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Articles

Diagnosis and strategies for water spring conservation or restoration in environments under anthropic pressure

Diagnóstico e estratégias para a conservação ou restauração de nascentes em ambientes com ações antrópicas

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ABSTRACT

The conservation and restoration of native vegetation around water springs is of the utmost importance to guarantee and maintain the quality and quantity of water resources, possessing a protective character under the legal premises of the new Brazilian Forest Code. In this context, this study aimed to diagnose and propose actions to preserve or restore native vegetation in the Permanent Preservation Areas (APPs) of ten springs located in environments under intense anthropogenic pressure (urbanization and mining) in the Córrego de Fechos watershed in Nova Lima - MG. The environmental diagnosis of the springs and their surroundings was based on several parameters such as land use, tree vegetation conservation status, natural regeneration, litter, the occurrence of invasive species, and soil conservation status. The best forest restoration alternatives were defined using the analytical key from Brancalion *et al.* (2015). Of the springs evaluated, 07 were classified as little disturbed, 02 as very disturbed, and only 01 as degraded, with no springs diagnosed as preserved. Concerning the restoration strategies, the natural regeneration and dense planting of native species in springs classified as little or very disturbed is indicated, with enrichment as an additional strategy for the very disturbed ones. For degraded springs, introducing native species in the whole area is recommended, with the need to use a high variability of species.

Keywords: Permanent Preservation Areas; Environmental degradation; Forest restoration

RESUMO

A conservação e restauração da vegetação nativa no entorno de nascentes são de suma importância para garantir e manter a qualidade e quantidade dos recursos hídricos, possuindo caráter protetivo nas premissas legais do novo Código Florestal Brasileiro. Neste contexto, objetivou-se neste estudo diagnosticar e propor ações de conservação ou restauração da vegetação nativa nas Áreas de Preservação Permanente (APPs) de dez nascentes localizadas em ambientes com intensa ação antrópica (urbanização e mineração) na microbacia do Córrego de Fechos em Nova Lima - MG. A partir de análises *in loco*, foi realizado o diagnóstico ambiental das nascentes e seu entorno, sendo este baseado em diversos parâmetros, tais como: formas de uso do solo, estado de conservação da vegetação arbórea, regeneração natural, serapilheira, ocorrência de invasoras e estado de conservação do solo. A definição das melhores alternativas de restauração florestal foi realizada a partir da aplicação da chave analítica de Brancalion *et al.* (2015). Dentre as nascentes avaliadas, 07 foram classificadas como pouco perturbadas, 02 como muito perturbadas e apenas 01 como degradada, não sendo registrada nenhuma nascente diagnosticada como conservada. Como estratégias de restauração, são indicados o favorecimento da regeneração natural de espécies nativas e o adensamento para aquelas nascentes classificadas como pouco ou muito perturbadas, sendo o enriquecimento indicado como uma estratégia adicional para as muito perturbadas. Quanto à nascente que se encontra degradada é indicada a introdução de espécies nativas em área total, com necessidade de uso de elevada riqueza de espécies.

Palavras-chave: Áreas de Preservação Permanente; Degradação ambiental; Restauração florestal

1 INTRODUCTION

The conservation and restoration of vegetation around springs are fundamental to guaranteeing and maintaining the water quality resources and flow regime, as well as soil stability, preventing silting of watercourses, and promoting the effectiveness of ecological corridors that guarantee biodiversity and local ecosystem maintenance.

According to the legal premises of the new Brazilian Forest Code, Law no. 12.651/2012 (BRASIL, 2012), Permanent Preservation Areas (APPs) are defined as protected areas, whether or not they are covered by native vegetation, to preserve water resources, the landscape, geological stability, and biodiversity, facilitating the gene flow of fauna and flora, as well as to conserve the soil and ensure the well-being of human populations. As indicated in item IV of Article 4 of the mentioned law, the APP of springs, whatever their topographical situation, corresponds to an area with a minimum radius of 50 meters.

The environmental degradation of spring APPs can occur for several reasons, including unplanned urbanization and the development of certain economic activities, such as farming, mining, industries, and urbanization, among others. These possible degradation factors can lead to disorderly occupation of environmentally sensitive areas, a rise in demand for natural resources, pollution, contamination of ecosystems, and loss of biodiversity.

In metropolitan regions or large urban centers, managing water resources is a never-ending challenge for public managers since they need to guarantee water supply adequately in quantity and quality. In this sense, reinforcing policies and actions aimed at the conservation or restoration of spring areas can ensure the maintenance of crucial ecosystem services, such as water supply and the regulation of the hydrological cycle for local or regional climate.

By carrying out diagnoses of spring areas, it is possible to identify their degradation status and thus assign the necessary management, conservation, or intervention actions. Landscape conservation and proper soil management in recharge areas are determining factors for springs' maintenance since those places guarantee the regularity of the water table and the quantity and quality of the water drained by the springs in a particular region (FELIPPE & JÚNIOR, 2009).

For didactic purposes, an analogy can be made between a degraded area and a patient who needs to be examined and diagnosed by the doctor/restoration agent so the therapies/restoration methods can be prescribed. Once the prescriptions have been applied, the doctor/restorer will monitor the patient/degraded area to assess whether the recommended treatment has been effective or whether new medications/ interventions will be needed to achieve the desired result (BRANCALION *et al.*, 2015).

Based on the above, this study aimed to diagnose and propose actions to preserve or restore native vegetation in spring APP environments under different anthropogenic pressures in the Córrego de Fechos watershed in Nova Lima - MG.

2 MATERIALS AND METHODS

The methodology used in this work began with the characterization of the study area, the Córrego de Fechos watershed, in the metropolitan region of Belo Horizonte. Based on the mapping of water springs in this region, a diagnosis protocol was applied to assess their conservation status and determine restoration strategies. The methodology employed an analytical key for choosing forest restoration methods based on the spring classifications.

2.1 Study area characterization

The Córrego de Fechos watershed is situated within the area of influence of the Fechos Ecological Station in the mid-western part of Minas Gerais state, within the limits of Nova Lima county in the metropolitan region of Belo Horizonte. It is a watershed belonging to the Velhas River basin, a strategic territorial unit (UTE) called Águas da Moeda UTE. UTEs are defined to facilitate actions and planning in the basins, which has an extensive area (CBH RIO DAS VELHAS, 2022).

The mentioned watershed covers an area of approximately 27.6 km², with a main watercourse running nearly 9.7 km to its mouth in the Macacos Stream. Within the boundaries of this watershed, various land uses and cover can be identified, such as mining activities, urbanized areas, and conservation units, namely the Fechos Ecological Station, the Environmental Protection Area of the Belo Horizonte Metropolitan Region (APA Sul RMBH) and the Serra do Rola Moça Park. It should be noted that in this region, water is collected to supply the population of Belo Horizonte, strategically functioning for the water security of the region's residents (EUCLYDES, 2011). This underground water collection accounts for around 8% of the RMBH agency's supply (COPASA, 2001).

2.2 Selection and mapping of springs

The Nova Lima region has several springs due to its geographical characteristics, and to identify and diagnose some of them, an in-loco visit was paid. One of the criteria used to select the springs assessed in this work was easy access to the areas with anthropogenic alterations (urbanization and mining) since there are few mapping studies for this spring region.

The springs were diagnosed according to the order in which they were mapped (N01 to N10, Table 1), classified as punctual or diffuse, and their geographical coordinates were recorded at the point closest to the spring centers. The geographical data obtained was spatialized using ArcGis 10.5 software.

Table 1 – Location of the inspected and diagnosed springs

Identification of springs	Location	Coordinates		Type of water spring
		South	West	
N01	Jardim Canadá/ Nova Lima - MG	20.051286666666666 S	43.99748333333335 W	Diffuse
N02	Jardim Canadá/ Nova Lima - MG	20.050766666666668 S	43.99745500000001W	Diffuse
N03	Road to Mineração Morro do Chapéu/ Nova Lima - MG	20.11282333333333 S	43.91556833333334 W	Punctual
N04	Presidente Juscelino Kubitschek Highway/ Nova Lima - MG	20.112381666666668 S	43.914984999999994W	Diffuse
N05	Road to Mineração Morro do Chapéu/ Nova Lima - MG	20.112540000000003 S	43.91501 W	Diffuse
N06	Road to Mineração Morro do Chapéu/ Nova Lima - MG	20.112395 S	43.914135 W	Punctual
N07	Presidente Juscelino Kubitschek Highway/ Nova Lima -MG	20.111850 S	43.913551 W	Diffuse
N08	Road to Mineração Morro do Chapéu/ Nova Lima - MG	20.11176 S	43.91274333333334 W	Punctual
N09	Presidente Juscelino Kubitschek Highway/ Nova Lima - MG	20.11347333333333 S	43.914376666666676 W	Punctual
N10	São Sebastião das Águas Claras/Nova Lima - MG	20.070716 S	43.89528 W	Punctual

Source: Authors (2022)

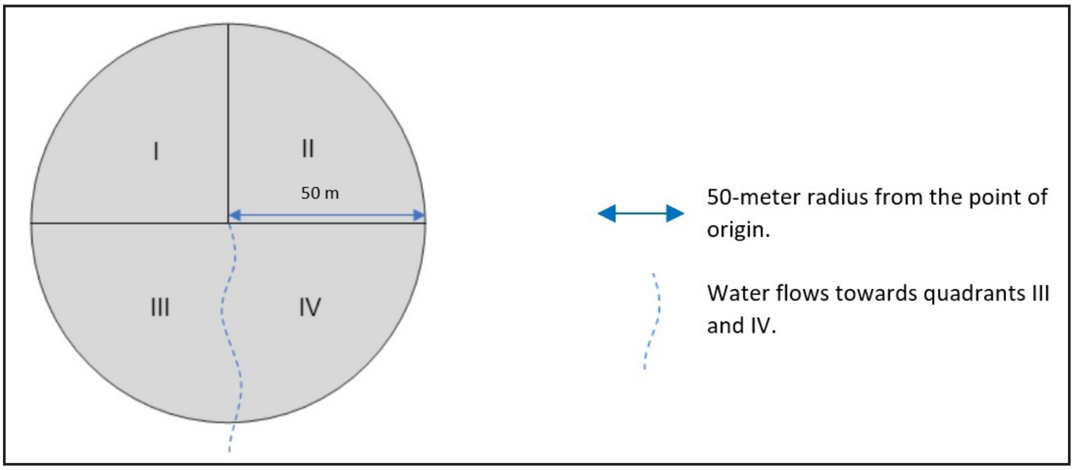
The Environmental Protection Area covers all the springs to the South of the Metropolitan Region of Belo Horizonte – APA Sul RMBH. Despite other conservation units, this area has been extensively altered by anthropogenic activity, consisting of built-up areas and several mining dams.

2.3 Diagnosis of springs

Initially, a script was used with the identification (ID), the geographical coordinates, the type of spring (point or diffuse), the date, and the agent responsible for the diagnosis (CASTRO; GOMES, 2001).

The spring APP was divided into 04 quadrants: I, II, III, and IV, according to the methodology proposed by Faria *et al.* (2012) and adapted by Andrade (2019), for an individualized assessment of each one. In the sketch, the spring was the center of the circumference, and the water flowed towards quadrants III and IV, as shown in Figure 1. This spring sketch was used in the field, and the delimitation of the APP area was made from a radius of 50 meters, as established by the New Forest Code (BRASIL, 2012).

Figure 1 – Quadrants I, II, III, and IV used in the water spring APPs for the diagnosis.



Source: Faria *et al*., 2012, adapted by Andrade, 2019

Regarding the diagnosis of the water springs, the protocol of Faria *et al.* (2012) was used, adapted by Andrade (2019), and the following parameters were assessed: Forms of land use, Conservation Status of the Arboreal Vegetation, Natural Regeneration, Litter, Occurrence of Invasive Plants, Conservation Status of the Soil and Relief (Table 2). In this evaluation protocol, each parameter has a weight, and each condition within the same parameter is assigned a corresponding score.

Table 2 – Parameters, scores, and weights used in the field form to characterize the conservation status of water springs

Parameters, scores, and weights used/assessed in the field form					
Identification	**Parameter**	**Classification**	**Scores**	**Descriptions**	**Weights**
A	Land use	Degraded	1	Area occupied by agricultural pasture with more than 10% exposed soil	0.35
		Very disturbed	3	Occupied area, predominantly (> 50%) crops	
			4	Occupied area, predominantly (> 50%) exotic grassland	
		Little disturbed	6	50 to 75% native vegetation	
			8	75 to 89% area occupied by native vegetation	
		Preserved	10	90% of the occupied area by native vegetation (forest, cerrado, or field)	
B	Tree Vegetation Conservation Status	Degraded	1	Characterized only by isolated tree shrubs or those that form a tree vegetation strip	0.15
		Very disturbed	4	Early succession stage: no canopy stratification; young tree, shrub, liana and pioneer individuals, average DBH < 10 cm, no epiphytes	
		Little disturbed	7	Medium stage of succession: formation of canopy and understory; canopy with average height between 5 and 12 m; average DBH of 10 to 18 cm; presence of epiphytes	
		Preserved	10	Advanced stage of succession: formation of canopy, sub-canopy and understory; canopy height greater than 12 meters; average DBH greater than 18 cm; presence of epiphytes	

To be continued ...

Table 2 – Conclusion

Parameters, scores, and weights used/assessed in the field form					
Identification	**Parameter**	**Classification**	**Scores**	**Descriptions**	**Weights**
C	Natural Regeneration	Degraded	1	There is no natural regeneration due to burning, mowing by the owner, trampling by cattle, etc.	0.15
		Very disturbed	5	Disturbed natural regeneration, compromising seed germination and reducing the number of small-sized individuals	
		Preserved	10	It has well-developed regeneration with individuals of different species varying between 0.5 and 3.0 m in height	
D	Litter	Degraded	1	Lack of litter	0.05
		Little disturbed	5	Partial presence of litter	
		Preserved	10	Presence of litter	
E	Invasive Plant Occurrence	Degraded	1	High density of invasive plants	0.05
		Little disturbed	5	Low density of invasive plants	
		Preserved	10	Lack of invasive plants	
F	Soil Conservation Status	Degraded	1	Areas where the soil is highly altered, unstable, lacking vegetation cover, and with the formation of deep furrows (> 0.5 m)	0.20
		Little disturbed	5	Areas where the soil is disturbed, with slight compaction evidence, well-defined furrows/tracks, the presence of gullies, and signs of potential degradation	
		Preserved	10	Areas where the soil is reasonably conserved, devoid of furrows, gullies and laminar erosion evidence.	
G	Land Relief	Degraded	1	Highly undulating terrain	0.05
		Little disturbed	5	Moderately undulating terrain	
		Preserved	10	Flat terrain (floodplain- várzea)	

Source: Adapted from Andrade (2019)

As shown in Figure 1, all the parameters were assessed for each quadrant. Considering the average score of the four quadrants evaluated, this value was multiplied by a weight, reflecting their degree of importance for the conservation of the springs, according to the formula below. Based on the PNi values, as showed in Equation (1), the springs were classified as conserved, little disturbed, very disturbed, or degraded based on the value ranges shown in Table 3.

$$PN_i = \sum Py_i \times Fy_i \tag{1}$$

Where: PN_i = Final score for spring I; Py_i = Score for parameter y of spring i; Fy_i = Weight of parameter y of spring i; y = Parameters A, B, C, D, E, F and G; i = 1 ... n.

Table 3 – Classification of the conservation status of the water spring surroundings, corresponding to the PNi interval regarding the final score for each spring

Classification	**PN_i value range**
Preserved	> 9
Little disturbed	7 a 8,9
Very disturbed	5 a 6,9
Degraded	< 5

Source: Faria *et al*., 2012, adapted by Andrade, 2019

The water recharge areas were assessed in the general context of landscape, type of relief, conservation status, and land use, but no scores were given.

2.5 Key to choosing forest restoration methods

After classifying the water spring conservation status, a diagnosis was applied using the analytical key for choosing forest restoration methods, according to Brancalion *et al.* (2015). Table 4 shows that each item analyzed in the diagnosis possesses alternatives that will lead to a subsequent item until the final indication of the restoration method is adopted.

Table 4 – Application of the key to define the forest restoration method to be considered according to the scenario found in the field during the diagnosis

Diagnosis	
D 1. Degradation factors	
D1.1 Fires	goes to *item A1.1*
D1.2 Livestock use	goes to *item A1.2*
D1.3 Agricultural use	goes to *item A1.3*
D1.4 Use for commercial forestry	goes to *item D3*
D1.5 Flood discharge	goes to *item A1.4*
D1.6 Mining	goes to item A1.5
D1.7 Predatory exploitation of fauna and flora	goes to *item A1.6*
D 2. Soil conditions	
D2.1 Non-degraded soil	goes to *item D4*
D2.2 Degraded soil	goes to *item A2*
D 3. Natural regeneration in the understory of commercial tree species stands	
D3.1 Low or nil, regardless of the area's relief	*goes to item A3.1*
D3.2 Moderate, on smooth undulating terrain	goes to *item A3.2*
D3.3 Moderate, in areas of rugged terrain	goes to *item A3.3*
D3.4 High, regardless of the area's relief	goes to *item A3.3*
D.4 Regeneration community of native species and isolation of the landscape area	
D4.1 High density of various regeneration species, in isolated areas or not in the landscape	goes to *item A4*
D4.2 High density of a few regeneration species, in area not isolated in the landscape	goes to *item A4.1*
D4.3 High density of a few regeneration species in an isolated area in the landscape	goes to *item A4.2*
D4.4 Moderate density of many regeneration species, in an area not isolated in the landscape	goes to *item A4.3*
D4.5 Moderate density of a few regeneration species, in an isolated area in the landscape	goes to *item A4.4*
D4.6 Low or no density of regeneration plants, in an area not isolated in the landscape	goes to *item A4.5*
D4.7 Low or no density of regeneration plants, in an isolated area in the landscape	goes to *item A4.6*
D.5 Degradation status of forest fragments	
D5.1 Preserved fragments	goes to *item A5.1*
D5.2 Fragments that could be restored	goes to *item A5.2*
D5.3 Fragments in need of restoration	goes to *item A5.3*

To be continued ...

Table 4 – Conclusion

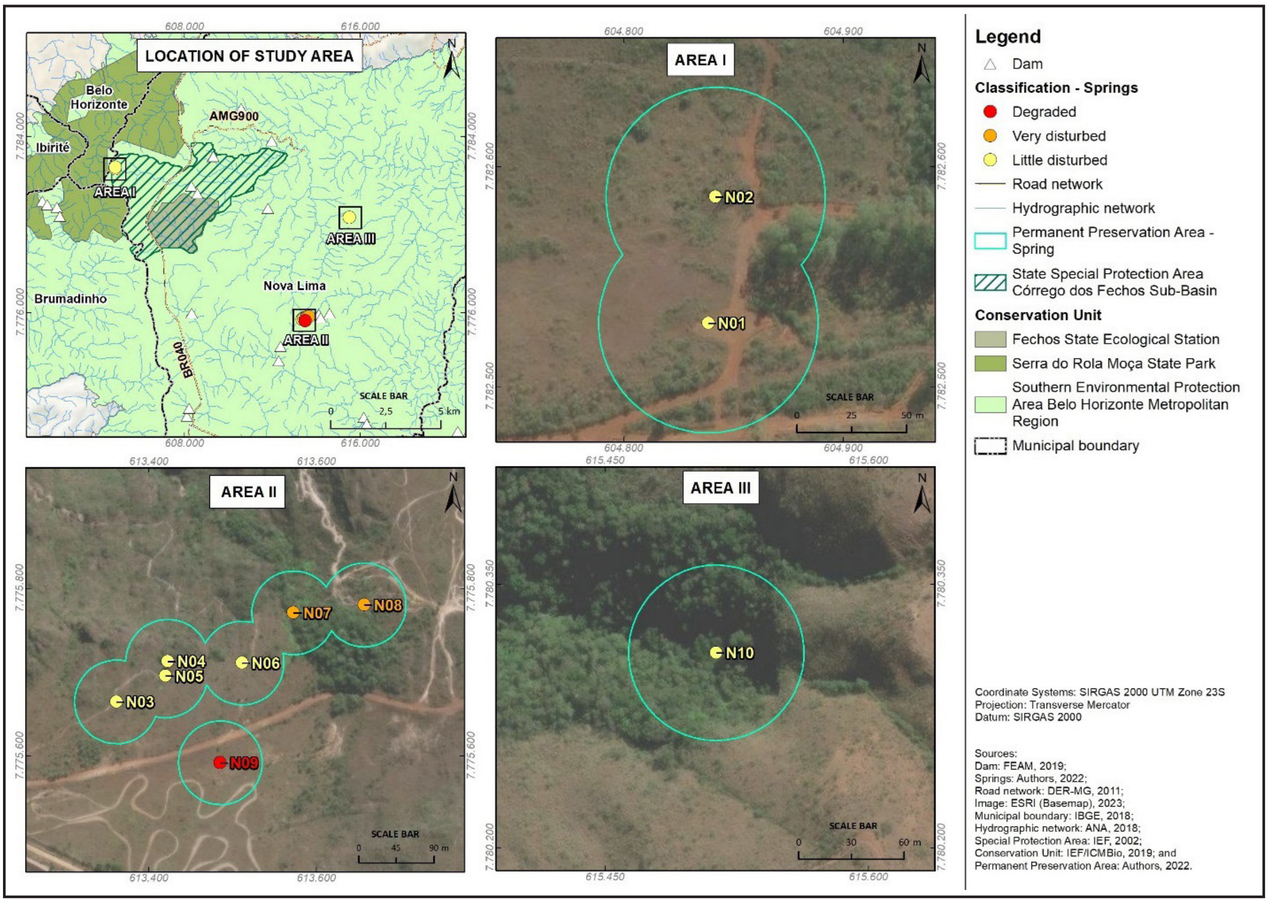
RESTORATION ACTIONS	
A1. Isolating degradation factors	
A1.1 Fire protection measures	goes to item D2, in the case of areas in use or abandoned, or D5, in the case of forest remnants
A1.2 End of livestock use	goes to item D2, in the case of areas in use or abandoned, or D5, in the case of forest remnants
A1.3 End of agricultural use	goes to item D2
A1.4 Adoption of soil conservation practices in surrounding agricultural areas	goes to item D2, in the case of areas in use or abandoned, or D5, in the case of forest remnants
A1.5 End of mining use	goes to item D2
A1.6 Nature protection program	goes to item D5
A2. Soil restoration	goes to *item D4*
A3. Removal of commercial tree species stands	
A3.1 Traditional wood harvesting	*goes to item D4*
A3.2 Low impact harvesting	goes to *item D4*
A3.3 Death of standing trees	goes to *item D4*
A4. Restoration method	
A4.1 Promoting the natural regeneration of native species	
A4.2 Promoting the natural regeneration of native species and enrichment	
A4.3 Promoting the natural regeneration and dense planting of native species	
A4.4 Promoting the natural regeneration, dense planting and enrichment of native species	
A4.5 Introduction of native species in a total area, without the need to use a high diversity of species	
A4.6 Introduction of native species in a total area, with the need to use a high diversity of species	
A5. Management of degraded forest fragments	
A5.1 Expanding the role of biodiversity conservation	
A5.2 Expanding the role of biodiversity conservation and accelerating secondary succession	
A5.3 Expanding the role of biodiversity conservation and restoration of degraded fragments	

Source: Adapted from Brancalion *et al*. (2015)

3 RESULTS AND DISCUSSIONS

Of the 10 springs assessed, 07 were classified as little disturbed, 02 as very disturbed, and only 01 as degraded. None of the springs were classified as conserved (Figure 2 and Table 5). The different parameters that resulted in these classifications are contextualized below, as are the indications of conservation or restoration strategies based on the application of the analytical key by Brancalion *et al.* (2015).

Figure 2 – Location of the springs diagnosed in the study area and their scope in Nova Lima County - MG



Source: Authors (2022)

Table 5 – Final score, classification, and restoration strategies by applying the analytical key for the springs assessed from the on-site diagnosis

Diagnosis of water spring apps			
Identification of the spring	**Final score**	**Classification**	**Restoration strategy with the application of the analytical key**
N01	7.65	LITTLE DISTURBED	A4.3 Promoting the natural regeneration and dense planting of native species
N02	7.47	LITTLE DISTURBED	A4.3 Promoting the natural regeneration and dense planting of native species
N03	8.10	LITTLE DISTURBED	A4.3 Promoting the natural regeneration and dense planting of native species
N04	8.10	LITTLE DISTURBED	A4.3 Promoting the natural regeneration and dense planting of native species
N05	8.10	LITTLE DISTURBED	A4.3 Promoting the natural regeneration and dense planting of native species
N06	8.10	LITTLE DISTURBED	A4.3 Promoting the natural regeneration and dense planting of native species
N07	5.07	VERY DISTURBED	A4.4 Promoting the natural regeneration, dense planting and enrichment of native species
N08	6.10	VERY DISTURBED	A4.4 Promoting the natural regeneration, dense planting and enrichment of native species
N09	4.30	DEGRADED	A4.6 Introduction of native species in the total used area with a high diversity of species
N10	8.20	LITTLE DISTURBED	A4.3 Promoting the natural regeneration and dense planting of native species

Source: Authors (2022)

The term “disturbed” refers to areas subject to diverse interferences that can become degraded over time. In the case of springs, this term is used when there is native vegetation in their surroundings, but they are inserted in environments with some factors that could compromise their conservation status in the future (PINTO, 2005).

When the diagnosis was applied, it was observed that the springs classified as “little disturbed” were of the punctual (N03, N06, N10) or diffuse (N01, N02, N04, N05) type. Regarding land use, the areas surrounding these springs have 50% or more of their area occupied by exotic pasture, where the molasses grass, *Melinis minutiflora* P.Beauv. (Poaceae), is predominant. Due to its rapid growth and extensive ground cover, this invasive grass hinders native species, de-characterizing the local phytophysiognomy and compromising biodiversity (MARTINS *et al.*, 2004).

The conservation status of the tree vegetation around these springs is characterized by an early stage of succession, where there is no canopy stratification with young tree shrubs and no epiphytes, which could be compromised in the future if the strategies for restoring the springs are not implemented (CALMON, 2021).

In the areas where these springs are located, natural regeneration is compromised, which can affect seed germination and reduce the tree species' seedling recruitment precisely because of the *M. minutiflora* presence - a factor that hinders succession. This and other invasive grasses, such as *Urochloa humidicola* (Rendle) Morrone & Zuloaga (Signalgrass - Brachiaria), and *Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs (Guinea grass), both Poaceae, are the biggest obstacles to the success of reforestation projects (GONÇALVES *et al.*, 2021).

The springs classified as little disturbed are found in areas whose relief is moderately undulating, with the soil in a good conservation state, devoid of any erosion process, meaning positive evidence from the point of view of the spring conservation since erosion is responsible for silting up watercourses and springs (BRANCALION *et al.*, 2015). Springs in favorable conservation states should be free from furrows, gullies, and signs of soil movement (FARIA *et al.*, 2012).

The recharge areas of all water springs assessed in the context of the landscape have vegetation cover along their entire length, guaranteeing regularity of the water table and quantity and quality of the water drained into the region's springs. A vegetation cover in the recharge areas represents a greater chance of water infiltrating the soil and maintaining these springs. The lack of vegetation cover implies increased surface runoff with higher chances of these outcrops disappearing (OLIVEIRA *et al.*, 2014).

The strategy for restoring these springs is to promote natural regeneration and density of these native species (code A4.3), according to the key applied (BRANCALION *et al.*, 2015). To arrive at this indication for restoring the areas, the situation in which the source of mining degradation ceases (code D1.6) in soils with a non-degraded condition (code D2) and with a moderate density of many regeneration species (code D4.4) is considered. It should be noticed that the first item in the "Degradation factors" key (D1) refers to any anthropogenic activity that could result in negative impacts on the remaining fragments and the areas targeted for restoration.

Promoting natural regeneration in the area can be done with or without management. In the case of an area where invasives are present, natural regeneration must be carried out by adopting specific actions to induce and facilitate the triggering of that process. Besides, weeding competing plants around the regeneration ones, controlling lianas and invasive exotic trees, fertilizing the regeneration plants, controlling leaf-cutting ants in the area, and soil decompaction are strategies that guarantee the regeneration advance in the area (BRANCALION *et al.*, 2015; GONÇALVES *et al.*, 2021).

The dense planting indicated by the analytical key can ensure that early successional species are introduced into the area in spaces where regeneration has not occurred (EMBRAPA, 2022) by planting or sowing species from the filling group (BRANCALION *et al.*, 2015). Dense planting consists of increasing the plant population per unit area. Usually, more than a thousand plants are planted per hectare, with a high species diversity (VILLA *et al.*, 2016). The spacing used for dense planting is generally 3 m × 3 m, and 2 m × 2 m or 3 m × 2 m can be used, depending on local needs (SILVA, 2022b).

Two springs were classified as very disturbed: N07 (diffuse type) and N08 (punctual type), with final scores of 5.07 and 6.10, respectively. Concerning these springs, there was a predominance of exotic pasture (*M. minutiflora*) in the surrounding areas, as in the little disturbed springs. The tree vegetation in these spring APPs is at a medium stage of succession, characterized by forming a canopy (average height of 05 m and DBH of nearly 10 cm) and bearing epiphytes.

The molasses grass invasion represents an obstacle to the ecosystem functioning and biological diversity that makes it up (PYŠEK *et al.*, 2020). It should be noted that the presence of this invasive grass in the area can interfere with the evolution of succession and compromise the entire ecosystem (MARTINS *et al.*, 2004; DAMASCENO *et al*., 2018).

Natural regeneration in the N07 and N08 spring APPs is compromised, negatively interfering with seed germination and the quantity of small regeneration plants, with no litter in the area. These parameters indicate that the area is not progressing along the forest restoration path and that interventions are needed to make this happen.

The terrain of these areas is classified as highly undulating, and soil conservation status is disturbed, with evidence of slight compaction and well-defined furrows/tracks with potential for degradation. It can be realized that the area is used for sports by hikers. Although the trails are practiced in public areas (in this case, areas that cover the APA Sul RMBH conservation unit), many studies point out that visiting these places can cause environmental impacts and lead to soil degradation due principally to erosion and compaction (SILVA; BOTELHO, 2021).

Applying the analytical key suggests promoting the natural regeneration, dense planting, and enrichment of native species as restoration strategies (Code A4.4). The indication of the area restoration points to the end of mining (code A1.5) with degraded soils (code D2.2) that need recovery (Code A.2). In addition, the area has a moderate density of few regeneration species (code D4.4), which makes the strategy to be adopted even more decisive.

Enrichment becomes an additional strategy compared to the one related to restoring little disturbed springs. In the case of N07 and N08 springs, which are very disturbed, regeneration is predominantly made up of species at a medium stage of succession. The applied enrichment strategy will allow the introduction of later-stage species, thus facilitating the forest's sustainability trajectory (ISERNHAGEN *et al.*, 2009).

In enrichment, the planting or sowing of native species should be carried out with the diversity group, also known as the non-pioneer group, amid the regenerative vegetation and the areas where dense planting has been carried out. Tree species, shrubs, and other life forms attractive to fauna are recommended to speed up the restoration trajectory and process. Enrichment can be carried out at a spacing of 6 m × 3 m, which can be altered according to local needs (SILVA, 2022b).

Only spring N09 (diffuse type) was classified as degraded, with a final score of 4.30 points. A "degraded" area implies a disruption in the balance of a stable environment that has reached a level where spontaneous restoration is impossible, becoming almost unfeasible without human interference to reverse the degradation processes (SILVA, 2022a).

The APP of spring N09 is located in a moderately undulating terrain, predominantly occupied by the exotic pasture of species M. minutiflora, which has hindered the start/advance of succession. In addition, the water that flows from this diffuse spring intercepts the edge of a road with heavy vehicle traffic leading to the mining area. Associated with this, and with contributions from the moderately undulating terrain, it is possible to observe the very prominent furrows and gullies in the soil as being the preferred flow path of this spring.

Given the evident environmental degradation in the area (mainly the landscape fragmentation), applying the key suggests introducing native species in a total area as a restoration strategy, with the need to use a high diversity of species (Code A4.6). Holistically, in the context of the landscape in which spring N09 is located, it is possible to notice the isolation of this APP from the remaining forest, which makes it more difficult for propagules and seeds to reach the area. In these cases, full-area planting through active restoration is essential since the expression of natural regeneration is almost nil, and secondary succession processes do not occur.

Total area planting can be done in two ways: staggered or not. Non-staggered possesses rows of pioneers and non-pioneers, based on the premise that the pioneer species will provide shade for the non-pioneer species, which will replace them throughout the succession process. The most common spacings for this kind of planting are 3.0 m × 2.0 m and 2.0 m × 2.0 m. It is possible to plant different combinations of ecological groups in diverse arrangements and proportions in the field (SILVA, 2022b).

Staggered planting takes place in two stages by combining species in a planting group (covering and diversity) but in different phases (staggered) (BRANCALION *et al.*, 2015). This planting methodology follows the model described by Brancalion *et al.* (2009), characterized by planting in rows of covering and diversity. Initially, fast-growing species are planted/sowed between the rows, employing species used as green manure that will allow the soil to be effectively covered, reducing the care with invasive grasses. After a year, the area is enriched by planting seedlings belonging to an ample number of species, considering the diversity and structure desired in future reforestation (NAVE *et al.*, 2015).

4 CONCLUSIONS

In all APPs of the springs diagnosed, it was possible to observe how anthropic actions negatively interfere with the composition and structure of the vegetation, compromising, among other things, soil conservation, maintenance of water resource quality, the water flow regime, and biodiversity. The presence of molasses grass (capim gordura) (*M. minutiflora*) in all APPs is a barrier to ecological succession since its invasive potential hinders seed germination and compromises the growth of native species.

Restoration strategies varied according to the environmental characteristics of each APP analyzed, with the promotion of natural regeneration and dense planting of native species indicated for those classified as little or very disturbed; regarding the latter, enrichment was also strongly recommended as an additional strategy. Concerning the APP diagnosed as degraded, total planting was recommended, with the need to use an ample diversity of species.

For all the situations encountered: little disturbed, very disturbed, and degraded springs, isolating the area is essential for the success of forest restoration in these areas. This is done by fencing off the area, preventing animals from accessing the APPs and contaminating the water. In addition, building up firebreaks is another positive action during the restoration process, guaranteeing the maintenance of plantations or even the advance of regeneration plants in the area.

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