and the construction of public and private infrastructure; however, rock exploitation can significantly alter the natural landscape, impacting biodiversity and ecosystem services and, consequently, it is essential to implement public policies to maintain an ecologically balanced environment and protect biodiversity (CAMPOS & BORGHA, 2017).

Regarding ore extraction, Brazilian legislation mandates that companies obtain licenses for activities that modify the environment by preparing an Environmental Impact Assessment (EIA) and its corresponding Environmental Impact Report (Rima) (BRASIL, 1986, 1988). The Brazilian Federal Constitution of 1988 designates the Union and the States as the competent authorities to legislate on fauna and flora (BRASIL, 1988, Article 4, Paragraph VI). Relevant federal laws include Law n. 11,428/2006, which addresses the use and protection of native vegetation in the Atlantic forest biome, and Law n. 12,651/2012, which concerns native vegetation protection. The "Atlantic Forest Law" stipulates that the removal of secondary vegetation in advanced and medium stages of regeneration for mining activities is permitted only through environmental licensing, contingent upon the presentation of EIA/RIMA and the demonstration of the absence of viable technical and locational alternatives (BRASIL, 2006, 2012).

The Federal Constitution (BRASIL, 1988, Article 20, Paragraph I) declares that mineral resources, including those underground, belong to the Union and guarantees the participation of states, the federal district, and municipalities in the exploitation results of mineral resources within their territories. Therefore, mining is a legal activity. Environmental scientists must anticipate potential environmental damages in the EIA for projects with high natural habitat degradation potential, such as rock quarrying (SÁNCHEZ, 2020).

Environmental indicators are widely used in the EIA to assess the environmental quality of a location and birds, in particular, can serve as indicators of environmental quality in the Atlantic Forest concerning mining projects (PENA *et al.*, 2017). Collecting data on bird population richness and abundance during field surveys is relatively straightforward (ANJOS, 2007). A trained ornithologist with local bird knowledge can efficiently gather sufficient composition data to support the EIA.

Habitat modifications can lead to quantitative and qualitative changes in bird species. This makes birds valuable for evaluating and simulating the effects of activities with potential environmental degradation on ecosystems (COELHO *et al.*, 2016). Additionally, some birds are highly sensitive to environmental changes, making them excellent bioindicators of environmental quality (AWADE & METZGER, 2008).

However, using birds as indicators of environmental quality in impact prediction necessitates prior knowledge of species ecology (*i.e.*, niche, habitat, guild, and geographical distribution) since species respond differently to impacts. For instance, forest-dwelling birds are more vulnerable to habitat loss than those inhabiting various environments (WILLIS, 1979; STOUFFER *et al.*, 2013). Therefore, assessing the impacts on birds based on their species-specific characteristics is crucial. This allows for the implementation of more effective mitigation measures to protect species most vulnerable to habitat loss.

In this study, we aimed to utilize birds recorded within the expansion area of a quarry in southern Brazil (CARLOS & TEIXEIRA, 2022; TEIXEIRA & CARLOS, 2023) as ecological indicators to: (1) identify

potential environmental impacts; (2) estimate the magnitude of these impacts; (3) provide essential information for assessing the significance of these impacts; (4) forecast the future environmental scenario with the analyzed project; and (5) propose mitigating alternatives should the state approve the activities.

MATERIAL AND METHODS

STUDY AREA

The study area, known as “Forquilhas”, is located within the municipality of São José in the state of Santa Catarina, Southern Brazil (27°32'35.45”S, 48°43'11.15”W), at altitudes ranging from 100 to 500 meters above sea level (m.a.s.l.) (figure 1). The climate is humid subtropical, featuring evenly distributed rainfall throughout the year and hot summers, without a defined dry season. The average annual precipitation ranges from 1500 to 2300 mm, and the average annual temperature is between 18 and 20°C (PANDOLFO *et al.*, 2002).

This region is part of the Atlantic Forest Biome, specifically the Dense Ombrophilous Submontane Forest formation (KLEIN, 1978). According to resolution No. 33/1994 of the Brazilian National Environment Council, the vegetation cover in the study area qualifies as secondary forest remnants in an advanced stage of regeneration (BRASIL, 1994). The canopy is relatively tall and heterogeneous, ranging from 10 to 18 meters in height, with emergent individuals exceeding 20 m (Ronaldo do Santos Jr., pers. comm.).

Mining activities began in the mid-1990s. Currently, the quarry spans approximately 30 hectares, encompassing roads, mining fronts, production areas, processing facilities, and support infrastructure. The proposed mine expansion will convert forested areas into exposed soils with little to no vegetation cover, over an area of 168 hectares (figure 1). The extracted basalt rock serves as raw material for the construction industry.

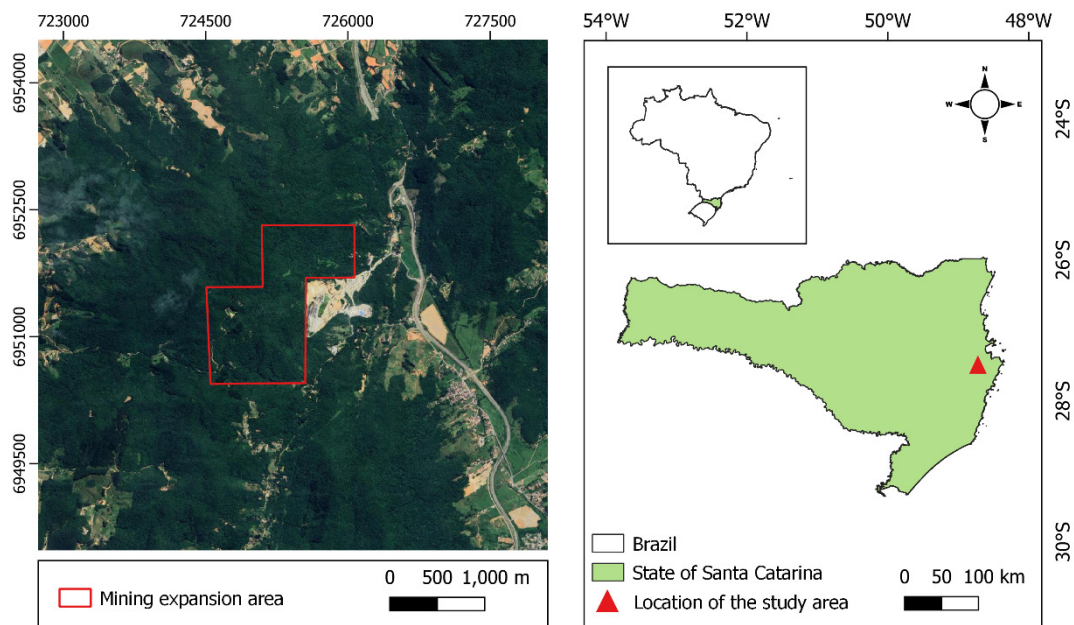


Figure 1 – Location of the study area in São José municipality, Santa Catarina, Brazil. The red polygon represents the quarry expansion area on the remaining Atlantic forest remnants (168 ha). Source: primary.

ENVIRONMENTAL IMPACTS OF QUARRYING ACTIVITIES

To identify potential impacts of quarrying activities, we conducted a systematic review of literature on research platforms, including Web of Science (Clarivate Analytics 2023) and Google Scholar. We focused on detecting impacts related to quarrying activities on the natural environment, specifically on birds. We used several keyword combinations (in Portuguese and English): (1) “impact and quarry” and “quarry and impact”, (2) “quarry and birds” and “birds and quarry”, (3) “environment and quarry” and “quarry and environment”, and (4) “quarry and impacts” and “impacts and quarry”.

Using the Excel spreadsheet editor from the Microsoft Professional Plus package (2019), we organized and analyzed the data. To determine the significance of each impact, screenings and calculations were conducted, initially considering only impacts based on the definition adopted by Sánchez (2020). Elements that did not represent consequences but rather their causes, such as vegetation cutting and soil removal, were excluded. These activities (aspects) lead to impacts like habitat loss, species migration, reduced vegetation cover, and erosion.

With the impacts defined, a matrix of aspects and impacts was constructed to correlate the possible interactions between quarrying activities and the environment (LEOPOLD *et al.*, 1971; SÁNCHEZ & HACKING, 2002). The matrix was organized with environmental impacts in rows and activity-derived aspects in columns (SÁNCHEZ & HACKING, 2002). A list of potential impacts on birds was compiled to calculate the significance of each impact, focusing on birds aligning with the study objectives.

The significance of each impact was determined by weighing its magnitude and importance (BRESSANE *et al.*, 2016; SÁNCHEZ, 2020). Attributes for calculating each impact on birds included duration, extent, and intensity for magnitude, and accumulation, reversibility, and sensitivity for importance (table 1). Values for magnitude and importance were obtained by summing the respective weights, and impact significance was calculated by multiplying magnitude by importance, following the method of Bressane *et al.* (2016).

An arbitrary scale (0, 1, 2, 3) was used to value each weight, with 0 and 3 representing the lowest and highest weights relative to the condition evaluated by the parameters’ weights. Impacts were classified as negative (-1) or positive (1), corresponding to the best and worst scenarios. The equation for calculating impact significance is defined by the following formula (BRESSANE *et al.*, 2016):

Equation 1: Global Impact Index

$$igi = \frac{1}{n} \sum_{i=1}^n \sigma_i$$

Where:

igi = Global Impact Index;

n = total number of impacts;

i = (1,2,3, ..., n); and,

σ_i = Impact Significance i , given by the Equation 2.

Equation 2: Significance

$$\sigma = \mu_i \cdot \iota_i$$

Where:

μ_i = Impact magnitude i ; and,

ι_i = Impact importance i .

Starting from the diagnosis of the EIA, we defined three groups of birds as environmental components to assess each impact: 1) forest birds, 2) generalists, and 3) open-area birds (CARLOS & TEIXEIRA, 2022; TEIXEIRA & CARLOS, 2023). We classified forest birds as those exclusively utilizing forest habitats, open-area birds as those inhabiting clearings or fields, and generalists as birds transitioning between forests and open areas (STOTZ *et al.*, 1996).

We calculated the significance of each impact based on the natural history of the birds. For the qualitative interpretation of each impact, we utilized the scale employed by Sánchez (2020). Each impact’s individual value could range from 3 to 81 (positive or negative), categorized into three intervals: between 3 and 29, indicating a low importance impact; between 30 and 56, denoting moderate importance; and between 57 and 81, representing high importance.

ENVIRONMENTAL IMPACTS OF QUARRYING ON BIRDS

We reviewed a total of 26 documents from 18 countries, examining the impacts of quarrying on bird populations (Appendix). The literature identified 25 impacts, three of which were categorized as positive, with the remainder being negative (table 2). The aspect-impact matrix (table 2) shows that the installation and ore extraction phases experienced the highest number of negative impacts, while positive impacts were linked to rehabilitating degraded areas, establishing new habitats, and providing shelter for various species. Environmental aspects such as vegetation suppression, soil removal, landscape alteration, and fragmentation showed significant interactions with impacts during the project’s installation and operation phases. Conversely, aspects like degraded areas and site abandonment exhibited more interactions after mine closure.

In general, forest birds had the most substantial global impact index ($\mu_i = -58$), followed by generalists ($\mu_i = -23$). Open-area birds demonstrated relatively low significance ($\mu_i = -1.6$). For forest birds, negative impacts such as habitat loss, population decline due to migration, reduced forest resources, and declining forest bird numbers held paramount importance ($\sigma_i > -56$). Conversely, positive impacts were associated with area recovery after the activities ceased, benefiting birds that exclusively inhabit open areas. Positive impacts such as the creation of new habitats were significant for open-area birds ($\sigma_i > 56$). Other impacts, like bird stress due to noise, forest height reduction, and leaf reduction due to dust, were moderately important ($\sigma_i < -26$) for all bird groups (tables 3, 4).

Table 1 – Environmental attributes used to calculate the significance of environmental impacts on birds.

Parameters	Conceptual alignment	Formulas/Possible values
Magnitude	Characteristic of impact related to quantification of effects on the environment in terms of duration, extent, and intensity.	$\mu_i = \sum_{j=1}^3 (p_j)_i$
Duration	Characteristic of impact related to qualification of effects on the environment in terms of accumulation, reversibility, and sensitivity.	short to middle term (1), long term (2) or permanent (3)
Extent	Quantification of the spatial extent of the impact; the territory affected.	point (1), local (2) or regional (3)
Intensity	Quantification of the level of alteration of the environmental characteristic; degree of modification.	low (1), medium (2), or high (3)
Importance	Characteristic of the impact related to the qualification of effects on the environment, in terms of accumulation, reversibility, and sensitivity.	$\iota_i = \sum_{j=4}^6 (p_j)_i$
Accumulation	Qualification regarding the possibility of improvement or worsening of the changes.	absent (0), uncertain (2) or present (3)
Reversibility	Qualification regarding the ability to return to a state of environmental balance.	reversible (1), uncertain (2), or non-reversible (3)
Sensitivity	Qualification regarding tolerance to changes considering the current condition.	null (0), partial (2) or total (3)
Significance	Synthesis of the environmental impact analysis through the integration of quantitative and qualitative parameters.	$\sigma = \mu_i \cdot \iota_i$

Source: Adapted from Bressane *et al.* (2016).

Table 2 – Matrix of interactions between environmental aspects and impacts caused by quarrying activities. Nature of impacts categorized as positive (+) or negative (-).

Environmental Impacts	Nature	Installation and operation of the mine					Drilling and blasting			Processing and transportation			Ore depletion													
		Vegetation suppression	Soil removal	Road construction	Landscape alteration	Slope Instability	Habitat fragmentation	Water table lowering	Surface Runoff	Hydrological regime	Rock disposal	Air displacement and dust	Ground vibrations	Point source noise	Diffuse noise	Soil compaction	Water consumption	Solid waste production	Sludge generation	Suspended particles	Degraded area	Invasive species	Dam formation	Acid drainage	Environmental restoration	Abandonment of area
Habitat loss	-	█	█	█	█	█														█	█				█	
Population decline due to migration	-	█	█	█	█	█														█	█				█	
Reduction in forest resources	-	█	█	█	█	█									█					█	█				█	
Increase in endogamy	-	█	█	█	█	█														█	█				█	
Decline in invertebrates	-	█	█	█	█	█									█					█	█				█	
Reduced nesting and foraging sites	-	█	█	█	█	█														█	█				█	
Territorial loss	-	█	█	█	█	█														█	█				█	
Affects the distribution of species in the surrounding region	-	█	█	█	█	█														█	█				█	
Impairs successful bird reproduction due to noise	-	█	█	█	█	█														█	█				█	
Reduction in forest canopy height and leaf number due to dust	-											█	█							█	█				█	
Affects bird diversity	-									█		█	█							█	█				█	
Causes stress in birds due to noise	-	█	█	█	█	█														█	█				█	
Reduces the formation and abundance of mixed-species flocks	-			█	█	█						█	█							█	█				█	
Reduction in reproductive success in sensitive bird species	-	█	█	█	█	█														█	█				█	
Affects bird behavior	-	█	█	█	█	█														█	█				█	
Collapse in interspecific associations between birds	-											█	█							█	█				█	

to be continued...

Table 3 – Magnitude (M) of environmental impacts on birds, where the environmental attributes used are categorized as duration (D), extension (E), and intensity (I). Nature (Nat) of impacts divided into positive (+) or negative (-).

Environmental impacts	Nat	Forest specialists				Generalists				Open areas			
		D	E	I	M	D	E	I	M	D	E	I	M
Habitat loss	-	3	2	3	8	3	2	2	7	1	1	1	3
Population decline due to migration	-	3	2	3	8	3	2	2	7	1	1	1	3
Reduction in forest resources	-	3	3	3	9	3	2	2	7	1	1	1	3
Increase in endogamy	-	3	2	2	7	3	2	1	6	1	1	1	3
Decline in invertebrates	-	3	1	3	7	3	1	2	6	1	1	2	4
Reduced nesting and foraging sites	-	3	1	3	7	3	1	1	5	1	1	1	3
Territorial loss	-	3	2	3	8	3	1	1	5	1	1	1	3
Affects the distribution of species in the surrounding region	-	3	2	3	8	2	1	1	4	1	1	1	3
Impairs successful bird reproduction due to noise	-	3	1	2	6	3	1	2	6	3	1	1	5
Reduction in forest canopy height and leaf number due to dust	-	3	1	2	6	3	1	2	6	1	1	1	3
Affects bird diversity	-	3	2	3	8	3	1	1	5	1	1	1	3
Causes stress in birds due to noise	-	3	1	2	6	3	1	1	5	3	1	1	5
Reduces the formation and abundance of mixed-species flocks	-	3	1	2	6	3	1	1	5				NA
Reduction in reproductive success in sensitive bird species	-	3	1	2	6				NA				NA
Affects bird behavior	-	3	1	2	6	3	1	1	5	3	1	1	5
Collapse in interspecific associations between birds	-	3	2	2	7	3	1	1	5	1	1	1	3
Insectivorous birds are subjected to higher predation	-	3	1	1	5	3	1	1	5	1	1	1	3
Decline of birds in the forest, especially specialists	-	3	2	3	8				NA				NA
Reduced resources for specialist birds	-	3	1	3	7				NA				NA
Intensification of edge effects	-	3	2	2	7	3	1	1	5				NA
Imbalance in aquatic biota	-	3	2	3	8	3	1	1	5	3	1	1	5
Creation of new habitats	+			NA		3	1	1	5	3	1	2	6
Provides new shelters and refuges for animals	+			NA		3	1	1	5	3	1	2	6
Increased nesting opportunities for birds of prey	+			NA		3	1	1	5	3	1	2	6
Expanded nesting opportunities for swallows	+			NA					NA	3	1	2	6

Table 4 – Significance (S) of each impact established by the weightings between magnitude (M) and importance (I), where the secondary attributes used are categorized as accumulation (A), reversibility (R), and sensitivity. Nature of impacts divided into positive (+) or negative (-).

Environmental impact	Nat.	Forest specialists					Generalists					Open areas							
		M	A	R	S	I	S	M	A	R	S	I	S	M	A	R	S	I	S
Habitat loss	-1	8	3	3	3	9	-72	7	2	2	2	6	-42	3	2	1	2	5	-15
Population decline due to migration	-1	8	3	3	3	9	-72	7	2	2	2	6	-42	3	2	1	0	3	-9
Reduction in forest resources	-1	9	3	3	3	9	-81	7	2	2	2	6	-42	3	0	1	0	1	-3
Increase in endogamy	-1	7	3	3	3	9	-63	6	2	1	2	5	-30	3	0	1	0	1	-3
Decline in invertebrates	-1	7	3	3	3	9	-63	6	2	3	2	7	-42	4	2	1	2	5	-20
Reduced nesting and foraging sites	-1	7	3	3	3	9	-63	5	2	1	2	5	-25	3	2	1	2	5	-15
Territorial loss	-1	8	3	3	3	9	-72	5	2	2	3	7	-35	3	2	1	2	5	-15
Affects the distribution of species in the surrounding region	-1	8	3	2	3	8	-64	4	0	3	2	5	-20	3	0	1	0	1	-3
Impairs successful bird reproduction due to noise	-1	6	2	1	3	6	-36	6	2	1	2	5	-30	5	2	1	2	5	-25
Reduction in forest canopy height and leaf number due to dust	-1	6	3	2	3	8	-48	6	2	1	2	5	-30	3	0	1	0	1	-3
Affects bird diversity	-1	8	3	2	3	8	-64	5	2	1	2	5	-25	3	0	1	2	3	-9
Causes stress in birds due to noise	-1	6	3	1	3	7	-42	5	2	1	2	5	-25	5	2	1	2	5	-25
Reduces the formation and abundance of mixed-species flocks	-1	6	3	2	3	8	-48	5	2	1	0	3	-15					NA	
Reduction in reproductive success in sensitive bird species	-1	6	3	2	3	8	-48											NA	
Affects bird behavior	-1	6	3	1	3	7	-42	5	2	1	2	5	-25	5	2	1	2	5	-25
Collapse in interspecific associations between birds	-1	7	3	1	3	7	-49	5	2	1	2	5	-25	3	2	1	0	3	-9
Insectivorous birds are subjected to higher predation	-1	5	3	1	3	7	-35	5	2	1	2	5	-25	3	2	1	2	5	-15
Decline of birds in the forest, especially specialists	-1	8	3	2	3	8	-64											NA	
Reduced resources for specialist birds	-1	7	3	3	3	9	-63											NA	
Intensification of edge effects	-1	7	3	3	3	9	-63	5	0	3	0	3	-15					NA	
Imbalance in aquatic biota	-1	8	3	3	3	9	-72	5	0	3	2	5	-25	5	2	3	2	7	-35
Creation of new habitats	1					NA		5	2	2	2	6	30	6	3	3	3	9	54
Provides new shelters and refuges for animals	1					NA		5	2	1	2	5	25	6	3	2	3	8	48
Increased nesting opportunities for birds of prey	1					NA		5	2	2	2	6	30	6	3	2	3	8	48
Expanded nesting opportunities for swallows	1					NA								6	3	2	3	8	48

DISCUSSION

The global impact index clearly indicates that all three assessed bird groups are adversely affected by the negative consequences arising from the quarry expansion, except for certain species that inhabit open areas. Nevertheless, the most substantial impacts are discernibly linked to birds exclusively reliant on forest habitats. Projections emphasize that the most notable adverse effects on birds originate from the phases of the mine installation and operation, primarily due to the suppression of vegetation and the removal of organic soil substrates (MARCHEVSKY *et al.*, 2018). These activities result in habitat loss, diminished forest resources, and population declines, particularly impacting forest-dwelling avifauna (SCOTTON & ANDREATTA, 2021).

The results indicate that impacts with permanent duration hold more significance than temporary ones. It is reasonable to assume that diffuse and punctual noises will cease after the ore deposit is exhausted. However, it is impossible to guarantee the return of all displaced native avifauna even after mine abandonment (PENA *et al.*, 2017) and area recovery. Despite efforts in simultaneous environmental recovery during mining activities, the natural landscape conditions cannot be fully restored (DEIKUMAH *et al.*, 2014; SÁNCHEZ, 2020). Certain mitigating measures might reduce impacts by decreasing vegetation cover, but they cannot restore the original landscape (SOLERA *et al.*, 2014; CHENOT *et al.*, 2018).

Clear-cutting forests and removing organic matter from the soil are likely to reduce soil microbial activity and populations of associated invertebrates (ROVER & PERSSON, 2014; ZHANG *et al.*, 2018). Consequently, specialized forest sub-canopy birds are likely to be the first species to disappear from the area and its surroundings due to the lack of suitable ecological niches, even after area recovery (PATTEN & SMITH-PATTEN, 2012, POWELL *et al.*, 2015). Changes in the sub-canopy microclimate affect the survival of various invertebrate species that serve as food for birds, potentially reducing the food supply for sub-canopy insectivorous birds in the forest (VERGARA *et al.*, 2021).

During mine operation, an increase in water consumption for ore processing is anticipated. Additionally, air quality alterations due to suspended particulate matter from heavy truck traffic, as well as increased soil compaction, are expected (FALEIRO & LOPES 2011; COELHO *et al.*, 2016). Furthermore, particulate matter emissions can diminish plant photosynthetic capacity due to dust accumulation on leaf surfaces (LAMEED & AYODELE, 2010), leading to leaf loss and reduced forest resources for birds. Specialized forest and frugivorous birds were strongly negatively affected by adjacent mining activities in the Atlantic Forest highlands in Brazil (DEIKUMAH *et al.*, 2014). Hence, the results of this study suggest that increased surface mining in the region will likely result in population declines for birds utilizing forest remnants around the quarry.

After ore depletion in the area, at least two distinct scenarios are anticipated: (i) complete abandonment or (ii) environmental recovery (CAMPOS & BORGA, 2017). In the worst-case scenario, cumulative effects may include degraded sites, dam formation, and acid mine drainage (DARWISH *et al.*, 2011). In the best-case scenario, human interventions for environmental recovery are expected to create new habitats, provide shelter, and offer nesting sites suitable for birds (READ *et al.*, 2000).

Among the evaluated bird groups, some species might benefit from the new scenario caused by ore extraction. For example, the creation of new habitats favors foraging and nesting of migratory swallows (Hirundinidae) and generalist birds of prey (Cathartidae, Accipitridae), increasing their abundance in forest edge areas (ROHRER *et al.*, 2020). Birds utilizing rocky vegetation might expand their home range (TELEA *et al.*, 2019). Consequently, positive impacts such as creating new habitats, providing bird shelter, and offering nesting sites were significantly positive for birds using open areas, although the resource supply might be compromised. Depending on the local landscape, mining excavations can create favorable environments for species utilizing lacustrine habitats (KALARUS *et al.*, 2019). In a study conducted in wetlands in the UK, the open aspect of areas recovered by sand mining provided essential additional floodplain habitats for waders (Charadriiformes), if managed for that purpose. For instance, species such as *Tringa ochropus*, *Charadrius hiaticula*, and *Haematopus ostralegus* benefited from these new habitats (DAY *et al.*, 2017).

However, it is necessary to analyze the landscape context in which the mining area is situated. It is presumed that regions naturally arid or historically occupied by anthropogenic matrices have

fewer negative impacts than preserved tropical forests (SÁNCHEZ, 2020). Pena *et al.* (2017) reported that all endemic species of the Atlantic Forest Mountain tops in the eastern region of Brazil have their distribution directly or indirectly affected by mining activities. According to Zhang *et al.* (2018), quarry mining devastates vegetation and related ecosystem functions; hence, vegetation restoration can be severely restricted by local conditions and recovery is generally slow, and the remaining plants tend to persist in grass and shrub stages for a long time. However, this directly depends on the procedures and methods used for habitat recovery and restoration.

Despite the predicted negative impacts, it is known that mining is one of the world's oldest activities and will not cease to exist anytime soon. Thus, due to legislation favoring the protection of a balanced natural environment, it is necessary to propose mitigating measures to minimize the impacts caused by potentially degrading activities such as quarries. For example, in the USA, legislation requires a neutral balance between losses and gains in wetland areas, encourages the use of compensation banks to facilitate exchanges, and promotes wetland recovery (U.S. ENVIRONMENTAL PROTECTION AGENCY, 2008). In Canada, compensation must ensure the productive capacity of the natural habitat, replacing the affected habitat with another of equivalent conditions. In the European Union, a site should never be irreversibly impacted before compensation is implemented (UNECE, 2018). In Brazil, the Federal Constitution obliges mining companies to restore areas after the activity ceases (BRAZIL, 1988, Article 225, Paragraph VII, § 2nd). Conama Resolution n. 2 of 1996, in its article 1, §1, requires the implementation of a conservation unit or other alternatives as a requirement for licensing to repair environmental damage caused by forest destruction and other ecosystems (BRAZIL, 1996). The Brazilian Forest code and the Atlantic Forest Law (BRAZIL, 2006, 2012) demand environmental compensation and forest replacement for cutting native vegetation in medium and advanced stages of regeneration.

CONCLUSION

This study harnessed birds as a pivotal environmental indicator for forecasting impacts, offering precise estimations regarding their magnitude and significance throughout the quarry's establishment, operation, and closure phases. The literature review illuminated that while these impacts are globally acknowledged, their cumulative effects are poised to be more profound in tropical regions, exemplified by the intricate ecosystem of the Atlantic Forest.

The conclusive prognosis accentuated the disproportionate burden of impacts on forest-dwelling species. Acquiring preliminary data about the assessed environmental component during the diagnostic phase emerged as pivotal. In the case of birds, delving into their natural history proved invaluable, enabling tailored prognoses in accordance with the unique traits of each species.

The applied methodology not only minimized subjectivity in impact assessment but also underscored the potential of birds as potent tools for guiding environmental impact analyses, especially in the face of activities with the transformative potential akin to mining. As a result, this protocol's adaptability to other faunal groups becomes apparent. This study's pioneering efforts have set the stage for establishing a robust, active protocol in the environmental impact analysis of mining ventures in southern Brazil.

REFERENCES

- Alvarez-Berríos, N., Marconi, C. C., Andrés, H. S., Delgado, C. J. A., Dañobeytia, F. R. & Aide, T. M. Impacts of small-scale gold mining on birds and anurans near the Tambopata Natural Reserve, Peru, assessed using passive acoustic monitoring. *Tropical Conservation Science*. 2016; 9(2): 832-851.
doi: <https://doi.org/10.1177/194008291600900216>
- Anjos, L. D. A eficiência do método de amostragem por pontos de escuta na avaliação da riqueza de aves. *Revista Brasileira de Ornitologia*. 2007; 15(2): 239-243.

Awade, M. & Metzger, J. P. Using gap-crossing capacity to evaluate functional connectivity of two Atlantic rainforest birds and their response to fragmentation. *Austral Ecology*. 2008; 33(7): 863-871.
doi: <https://doi.org/10.1111/j.1442-9993.2008.01857>

Brasil. Constituição da República Federativa do Brasil. Brasília: Senado Federal; 1988. 454 p.

Brasil. Lei n.º 11.428, de 22 de dezembro de 2006. Dispõe sobre a utilização e proteção da vegetação nativa do bioma mata atlântica, e dá outras providências. Brasília, DF; 2006. Available at: http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2006/lei/l11428.htm. Access on: 30 May 2025.

Brasil. Lei n.º 12.651, de 25 de maio de 2012. Dispõe sobre a proteção da vegetação nativa; altera as Leis n.ºs 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis n.ºs 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória n.º 2.166-67, de 24 de agosto de 2001; e dá outras providências. Brasília, DF; 2012. Available at: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm. Access on: 30 May 2025.

Brasil. Resolução Conama n.º 001, de 23 de janeiro de 1986. Define as situações e estabelece os requisitos e condições para desenvolvimento de Estudo de Impacto Ambiental – EIA e respectivo Relatório de Impacto Ambiental – RIMA. Brasília, DF; 1986. Available at: <http://www.ibama.gov.br/sophia/cnia/legislacao/MMA/RE0001-230186.PDF>. Access on: 20 May 2025.

Brasil. Resolução Conama n.º 02, de 18 de abril de 1996. Estabelece diretrizes para os órgãos ambientais quanto ao cálculo, cobrança, aplicação, aprovação e controle de gastos de recursos advindos de medidas compensatórias, conforme definição do Sistema Nacional de Unidades de Conservação. Brasília, DF, 1996. Available at: <https://www.ibama.gov.br/sophia/cnia/legislacao/MMA/RE0002-180496.PDF>. Access on 20 May 2025.

Brasil. Resolução Conama n.º 33, de 7 de dezembro de 1994. Define estágios sucessionais das formações vegetais que ocorrem na região da mata atlântica do estado do Rio Grande do Sul, visando viabilizar critérios, normas e procedimentos para o manejo, utilização racional e conservação da vegetação natural. Brasília, DF; 1994. Available at: <http://www.ibama.gov.br/sophia/cnia/legislacao/mma/re0004-040594.pdf>. Access on: 20 May 2025.

Bressane, A., Reis, F. A. G. V., Giordano, L. D. C., Roveda, J. A. F., Roveda, S. R. M. M., Martins, A. C. G. & Mochizuki, P. S. Construção de um índice global de impacto para análise ambiental comparativa aplicada à adequação de empreendimentos irregulares. *Engenharia Sanitária e Ambiental*. 2016; 22: 111-122.
doi: <https://doi.org/10.1590/S1413-41522016140136>

Campos, R. F. F. & Borga, T. Proposta de recuperação de uma área degradada pela atividade de extração de basalto no município de Caçador, Santa Catarina. *Geonorte*. 2017; 8(29): 23-37.
doi: <https://doi.org/10.21170/geonorte.2017.V.8.N.29.23.37>

Carlos, C. J. & Teixeira, C. D. Um banco de dados de aves de uma área de mata atlântica em Santa Catarina, Sul do Brasil. *Latin American Data in Science*. 2022; 2(2): 54-59.
doi: <https://doi.org/10.53805/lads.v2i2.51>

Chenot, J., Jaunatre, R., Buisson, E., Bureau, F. & Dutoit, T. Impact of quarry exploitation and disuse on pedogenesis. *Catena*. 2018; 160: 354-365.
doi: <https://doi.org/10.1016/j.catena.2017.09.012>

Coelho, M. T. P., Raniero, M., Silva, M. I. & Hasui, É. The effects of landscape structure on functional groups of Atlantic forest birds. *The Wilson Journal of Ornithology*. 2016; 128(3): 520-534.
doi: <https://doi.org/10.1676/1559-4491-128.3.520>

Darwish, T., Khater, C., Joma, A. I., Stehouwer, R., Shaban, A. & Hamzé, M. Environmental impact of quarries on natural resources in Lebanon. *Land Degradation & Development*. 2011; 22(3): 345-358.
doi: <https://doi.org/10.1002/ldr.1011>

Day, G., Mayes, W. M., Wheeler, P. M. & Hull, S. L. Can aggregate quarry silt lagoons provide resources for wading birds? *Ecological Engineering*. 2017; 105: 189-197.
doi: <https://doi.org/10.1016/j.ecoleng.2017.04.055>

- Deikumah, J. P., Mcalpine, C. A. & Maron, M. Mining matrix effects on West African rainforest birds. *Biological Conservation*. 2014; 169: 334-343.
doi: <https://doi.org/10.1016/j.biocon.2013.11.030>
- EPA-U.S. – Environmental Protection Agency. EPA's 2008 Report on the Environment. National Center for Environmental Assessment, EPA/600/R-07/045F. Washington: EPA. Available at: <http://www.epa.gov/roe>. Access on: 20 May 2025.
- Faleiro, F. F. & Lopes, L. M. Aspectos da mineração e impactos da exploração de quartzito em Pirenópolis – GO. *Ateliê Geográfico*. 2011; 4(3): 12-23.
doi: <https://doi.org/10.5216/ag.v4i3.16655>
- Gaio, A. *Lei da Mata Atlântica comentada*. São Paulo: Almedina; 2018. 349 p.
- Ibama – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. *Manual de recuperação de áreas degradadas pela mineração: técnicas de revegetação*. Brasília: IBAMA; 1990. 96 p.
- IBGE – Instituto Brasileiro de Geografia e Estatística. *Projeção da população do Brasil e Unidades da Federação por sexo e idade para o período 2010-2060*. Rio de Janeiro; 2020. Available at: <https://www.ibge.gov.br/estatisticas/sociais/populacao/9109-projecao-da-populacao.html?=&t=resultados>. Access on: 30 May 2025.
- Kalarus, K., Halecki, W. & Skalski, T. Both semi-natural and ruderal habitats matter for supporting insect functional diversity in an abandoned quarry in the city of Kraków (S Poland). *Urban Ecosystems*. 2019; 22(5): 943-953.
doi: <https://doi.org/10.1007/s11252-019-00869-3>
- Klein, R. M. *Mapa fitogeográfico do estado de Santa Catarina*. Itajaí: Herbário Barbosa Rodrigues; 1978. 24 p.
- Lameed, G. A. & Ayodele, A. E. Effect of quarrying activity on biodiversity: case study of Ogbere site, Ogun State, Nigeria. *African Journal of Environmental Science and Technology*. 2010; 4(11): 740-750.
- Leopold, L. B., Clarke, E. F., Hanshaw, B. B. & Balsley, R. J. *A procedure for evaluating environmental impact*. Washington: U.S. Geological Survey (USGS Numbered Series 655); 1971. 16 p.
- Marchevsky, N. J., Giubergia, A. A. & Ponce, N. H. Evaluación de impacto ambiental de la cantera “La Represa”, en la provincia de San Luis, Argentina. *Tecnología y Cultura Afirmando el Conocimiento*. 2018; 22(56): 51-61.
doi: <https://doi.org/10.14483/22487638.12907>
- Pandolfo, C., Braga, H. J., Silva Júnior, V. D., Massignan, A. M., Pereira, E. S., Thomé, V. M. R. & Valci, F. V. *Atlas climatológico digital do estado de Santa Catarina*. Florianópolis: Epagri; 2002. CD-ROM.
- Patten, M. A. & Smith-Patten, B. D. Testing the microclimate hypothesis: light environment and population trends of Neotropical birds. *Biological Conservation*. 2012; 155: 85-93.
doi: <https://doi.org/10.1016/j.biocon.2012.06.004>
- Pena, J. C. D. C., Goulart, F., Fernandes, G. W., Hoffmann, D., Leite, F. S., dos Santos, N. B. & Rodrigues, M. Impacts of mining activities on the potential geographic distribution of eastern Brazil mountaintop endemic species. *Perspectives in Ecology and Conservation*. 2017; 15(3): 172-178.
doi: <https://doi.org/10.1016/j.pecon.2017.07.005>
- Pinto, L. F. G., Hirota, M. & Rosa, M. Atlas da mata atlântica e mapbiomas se complementam no monitoramento do bioma. 2021. Available at: <https://www.sosma.org.br/artigos/atlas-da-mata-atlantica-e-mapbiomas-se-complementam-no-monitoramento-do-bioma/>. Access on: 20 May 2025.
- Pinto, L. F. G. & Voivodic, M. Recuperação da mata atlântica é oportunidade única para enfrentar mudança climática: Com combate ao desmatamento, Brasil pode contribuir para que metas do Acordo de Paris sejam alcançadas. 2021. Available at: <https://www1.folha.uol.com.br/ilustrissima/2021/05/recuperacao-da-mata-atlantica-e-oportunidade-unica-para-enfrentar-mudanca-climatica.shtml>. Access on: 20 May 2025.
- Powell, L. L., Cordeiro, N. J. & Stratford, J. A. Ecology and conservation of avian insectivores of the rainforest understory: a pantropical perspective. *Biological Conservation*. 2015; 188: 1-10.
doi: <https://doi.org/10.1016/j.biocon.2015.03.025>

- Read, J. L., Reid, N. & Venables, W. N. Environmental auditing: Which birds are useful bioindicators of mining and grazing impacts in arid South Australia? *Environmental Management*. 2000; 26(2): 215-232.
doi: <https://doi.org/10.1007/s002670010083>
- Rezende, C. L., Scarano, F. R., Assad, E. D., Joly, C. A., Metzger, J. P., Strassburg, B. B. N. & Mittermeier, R. A. From hotspot to “hopespot”: an opportunity for the Brazilian Atlantic forest. *Perspectives in Ecology and Conservation*. 2018; 16(4): 208-214.
doi: <https://doi.org/10.1016/j.pecon.2018.10.002>
- Rohrer, Z., Rebollo, S., Monteagudo, N. & Talabante, C. Eagle Owl presence and diet at mining sites: implications for restoration and management for cliff-nesting birds. *Restoration Ecology*. 2020; 28(6): 1541-1550.
doi: <https://doi.org/10.1111/rec.13256>
- Rover, T. D. & Persson, T. The concept of ecosystem services: Integrating the concept of ecosystem services on the environmental impact assessment of the Bunge Quarry [Master's Dissertation]. Uppsala: Uppsala University; 2014.
- Sánchez, L. E. Avaliação de impacto ambiental: conceitos e métodos. São Paulo: Oficina de Textos; 2020. 494 p.
- Sánchez, L. E. & Hacking, T. An approach to linking environmental impact assessment and environmental management systems. *Assessment and Project Appraisal*. 2002; 20(1): 25-38.
doi: <https://doi.org/10.3152/147154602781766843>
- Scotton, M. & Andreatta, D. Anti-erosion rehabilitation: effects of revegetation method and site traits on introduced and native plant cover and richness. *The Science of the Total Environment*. 2021; 776: 145915.
doi: <https://doi.org/10.1016/j.scitotenv.2021.145915>
- Solera, M. L., Gallardo, A. L. C. F., Souza, C. A., Longo, M. H. C. & Braga, T. O. Bioengenharia de solos: aplicabilidade na recuperação de áreas mineradas e na oferta de serviços ambientais. *Brazilian Journal of Environmental Sciences*. 2014; 34: 46-59. Available at: https://www.rbciamb.com.br/Publicacoes_RB CIAMB/article/view/216. Access on: 20 May 2025.
- Stotz, D. F., Fitzpatrick, J. W., Parker III, T. A. & Moskovits, D. K. Neotropical birds: ecology and conservation. Chicago: University of Chicago Press; 1996. 478 p.
- Stouffer, P. C., Johnson, E. I. & Bierregaard Jr., R. O. Breeding seasonality in central Amazonian rainforest birds. *The Auk*. 2013; 130(3): 529-540.
- Teixeira, C. D. & Carlos, C. J. Avifauna de uma área de floresta atlântica no Sul do Brasil sob influência de atividade minerária. *Iheringia, Série Zoologia*. 2023; 13: e2023012.
doi: <https://doi.org/10.1590/1678-4766e2023012>
- Telea, A., Topliceanu, T. S., Balasoiu, D., Serban, R. & Cogalniceanu, D. Biodiversity in quarries – a study case from Iglicioara Quarry, Romania. *Academy of Romanian Scientists. Annals Series on Biological Sciences*. 2019; 8(1): 5-16.
- Tsolaki-Fiaka, S., Bathrellos, G. D. & Skilodimou, H. D. Multi-criteria decision analysis for an abandoned quarry in the Evros Region (NE Greece). *Land*. 2018; 7(2): 43-69.
doi: <https://doi.org/10.3390/land7020043>
- Unece – United Nations Economic Commission for Europe. Guidance on environmental compensation. Geneva: United Nations Economic Commission for Europe; 2018. 48 p. Available at: <https://unece.org/>. Access on: 20 May 2025.
- Vergara, P. M., Fierro, A., Alaniz, A. J., Carvajal, M. A., Lizama, M. & Llanos, J. L. Landscape-scale effects of forest degradation on insectivorous birds and invertebrates in austral temperate forests. *Landscape Ecology*. 2021; 36(1): 191-208.
doi: <https://doi.org/10.1007/s10980-020-01133-2>
- Willis, E. O. The composition of avian communities in remanescent woodlots in southern Brazil. *Papéis Avulsos de Zoologia*. 1979; 33(1): 1-25.
- Zhang, Q., Zhang, T. & Liu, X. Index system to evaluate the quarries ecological restoration. *Sustainability*. 2018; 10(3): 619-630.
doi: <https://doi.org/10.3390/su10030619>

Appendix – List of references used in the systematic review

- Armaghani, D. J., Hajihassani, M., Monjezi, M., Mohamad, E. T., Marto, A. & Moghaddam, M. R. Application of two intelligent systems in predicting environmental impacts of quarry blasting. *Arabian Journal of Geosciences*. 2015; 8(11): 9647-9665.
doi: 10.1007/s12517-015-1908-2
- Bacci, D. L. C., Landim, P. M. B. & Eston, S. M. Aspectos e impactos ambientais de pedreira em área urbana. *Revista Escola de Minas [online]*. 2006; 59(1): 47-54.
doi: 10.1590/S0370-44672006000100007
- Benetková, P., Tichý, L., Háněl, J., Kukla, J., Vicentini, F. & Frouz, J. The effect of soil and plant material transplants on vegetation and soil biota during forest restoration in a limestone quarry: a case study. *Ecological Engineering*. 2020; 158: 106039.
doi: 10.1016/j.ecoleng.2020.106039
- Campos, R. F. F., & Borga, T. Proposta de recuperação de uma área degradada pela atividade de extração de basalto no município de Caçador, Santa Catarina. *Revista Geonorte*. 2017; 8(29): 23-37.
doi: 10.21170/geonorte.2017.V.8.N.29.23.37
- Chenot, J., Jaunatre, R., Buisson, E., Bureau, F. & Dutoit, T. Impact of quarry exploitation and disuse on pedogenesis. *Catena*. 2018; 160: 354-365.
doi: 10.1016/j.catena.2017.09.012. hal-01790691
- Coelho, Y. C. D. M. C., Lucas, F. C. A & Sarmiento, P. S. D. M. S. Percepção ambiental e mineração de agregados: o olhar da população urbano-rural de Ourém, Pará, Brasil. *Desenvolvimento e Meio Ambiente*. 2020; 53: 38-60.
doi: 10.5380/dma.v53i0.60771
- Dada, E. Environmental impact of quarry activities in Supare-Akoko, Ondo State, Nigeria. *Journal of Geography and Planning Sciences*. 2018; 3(1): 101-111.
- Da Silva, F. P., De Moura, G. J. B. & Dos Santos, C. A. B. Representações dos moradores do entorno das áreas de exploração sobre a importância e impactos da mineração. *Geosul*. 2018; 33(66): 128-146.
doi: 10.5007/2177-5230.2018v33n66p128
- Darwish, T., Khater, C., Jomaa, I., Stehouwer, R., Shaban, A. & Hamzé, M. Environmental impact of quarries on natural resources in Lebanon. *Land Degradation & Development*. 2011; 22(3): 345-358.
doi: 10.1007/s10661-014-3957-5
- Day, G., Mayes, W., Wheeler, P & Hull, S. Can aggregate quarry silt lagoons provide resources for wading birds? *Ecological Engineering*. 2017; 105: 189-197.
doi: 10.1016/j.ecoleng.2017.04.055
- De Castro Pena, J. C., Goulart, F., Wilson Fernandes, G., Hoffmann, D., Leite, F. S. F., Britto dos Santos, N. & Rodrigues, M. Impacts of mining activities on the potential geographic distribution of eastern Brazil mountaintop endemic species. *Perspectives in Ecology and Conservation*. 2017; 15(3): 172-178.
doi: 10.1016/j.pecon.2017.07.005
- Deikumah, J. P., McAlpine, C. A. & Maron, M. Mining matrix effects on West African rainforest birds. *Biological Conservation*. 2014; 169: 334-343.
doi: 10.1016/j.biocon.2013.11.030
- Fernandes Faleiro, F. & Lopes, L. Aspectos da mineração e impactos da exploração de quartzito em Pirenópolis – GO. *Ateliê Geográfico*. 2011; 4(3): 12-23.
doi: 10.5216/ag.v4i3.16655
- Fişne, A., Kuzu, C. & Hüdaverdi, T. Prediction of environmental impacts of quarry blasting operation using fuzzy logic. *Environmental Monitoring and Assessment*. 2011; 174(1): 461-470.
doi: 10.1007/s10661-010-1470-z

- Gajera, N. B., Mahato, A. K. R. & Kumar, V. V. Status, distribution, and diversity of birds in mining environment of Kachchh, Gujarat. *International Journal of Biodiversity*. 2013; 13: 1-11.
doi: 10.1155/2013/471618
- Gazi, A., Skevis, G. & Founti, M. A. Energy efficiency and environmental assessment of a typical marble quarry and processing plant. *Journal of Cleaner Production*. 2012; 32: 10-21.
doi: 10.1016/j.jclepro.2012.03.007
- Ibama – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Manual de recuperação de áreas degradadas pela mineração: técnicas de revegetação. Brasília; 1990. 96 p.
- Koshelev, V. A., Pakhomov, O. Y. & Busel, V. A. The formation of sclerophilic ornithocomplexes in the quarries in the south of Ukraine and their conservation prospects. *Ecology, Environment and Conservation*. 2020; 26(1): 411-419.
- Lameed, G. A. & Ayodele, A. E. Effect of quarrying activity on biodiversity: case study of Ogbere site, Ogun State, Nigeria. *African Journal of Environmental Science and Technology*. 2010; 4(11): 740-750. Available at: www.ajol.info/index.php/ajest/article/view/71340.
- Marchevsky, N. J., Giubergia, A. A. & Ponce, N. H. Evaluación de impacto ambiental de la cantera “La Represa”, en la provincia de San Luis, Argentina. *Tecnura*. 2018; 22(56): 51-61.
doi: 10.14483/22487638.12907
- Melodi, M. M. Assessment of environmental impacts of quarry operation in Ogun State, Nigeria. *Fuoye – Journal of Engineering and Technology*. 2017; 2(2): 100-103.
doi: 10.46792/fuoyejet.v2i2.14192
- Ogan, D., Ndekugri, I., Oduoza, C. & Khatib, J. Principles for developing an effective framework to control minerals and rocks extraction impacts, mitigate waste and optimise sustainable quarries management. *Resources Policy*. 2016; 47: 164-170.
doi: 10.1016/j.resourpol.2016.01.004
- Oliveira, E. M. D. Impacto ambiental na exploração de pedreiras [Dissertação de Mestrado]. Porto: Departamento de Geologia da Faculdade de Ciências da Universidade do Porto; 2006.
- Peng, X., Shi, G., Zheng, J., Liu, J., Shi, X., Xu, J. & Feng, Y. Influence of quarry mining dust on PM_{2.5} in a city adjacent to a limestone quarry: seasonal characteristics and source contributions. *The Science of the Total Environment*. 2016; 550: 940-949.
doi: 10.1016/j.scitotenv.2016.01.195
- Phillips, J. The level and nature of sustainability for clusters of abandoned limestone quarries in the southern Palestinian West Bank. *Applied Geography*. 2012; 32(2): 376-392.
doi: 10.1016/j.apgeog.2011.06.009
- Pratt, A. & Beck, J. Greater sage-grouse response to bentonite mining. *The Journal of Wildlife Management*. 2019; 83(4): 866-878.
doi: 10.1002/jwmg.21644
- Read, J. L., Reid, N. & Venables, W. N. Environmental auditing: Which birds are useful bioindicators of mining and grazing impacts in arid South Australia? *Environmental Management*. 2000; 26(2): 215-232.
doi: 10.1007/s002670010083
- Rohrer, Z. Breeding cliff-nesting birds at mining sites: management recommendations [Tese de Doutorado]. Alcalá de Henares: Universidad de Alcalá; 2019. Available at: <http://hdl.handle.net/10017/42708>.
- Rohrer, Z., Rebollo, S., Monteagudo, N. & Talabante, C. Eagle Owl presence and diet at mining sites: implications for restoration and management for cliff-nesting birds. *Restoration Ecology*. 2020; 28(6): 1541-1550.
doi: 10.1111/rec.13256
- Rover, T. D. & Persson, T. The concept of ecosystem services: Integrating the concept of ecosystem services on the environmental impact assessment of the Bunge Quarry [Master's Dissertation]. Uppsala: Uppsala University; 2014.

- Salgueiro, P. A., Silva, C., Silva, A., Sá, C. & Mira, A. Can quarries provide novel conditions for a bird of rocky habitats? *Restoration Ecology*. 2020; 28: 988-994.
doi: 10.1111/rec.13080
- Scotton, M. & Andreatta, D. Anti-erosion rehabilitation: effects of revegetation method and site traits on introduced and native plant cover and richness. *Science of the Total Environment*. 2021; 776: 145915.
doi: 10.1016/j.scitotenv.2021.145915
- Solera, M., Gallardo, A., Souza, C., Longo, M. & Braga, T. Bioengenharia de solos: aplicabilidade na recuperação de áreas mineradas e na oferta de serviços ambientais. *Brazilian Journal of Environmental Sciences (online)*. 2014; (34): 46-59. Available at: http://rbciamb.com.br/index.php/Publicacoes_RBCIAMB/article/view/216.
- Sonter, L. J., Barrett, D. J., Soares-Filho, B. S. & Moran, C. J. Global demand for steel drives extensive land-use change in Brazil's Iron Quadrangle. *Global Environmental Change*. 2014; 26: 63-72.
doi: 10.1111/cobi.12260
- Tsolaki-Fiaka, S., Bathrellos, G. & Skilodimou, H. Multi-criteria decision analysis for an abandoned quarry in the Evros Region (NE Greece). *Land*. 2018; 7(2): 43-63.
doi: 10.3390/land7020043
- Zhang, Q., Zhang, T. & Liu, X. Index system to evaluate the quarries ecological restoration. *Sustainability*. 2018; 10(3): 619.
doi: 10.3390/su10030619