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# A buried umbrella: historical changes in the landscape surrounding the habitats of threatened troglobitic isopods in Brazil

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**ABSTRACT:** Impacts on karst environments exert particularly severe effects on species restricted to subterranean habitats (troglobites), as disturbances in surface ecosystems are typically transmitted to subsurface compartments. Given the high habitat specificity of these organisms and the extensive alteration of epigean environments, we investigated the potential impacts and pressures affecting 17 troglobitic isopod species of *Spelunconiscus*, all endemic to the Arcos-Pains-Doresópolis speleological province in southeastern Brazil. To assess temporal landscape changes surrounding the caves inhabited by these species, we delineated 14 drainage areas using the ottobasin methodology. These areas were analyzed based on land-use and land-cover maps derived from Landsat satellite images for the years 1984 and 2019. Subsequently, we ranked the ottobasins according to the degree of anthropogenic impact to guide conservation and management priorities. Among the 14 areas evaluated, 11 exhibited an increase in native vegetation cover. Nevertheless, expansions of mining, agriculture, and silviculture were also detected. The most intense impacts occurred in the upstream sectors of the ottobasins, which exert greater influence on the subterranean environment due to their hydrological connectivity with the caves. The Eden cave ottobasin emerged as the most threatened, combining intense anthropogenic pressure with the highest diversity of endemic troglobites. Prioritizing the protection and conservation of the five most impacted ottobasins would safeguard approximately 60.5% of the troglobitic species recorded in these areas, corresponding to 46% of all troglobitic species in the province. In contrast, extending protection to all 14 ottobasins would ensure the preservation of 76% of the province's troglobitic fauna.
**Key words:** land use, *Spelunconiscus*, mining, cave, umbrella species.

## 1. INTRODUCTION

Karst areas cover approximately 20% of the Earth's surface and include distinctive landforms such as dolines, blind valleys, sinkholes, and caves (FORD; WILLIAMS, 2007; GOLDSCHEIDER *et al.*, 2020). These systems are defined by the high solubility of their rocks and drainage patterns that frequently involve subterranean flows (JENNINGS, 1971). As a result, karst landscapes are particularly vulnerable, given their geological attributes that facilitate direct

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hydrological connectivity between surface and subterranean ecosystems (GUTIÉRREZ et al., 2014).

Anthropogenic disturbances in karst areas are especially concerning because pollutants and environmental changes can be rapidly transmitted through permeable rock, often reaching areas distant from their source. This dissemination occurs primarily through subterranean hydrological processes, which are less visible and difficult to monitor directly. Consequently, by the time impacts become evident, ecosystem alterations are typically at an advanced stage (FORD; WILLIAMS, 2007). The main drivers of change in karst landscapes are associated with land-use modifications, particularly urbanization, mining, deforestation, silviculture, agriculture, and livestock activities (VAN BEYNEN, 2012). Such activities impose severe environmental pressures that, in turn, negatively affect local biodiversity.

When pollutants reach subterranean habitats, they frequently alter species' richness and community composition, as caves are fragile ecosystems that often shelter threatened species, many of which are endemic to a single cave (CULVER; PIPAN, 2019). These alterations are particularly alarming because cave fauna play key ecological roles, such as maintaining water quality and supporting groundwater-dependent ecosystems (e.g., rivers and springs). Moreover, groundwater organisms are adapted to resource-limited and environmentally stable habitats, which makes them highly sensitive to anthropogenic disturbances (GRIEBLER; AVRAMOV, 2014). Due to these characteristics, subterranean species are increasingly recognized as promising bioindicators for environmental assessment and management (GRIEBLER et al., 2010).

The Karst Province of Alto São Francisco (KASP), located in southeastern lime and cement industries Brazil, contains the highest cave density in South America, with 2,503 registered caves (CECAV, 2021). However, this number is likely underestimated, as large portions of the region remain unexplored. Despite its outstanding speleological and biological significance, the KASP province is subject to multiple anthropogenic pressures, including limestone mining, lime and cement industries, groundwater extraction for industrial and domestic use, agricultural expansion, pasture establishment with consequent suppression of native vegetation, as well as the installation of cemeteries, solid waste disposal sites, and other contaminating activities (CAVALCANTI et al., 2012). Although the province harbors a remarkable diversity of troglobitic species, many remain undescribed (ZAMPAULO, 2010). Unfortunately, the exceptional biological richness and speleological importance of the area have not prevented increasing threats from intense human activities.

Among the cave-restricted taxa in the KASP province, isopods of the genus *Spelunconiscus* (Styloniscidae) stand out as potential models for the conservation of subterranean biodiversity. These groundwater-dependent organisms have restricted distributions and are therefore highly susceptible to anthropogenic impacts. Notably, the 17 caves in which *Spelunconiscus* occurs encompass 76% of all troglobitic species known from the KASP province. Given their ecological characteristics, these isopods can be regarded as umbrella species, since protecting them would also ensure the conservation of numerous co-occurring taxa (ROBERGE; ANGELSTAM, 2004). According to Lambeck (1997), the umbrella species concept is based on the premise that the ecological requirements of highly demanding species also encompass those of less demanding ones.

In this context, the present study evaluates temporal changes in land use and land cover surrounding caves harboring *Spelunconiscus* populations in the KASP speleological province. Additionally, we propose a ranking of conservation priorities based on the degree of anthropogenic impact within these areas. By assessing land-use dynamics and their potential implications for

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subterranean ecosystems, this study provides insights into the conservation status of caves in this karst region. The findings aim to support decision-making and guide management strategies to safeguard cave-restricted species, many of which face imminent risk of extinction.

## 2. METHODOLOGY

### *2.1 Study area*

The São Francisco River basin comprises a region where approximately 40% of the caves in the Brazilian territory are found (ICMBIO, 2020). The study area is located in the subbasin of tributaries of the Upper São Francisco River in the state of Minas Gerais, where approximately 54% of the caves in the São Francisco basin are concentrated (Cavalcanti et al., 2012), and covers part of the municipalities of Arcos, Córrego Fundo, Doresópolis, Formiga, Pains and Piumhi (Figure 1).

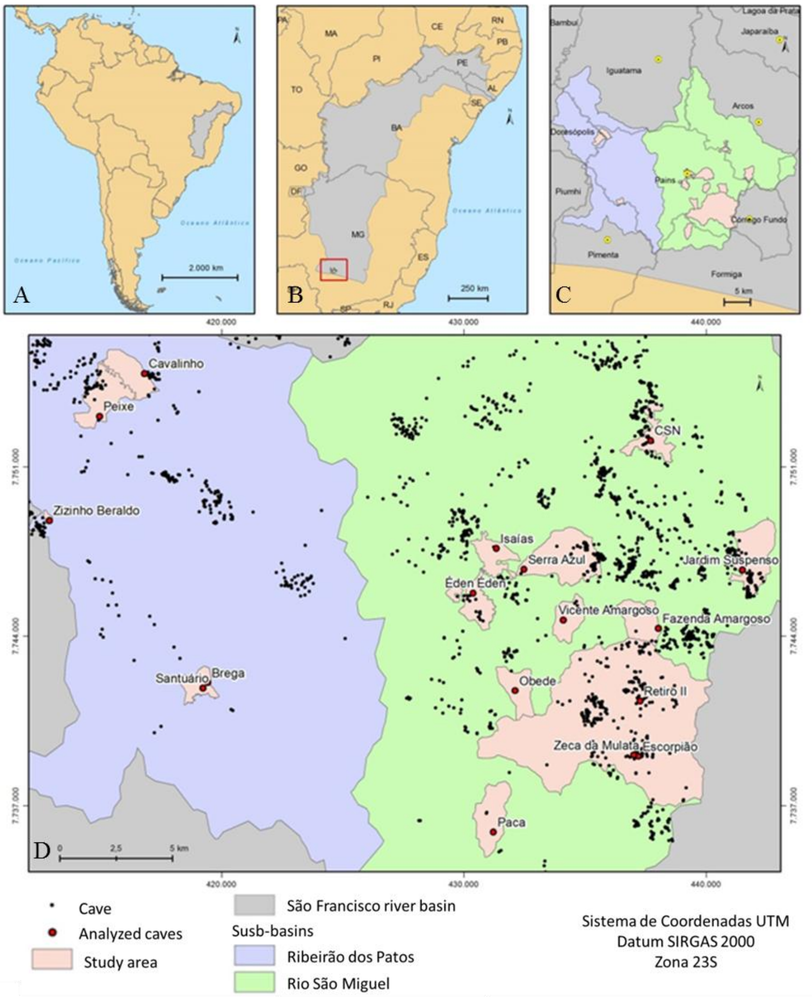


*Figure 1. A and B) Location of the São Francisco River basin in Brazil and Minas Gerais. C) São Miguel and Ribeirão dos Patos river basins and ottobasins studied. D) Location of the ottobasins and distribution of the caves in the speleological province.*

The caves considered in this study are those harboring populations of *Spelunconiscus* (Figure 2) within the Arcos-Pains-Doresópolis speleological province. All are situated in the São Miguel and Ribeirão dos Patos basins (Figure 1), tributaries on the right margin of the São Francisco River, where karst relief is well developed at both endokarst and exokarst levels. The analyzed region

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encompasses 14 areas surrounding 17 caves (Table 1), located within a karst landscape whose geomorphological compartmentalization includes fluvial plains, limestone outcrops, mountain ranges, and heterogeneous plateaus (MARTINS; RODRIGUES, 2016).

The local hydrographic network is relatively incipient due to the predominance of direct infiltration through limestone fissures and karst absorption features such as sinkholes (MENEGASSE et al., 2002). The regional vegetation is typical of the Cerrado biome (Brazilian savanna), which presents a continuum ranging from shrub-free grasslands (*campo limpo*) to denser arboreal formations, including deciduous and semideciduous seasonal forests, particularly associated with the bases of rocky outcrops (MELO et al., 2013; MENEGASSE et al., 2002).

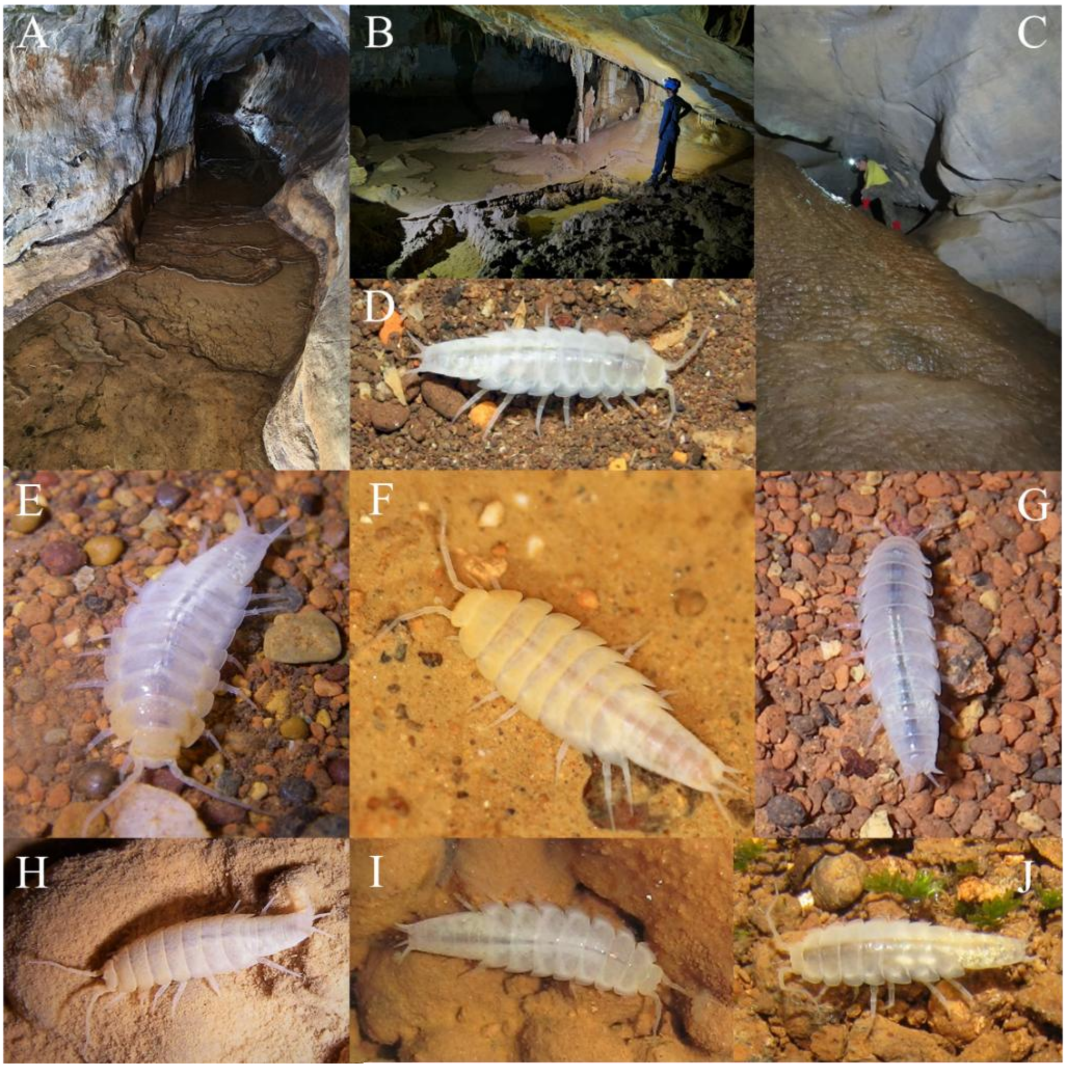


*Figure 2. Some species of Spelunconiscus (Isopoda: Styloniscidae) found in the studies caves: A) Microhabitat of Spelunconiscus sp. in Escorpião cave; B) Microhabitat of Spelunconiscus sp. in Santuário cave; C) Microhabitat of Spelunconiscus sp. in Brega cave; D-J) distinct species of Spelunconiscus sp found in the area.*

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*Table 1: Identification and geographic location of the caves included in the study area, with respective municipalities, geographic coordinates (latitude and longitude in degrees, minutes, and seconds; converted from SIRGAS 2000 / UTM), and altitude above sea level.*

| Caves | City | Latitude (S) | Longitude (W) | Altitude (m) |
|---|---|---|---|---|
| Brega | Pains | 20° 25' 23.81" | 45° 39' 19.41" | 708 |
| Cavalinho | Pains | 20° 33' 01.71" | 45° 40' 38.26" | 685 |
| CSN | Pains | 20° 30' 57.14" | 45° 27' 37.10" | 767 |
| Éden | Pains | 20° 27' 39.79" | 45° 31' 38.88" | 709 |
| Escorpião Cave | Pains | 20° 21' 16.24" | 45° 27' 46.39" | 822 |
| Fazenda Amargoso | Pains | 20° 26' 04.48" | 45° 26' 56.75" | 847 |
| Isaías | Pains | 20° 28' 53.42" | 45° 30' 34.82" | 732 |
| Jardim Suspenso | Arcos | 20° 28' 09.72" | 45° 25' 56.34" | 896 |
| Obede | Pains | 20° 24' 55.74" | 45° 29' 59.03" | 726 |
| Paca | Formiga | 20° 22' 26.16" | 45° 31' 00.84" | 772 |
| Peixe | Doresópolis | 20° 31' 43.26" | 45° 42' 16.66" | 697 |
| Retiro II | Pains | 20° 24' 17.95" | 45° 27' 44.77" | 811 |
| Santuário | Pains | 20° 25' 12.84" | 45° 39' 29.22" | 702 |
| Serra Azul | Pains | 20° 28' 13.68" | 45° 29' 39.20" | 771 |
| Vicente Amargoso | Pains | 20° 26' 39.43" | 45° 28' 47.83" | 794 |
| Zeca da Mulata | Pains | 20° 21' 20.60" | 45° 27' 58.77" | 837 |
| Zizinho Beraldo | Pains | 20° 29' 59.42" | 45° 44' 32.43" | 680 |

### *2.2 Delimitation of the surrounding areas*

To account for the interaction between ecological attributes of the areas surrounding the caves, we adopted the use of ottobasins (LUIZ; FARIA, 2013) to define their perimeters, as an alternative to the fixed 250-meter buffer established by current Brazilian speleological legislation (CONAMA, 2004). Because more than one cave may occur within the same ottobasin, certain regions encompassed two or three caves, as in the cases of the Santuário–Brega and Retiro II–Zeca da Mulata–Escorpião groups.

The delimitation of ottobasins was based on the spatial overlap of cave coordinates (Table 1) with the vector database provided by the Minas Gerais Institute of Water Management (IGAM, 2019). In a GIS environment, the selected polygons were subdivided to include only the slope where the caves were located. For ottobasins lacking active surface drainage that would allow subdivision by slope, the entire ottobasin was considered the study area. To evaluate the influence of anthropogenic activities, we also incorporated urbanized and mining areas intersecting the ottobasin polygons, provided these areas were located upstream of the caves.

### *2.3 Changes in the landscape*

The analysis of the landscape surrounding the caves was conducted in a GIS environment following the methodology of Gomes et al. (2019), adapted for the objectives of this study. Vegetation cover and land-use maps were generated using Landsat orbit–point 219-074 images acquired by the Thematic Mapper (TM, 06/13/1984) and the Operational Land Imager (OLI, 08/01/2019). The classification legend was based on the *Manual Técnico de Uso da Terra* (IBGE, 2013) and included the following classes: Water, Urban Areas, Mining Areas, Cropland–Pastureland, Forestry, Forestland, and Grassland. Image classification was performed in Spring (INPE, 2001) using supervised region-growing with the Bhattacharya classifier and a 99% acceptance threshold. Post-classification procedures were carried out in ArcGIS, where raster data

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were converted into vector format and validated through field surveys, high-resolution imagery (GOOGLE, 2013), and orthoimages.

The reliability of the land-use and vegetation cover maps was tested using the Kappa index. Forty random points were generated per ottobasin in ArcGIS, which were validated through field observations and Google Earth imagery. A confusion matrix was constructed, from which the Kappa coefficient was calculated according to Congalton and Green (2019), as follows:

$$K = \frac{n \sum_{i=1}^{C} x_{ii} - \sum_{i=1}^{C} x_{i+} x_{i}}{n^{2} - \sum_{i=1}^{C} x_{ii}}$$

where $K$ is the Kappa coefficient; xiix_{ii}xii is the value in row $i$ and column $i$; xi+x_{i+}xi+ is the sum of row $i$; x+ix_{+i}x+i is the sum of column $i$; $n$ is the total number of samples; and $c$ is the total number of classes.

To evaluate changes in landscape structure relative to cave position (upstream vs. downstream), we used Alos Palsar radar images (JAXA/METI, 2011), processed in ArcGIS with the surface/contour tool to generate contour lines used for geomorphological compartmentalization. To increase accuracy, Alos Palsar data were integrated with land-use maps using the ArcGIS Zonal Statistics tool, allowing extraction of class-level statistics (pixel by pixel). Landscape metrics were then derived from the V-LATE 2.0 beta extension (Vector-based Landscape Analysis Tools), including number of patches (NP), class area (CA), average class size (ACS), standard deviation of patch size (SDPS), and mean shape index (MSI).

Vegetation-cover change from 1984 to 2019 was further evaluated using the annual deforestation rate (ADRR) proposed by de Barros Ferraz et al. (2009):

$$\text{ADRR} = \left(\frac{MF_n}{MF_1}\right)^{1/(Y_n - Y_1)} - 1$$

where $MF_n$ is the extent of mature forest in year $n$ (ha), $MF_1$ the extent of mature forest in year 1, $Y_n$ the final year, and $Y_1$ the initial year, with results expressed as % $yr^{-1}$.

To assess the impacts of mining activities, recognized as one of the most severe and irreversible threats to caves (BRASIL, 2008), we performed a spatial analysis of mining concessions recorded in the National Mining Agency (ANM, 2021) database and their overlap with the study areas.

*2.4 Ranking conservation efforts*

To establish conservation priorities for subterranean biodiversity, the ottobasins were categorized based on potentially impacting land uses (Table 2), using the disturbance index proposed by Van Beynen (2005) as a reference. Land-use impacts were classified according to their percentage of spatial occupation within each ottobasin. Additionally, upstream impacts were assigned higher weights, given their disproportionately greater influence on downstream subterranean habitats.

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Revista Brasileira de Espeleologia – RBEsp

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*Table. 2. Indicators used to classify the potentially impacting land use and occupation of the ottobasins.*

| **Land use and occupation** | **Classes of use** | | | **Upstream impact** | | | |
|---|---|---|---|---|---|---|---|
| **Indicator** | **3** | **2** | **1** | **0** | **3** | **2** | **1** |
| % of area occupied by mining | >66% | 34–66% | -33% | None | >20% | 10-20% | 1-10% |
| % of area occupied by urbanization | >66% | 34–66% | -33% | None | >20% | 10-20% | 1-10% |
| % of area occupied by agriculture and livestock | >66% | 34–66% | -33% | None | >20% | 10-20% | 1-10% |
| % of area occupied by forestry | >66% | 34–66% | -33% | None | >20% | 10-20% | 1-10% |

## 3. RESULTS

Over the analyzed period (1984–2019), there was a general reduction in areas allocated to agricultural activities, accompanied by increases in forest cover, mining, forestry, and urbanization (Table 3). Although mining occupied a relatively small percentage of some ottobasins, its absolute extent reached more than 75 ha in Jardim Suspenso, indicating a high level of impact.

The most pronounced negative changes were observed in the Jardim Suspenso and Retiro II–Zeca da Mulata–Escorpião ottobasins, where mining and forestry expanded considerably (Table 3). Land-use maps (Figures 3–7) highlighted shifts across all land-use and vegetation-cover classes. In the Zizinho Beraldo, CSN, and Fazenda Amargoso areas, forest regeneration declined, whereas in most other areas this class showed an increase. Overall, negative land-use changes were more evident upstream than downstream (Supplementary Material 1).

The highest annual deforestation rates were recorded in Fazenda Amargoso, followed by CSN and Zizinho Beraldo (Table 4). In these ottobasins, the principal drivers of deforestation were forestry, mining, and cropland/pastureland, respectively. According to the classification proposed by Figueiredo and Vieira (2007), the accuracy of the land-use and vegetation maps, assessed using the Kappa index, ranged from “excellent” ($0.8 < K \leq 1.0$) to “very good” ($0.6 < K \leq 0.8$) (Supplementary Material 2).

Landscape metrics for natural vegetation patches revealed a general reduction in the number of fragments across most ottobasins (Table 5). As with land-use changes, negative trends in landscape metrics were more pronounced in upstream than in downstream sectors (Supplementary Material 3).

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*Table 3. Changes of land use and vegetation cover in the ottobasins in which caves are present.*

| Ottobasin | Year | Forest | | Crop-livestock | | Mining | | Urban | | Forestry | | Water | | Natural grasslands | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | ha | % | ha | % | ha | % | ha | % | ha | % | ha | % | ha |
| Zizinho Beraldo | 1984 | 42.33 | 5.28 | 57.67 | 7.19 | | | | | | | | | | |
| Zizinho Beraldo | 2019 | 41.29 | 5.14 | 58.71 | 7.32 | | | | | | | 0.22 | | | |
| Jardim Suspenso | 1984 | 32.98 | 123.38 | 63.49 | 237.54 | 3.53 | 13.21 | | | | | | | | |
| Jardim Suspenso | 2019 | 34.54 | 129.23 | 37.07 | 138.68 | 20.10 | 75.20 | | | 8.07 | 30.21 | 0.22 | 0.83 | | |
| Vicente Amargoso | 1984 | 23.72 | 41.34 | 74.06 | 129.10 | | | | | 2.22 | 3.87 | | | | |
| Vicente Amargoso | 2019 | 27.29 | 47.57 | 71.69 | 125.00 | | | | | 1.01 | 1.77 | | | | |
| Santuário e Brega | 1984 | 29.54 | 38.79 | 70.46 | 92.54 | | | | | | | | | | |
| Santuário e Brega | 2019 | 35.94 | 47.21 | 64.06 | 84.15 | | | | | | | | | | |
| Cavalinho | 1984 | 25.58 | 58.53 | 74.42 | 170.30 | | | | | | | | | | |
| Cavalinho | 2019 | 25.71 | 58.82 | 71.07 | 162.60 | 2.63 | 6.03 | | | | | | | | |
| Peixe | 1984 | 43.50 | 129.40 | 46.37 | 137.90 | | | | | | | 5.01 | 14.90 | | |
| Peixe | 2019 | 45.66 | 135.80 | 46.56 | 138.50 | | | | | 3.15 | 9.36 | 4.07 | 12.09 | 0.57 | 1.68 |
| Obede | 1984 | 44.60 | 88.45 | 55.40 | 109.90 | | | | | | | | | | |
| Obede | 2019 | 57.62 | 114.30 | 40.00 | 79.33 | | | | | 2.38 | 4.71 | | | | |
| CSN | 1984 | 64.94 | 117.30 | 18.38 | 33.19 | 16.68 | 30.12 | | | 1.18 | 46.08 | | | | |
| CSN | 2019 | 57.25 | 103.40 | 17.47 | 31.54 | 25.28 | 45.65 | | | 9.26 | 358.44 | | | | |
| Retiro II – Zeca da Mulata – Escorpião | 1984 | 26.55 | 1033.90 | 71.36 | 2757.85 | | | | | | | 5.12 | 15.21 | | |
| Retiro II – Zeca da Mulata – Escorpião | 2019 | 41.42 | 1603.88 | 47.41 | 1835,77 | 1.44 | 55.89 | | | 6.37 | 358.44 | 0.24 | 9.18 | | |
| Serra Azul | 1984 | 17.57 | 91.61 | 82.16 | 428.5 | | | | | | | 0.19 | 1.41 | | |
| Serra Azul | 2019 | 32.88 | 171.5 | 58.00 | 302.6 | 1.78 | 9.28 | | | | | 0.22 | 5.05 | | |
| Isaías | 1984 | 6.39 | 11.61 | 44.73 | 81.3 | 0.72 | 1.98 | | | | | 0.27 | | | |
| Isaías | 2019 | 14.75 | 26.800 | 17.07 | 31.01 | 1.78 | 16.42 | 48.88 | 88.83 | | | 0.97 | | | |
| Éden | 1984 | 33.82 | 73.84 | 57.26 | 125.00 | | | | | | | | | | |
| Éden | 2019 | 51.80 | 112.9 | 27.21 | 59.31 | 7.53 | 16.42 | 12.85 | 28.00 | 18.24 | 42.03 | | | | |
| Fazenda Amargoso | 1984 | 35.77 | 82.45 | 63.37 | 146.10 | 8.92 | 19.47 | | | | | | | | |
| Fazenda Amargoso | 2019 | 31.32 | 72.19 | 49.18 | 113.40 | 1.27 | 2.92 | | | 0.61 | 1.33 | | | | |
| Paca | 1984 | 33.50 | 99.59 | 66.50 | 197.70 | 0.86 | | | | | | | | | |
| Paca | 2019 | 42.24 | 125.6 | 57.76 | 171.70 | | | | | | | | | | |

* Percentages may not sum to exactly 100% due to rounding.

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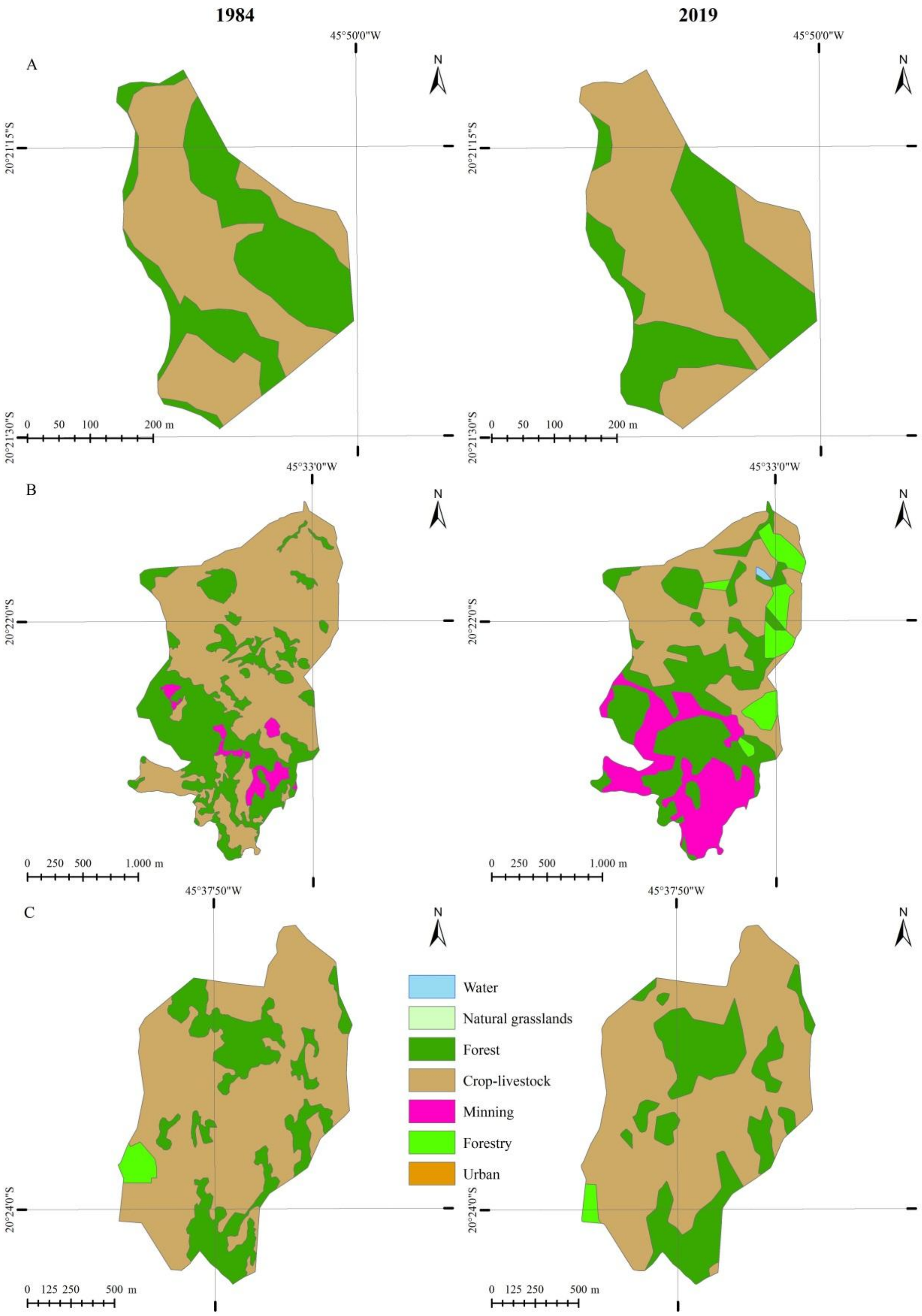


*Figure 3. Land use maps of 1984 and 2019 of the ottobasins. A) Zizinho. B) Jardim Suspenso. C) Vicente amargoso.*

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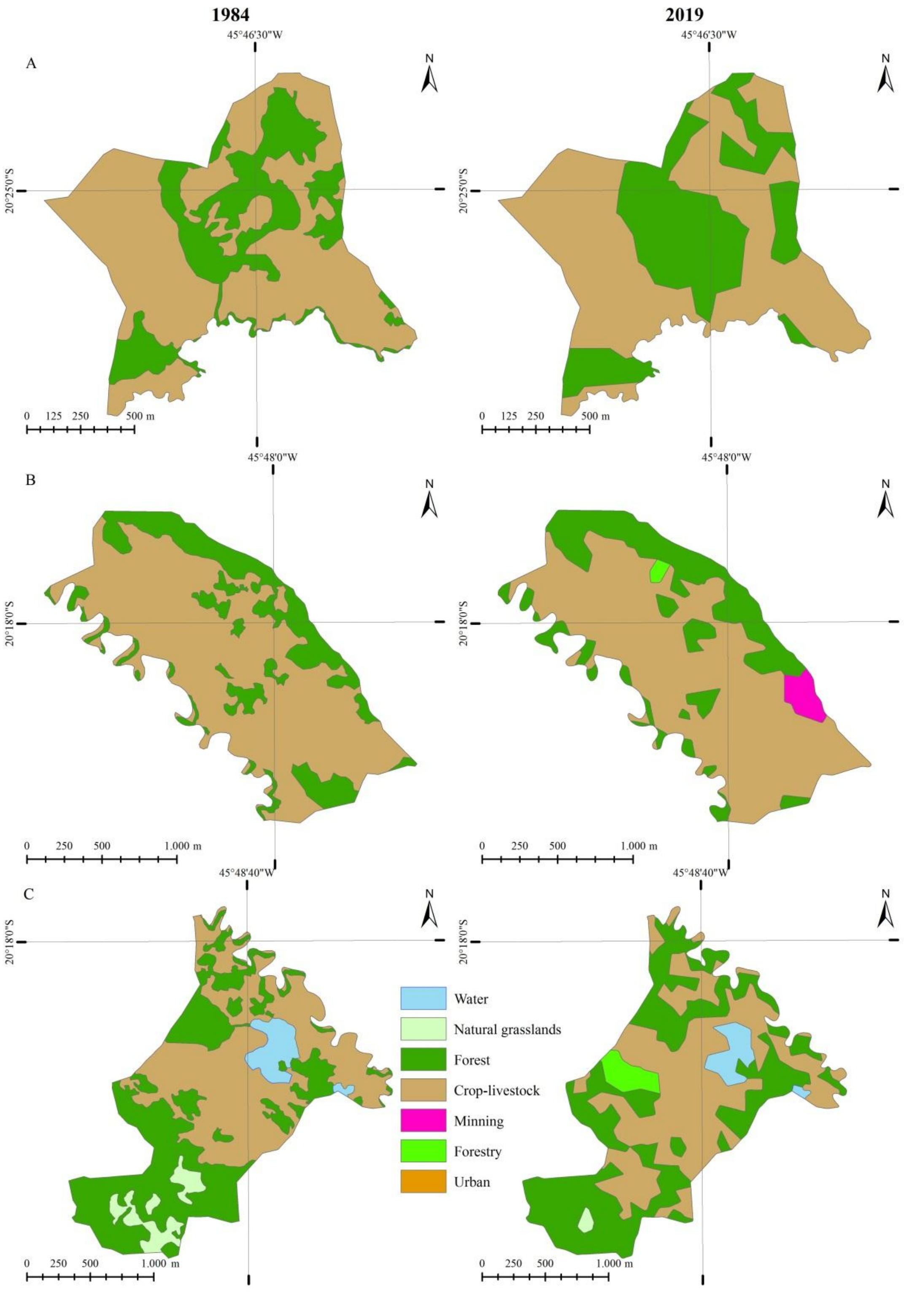


*Figure 4. Land use maps of 1984 and 2019 of the ottobasins. A) Santuário-Brega. B) Cavalinho. C) Peixe.*

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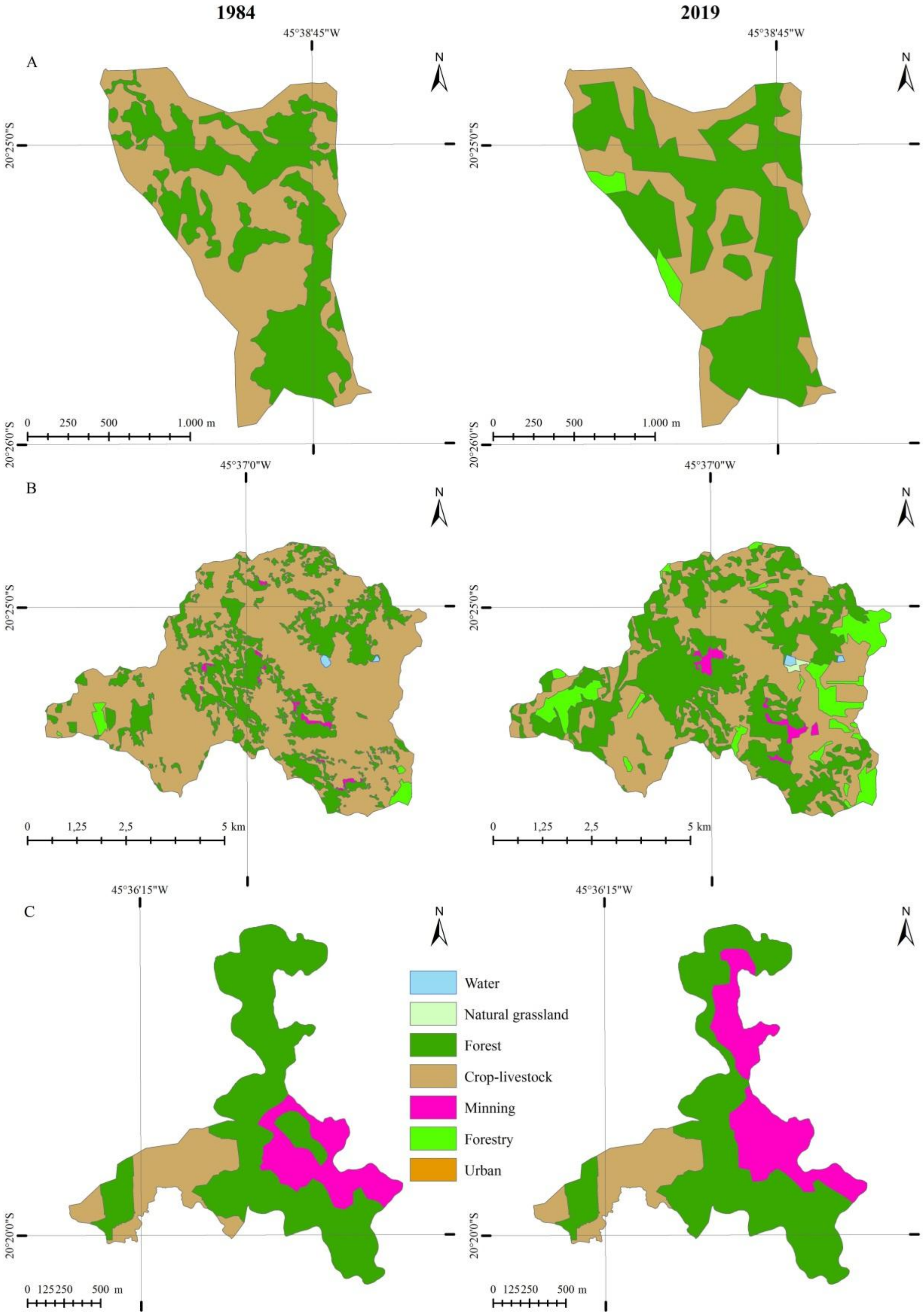


*Figure 5. Land use maps of 1984 and 2019 of the ottobasins. A) Obede. B) Retiro II-Zeca da Mulata- Escorpião. C) CSN.*

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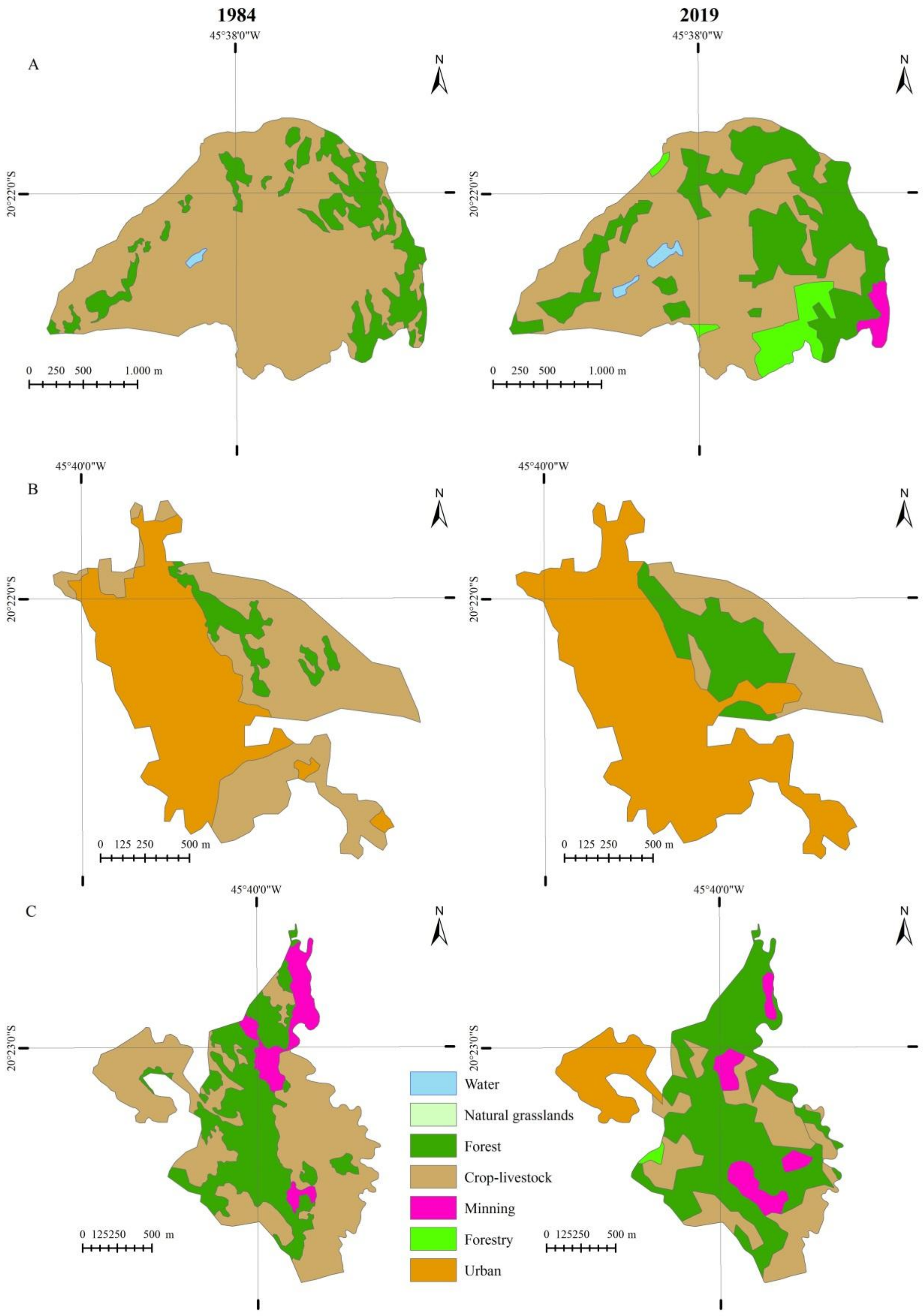


*Figure 6. Land use maps of 1984 and 2019 of the ottobasins. A) Serra Azul. B) Isaías. C) Éden*

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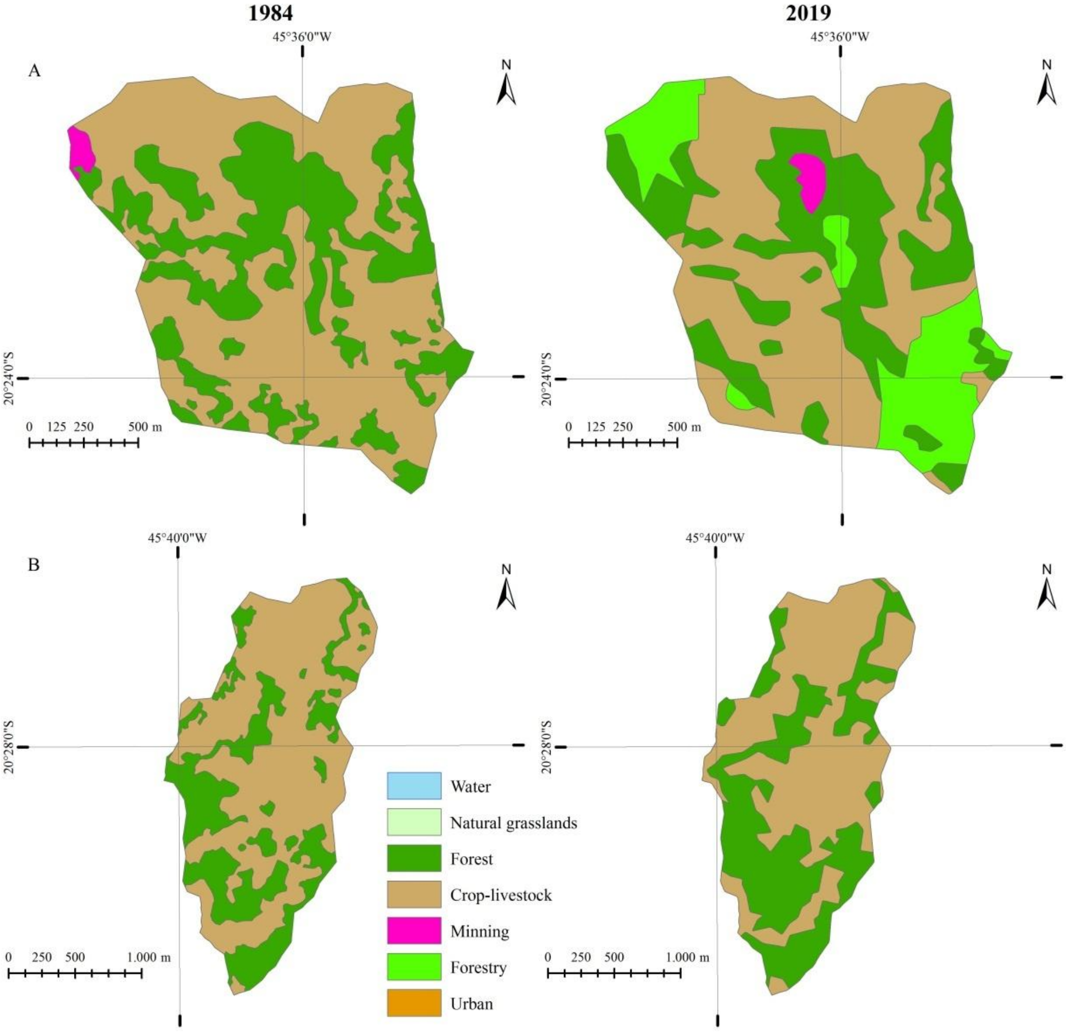


*Figure 7. Land use maps of 1984 and 2019 of the ottobasins. A) Fazenda Amargoso. B) Paca.*

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*Table 4. Annual deforestation/regeneration rate (ADRR) (% year⁻¹) for ottobasins.*

| Cave | | TAD/R |
|---|---|---|
| Zizinho Beraldo | Ziz | -0.072% |
| Jardim Suspenso | JdS | 0.132% |
| Vicente Amargoso | VcA | 0.402% |
| Santuário e Braga | SnB | 0.563% |
| Cavalinho | Cav | 0.014% |
| Peixe | Pex | 0.138% |
| Obede | Obd | 0.735% |
| CSN | CSN | -0.359% |
| Retiro II-Zeca da Mulata-Escorpião | RZE | 1.262% |
| Serra Azul | SeA | 1.808% |
| Isaías | Isa | 2.419% |
| Éden | Edn | 1.220% |
| Fazenda Amargoso | FzA | -0.379 |
| Paca | Pca | 0.665% |

*Table 5. Landscape metrics for the ottobasins generated for the upstream portion of the caves.*

| Ottobasins | Year | Classes | NP | CA | ACS | MSDC | TCA | ICA | MSI |
|---|---|---|---|---|---|---|---|---|---|
| Cavalinho | 1984 | Forest | 3 | 37605.85 | 12535.28 | 11960.7 | 20219.58 | 53.77 | 1.574 |
| | 2019 | Forest | 1 | 29206.66 | 29206.66 | 0 | 16901.11 | 57.87 | 2.122 |
| CSN | 1984 | Forest | 2 | 958582.8 | 479291.4 | 422705 | 850974.7 | 88.77 | 2.126 |
| | 2019 | Forest | 1 | 803321.8 | 803321.8 | 0 | 706804.7 | 87.99 | 3.07 |
| Éden | 1984 | Forest | 5 | 458900.2 | 91780.05 | 168869 | 359268.5 | 78.29 | 2.025 |
| | 2019 | Forest | 1 | 456373 | 456373 | 0 | 383603.9 | 84.05 | 3.066 |
| Fazenda Amargoso | 1984 | Forest | 12 | 108721.3 | 9060.11 | 10012.1 | 62149.2 | 57.16 | 1.58 |
| | 2019 | Forest | 9 | 61200.15 | 6800.02 | 5694.19 | 35824.05 | 58.54 | 1.507 |
| Isaías | 1984 | Forest | 4 | 23391.29 | 5847.82 | 5382.48 | 10761.49 | 46.01 | 1.47 |
| | 2019 | Forest | 2 | 105224.4 | 52612.2 | 42183.3 | 82209.18 | 78.13 | 1.599 |
| Jardim Suspenso | 1984 | Forest | 6 | 383659.5 | 63943.25 | 116313 | 280815.7 | 73.19 | 1.798 |
| | 2019 | Forest | 7 | 243571.4 | 34795.91 | 39211.3 | 183212.1 | 75.22 | 1.458 |
| Obede | 1984 | Forest | 7 | 646392.4 | 92341.77 | 127842 | 524001.1 | 81.07 | 1.818 |
| | 2019 | Forest | 4 | 845780.4 | 211445.1 | 320472 | 735959.2 | 87.02 | 1.631 |
| Paca | 1984 | Forest | 10 | 507015.2 | 50701.52 | 51436.1 | 385376.6 | 76.01 | 1.783 |
| | 2019 | Forest | 7 | 600652.4 | 85807.48 | 97709.8 | 484950.2 | 80.74 | 1.617 |
| Peixe | 1984 | Campo | 1 | 17359.41 | 17359.41 | 0 | 9813.42 | 56.53 | 1.717 |
| | | Forest | 11 | 216198.6 | 19654.42 | 28981.9 | 159427.7 | 73.74 | 1.392 |
| | 2019 | Forest | 9 | 193637.1 | 21515.23 | 15326.5 | 137881.6 | 71.21 | 1.315 |

ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Retiro II Zeca da Mulata | 1984 | Forest | 57 | 4528165 | 79441.49 | 245896 | 3603618 | 79.58 | 1.84 |
| | 2019 | Forest | 20 | 5903742 | 295187.1 | 628576 | 5092374 | 86.26 | 1.977 |
| Serra Azul | 1984 | Forest | 11 | 752250.5 | 68386.41 | 95478.7 | 567340.1 | 75.42 | 1.867 |
| | 2019 | Forest | 9 | 1464797 | 162755.2 | 437551 | 1269985 | 88.05 | 1.559 |
| Santuário-Brega | 1984 | Forest | 6 | 306604.1 | 51100.69 | 79464.4 | 217560.9 | 70.96 | 1.923 |
| | 2019 | Forest | 4 | 335053.2 | 83763.3 | 76773.6 | 266189.7 | 79.45 | 1.81 |
| Vicente Amargoso | 1984 | Forest | 7 | 238322.2 | 34046.02 | 44708.8 | 157629.8 | 66.14 | 1.95 |
| | 2019 | Forest | 8 | 281535.3 | 35191.91 | 49593.5 | 216925.9 | 77.05 | 1.388 |
| Zizinho | 1984 | Forest | 1 | 21357.08 | 21357.08 | 0 | 16017.35 | 75 | 1.096 |
| | 2019 | Forest | 1 | 19714.35 | 19714.35 | 0 | 14151.4 | 71.78 | 1.196 |

NP: number of patches. CA: class area (m²). ACS: average class size; MSDC: mean standard deviation of the class; TCA: total central area of the class; ICA: index in % of the central area of the class; MSI: mean shape index.

According to the mining processes registered with the DNPM, all analyzed areas have at least part of their territory under applicationfor mining concessions (Figure 8). Among these, Jardim Suspenso, Cavalinho, Peixe, CSN, Retiro II–Zeca da Mulata–Escorpião, Serra Azul, and Fazenda Amargoso already hold active concessions and currently contain quarries. Consequently, both medium- and long-term scenarios indicate that these areas may undergo severe impacts from mining activities.

When considering the ottobasins containing caves with *Spelunconiscus* species, the most threatened is that of the Éden cave, which harbors the highest richness of troglobitic species in the province (Table 6). The five caves identified as conservation priorities in the ranking together comprise 60.5% of the troglobitic richness of the analyzed ottobasins and 46% of the total troglobitic richness known for the entire province.

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ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

*Table 6. Ranking of ottobasins in terms of impacts. *S: Richness*

| Ottobasins | Score | Troglobites S | Endemic troglobites |
|---|---|---|---|
| Éden cave | 12 | 15 | 10 |
| Fazenda Amargoso cave | 10 | 3 | 1 |
| Cavalinho cave | 9 | 6 | 1 |
| Serra Azul cave | 9 | 4 | 1 |
| Isaías cave | 9 | 3 | 1 |
| Vicente Amargoso cave | 8 | 3 | 2 |
| Jardim Suspenso cave | 7 | 1 | 1 |
| Obede cave | 7 | 1 | 1 |
| Retiro II & Zeca da Mulata caves | 6 | 8 | 4 |
| Peixe cave | 6 | 2 | 1 |
| CSN cave | 5 | 1 | 1 |
| Paca cave | 5 | 2 | 1 |
| Santuário & Brega caves | 5 | 7 | 2 |
| Zizinho cave | 5 | 4 | 1 |

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**Revista Brasileira de Espeleologia – RBEsp**
ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

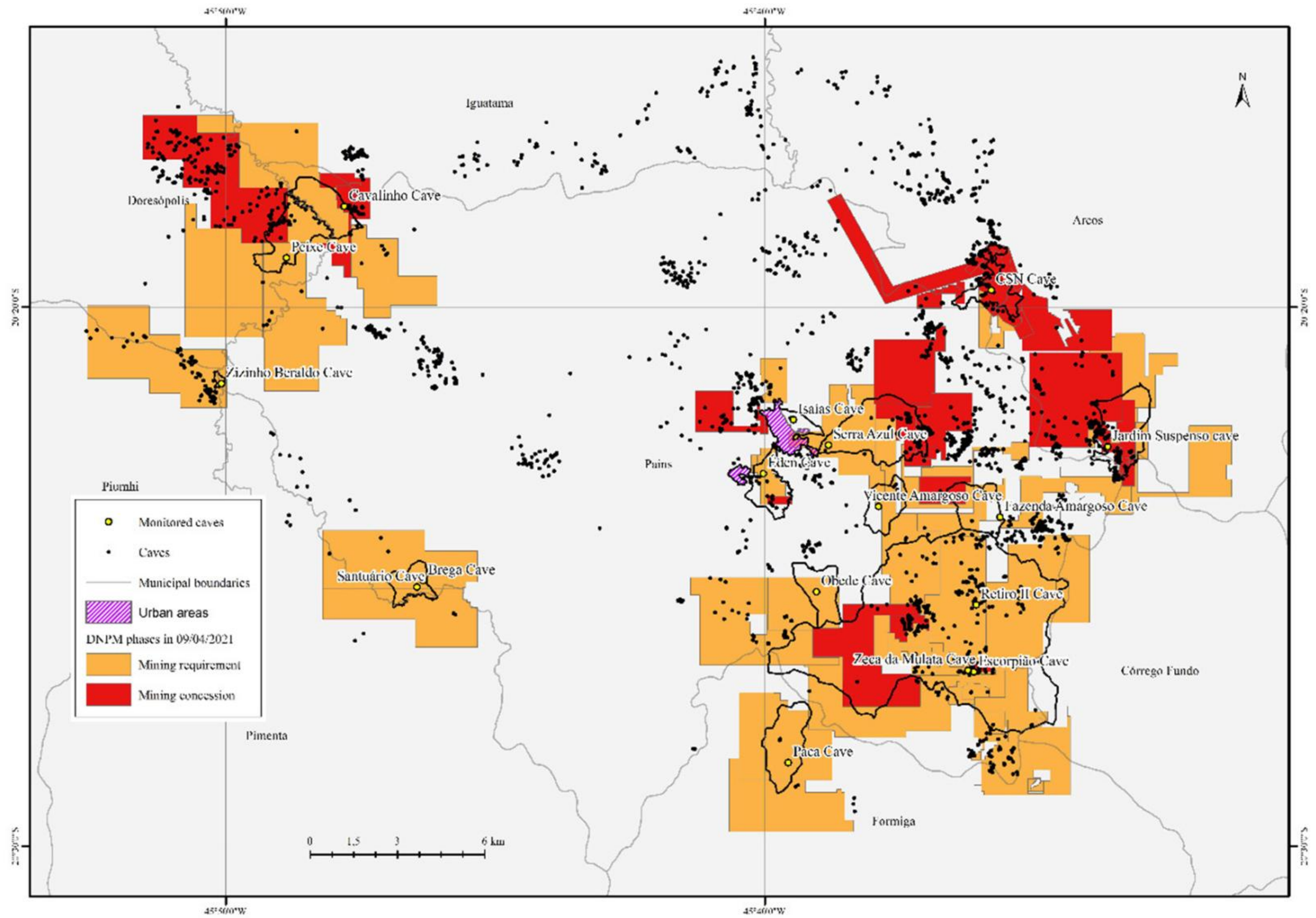


*Figure 8. Ottobasins and the process phases in the National Mining Agency (NMA).*

CENTRO NACIONAL DE PESQUISA E CONSERVAÇÃO DE CAVERNAS
ICMBio-MMA
Revista Brasileira de Espeleologia – RBEsp
ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

## 4. DISCUSSION AND CONCLUSION

Across the 14 areas analyzed, there was a general increase in mining, urban expansion, forestry, and cropland/pastureland in several ottobasins. Among these, Zizinho, CSN, and Fazenda Amargoso exhibited a reduction in forest cover over the 35-year period studied (Table 3), involving the conversion of several hectares of native vegetation in each basin. It is important to emphasize that an increase in native vegetation provides numerous ecological benefits, including regulating microclimate, light penetration, airflow, energy input, and water infiltration into subterranean systems (URICH, 2002). Thus, the loss of forest in these regions may directly reduce habitat quality for cave-restricted species.

In the Zizinho Beraldo ottobasin, agriculture–livestock areas increased by 1.04%, corresponding to approximately 0.13 ha. Although this expansion was modest in relative terms, it still represents a measurable alteration of the landscape. Livestock farming is associated with the conversion of native vegetation, changes in soil chemistry and percolating water, erosion, sedimentation, and agrochemical use (URICH, 2002). Agricultural practices in karst systems have strong implications for soil, water, and biodiversity (COXON, 2011). Erosion, for example, increases sediment deposition in both the epikarst and cave environments (GILLIESON; THURGATE, 1999; HARDWICK; GUNN, 1990). The widespread use of fertilizers and pesticides leads to infiltration of chemicals into groundwater, often reaching concentrations lethal to fauna (DI MARZIO et al., 2009). Elevated potassium ion ($K^+$) concentrations in groundwater from the KASP province (LUCON et al., 2018) are likely linked to fertilizer use. Laboratory studies have shown mortality of subterranean crustaceans at potassium salt concentrations ranging from 0.28 mg/L to 17.99 mg/L (REBOLEIRA et al., 2013). Such values are particularly concerning *Spelunconiscus* species, which depend heavily on percolation water and are thus highly exposed to ionic changes.

Mining activity increased significantly in several ottobasins, including Jardim Suspenso (+16.57%, >75 ha), CSN (+8.6%, ~46 ha), Cavalinho (+2.63%, ~6 ha), Serra Azul (+1.78%, ~9 ha), Retiro II–Zeca da Mulata–Escorpião (~1%, >55 ha), and Fazenda Amargoso, where mining decreased to approximately 3 ha in 2019.Although mining sometimes occupied a relatively small proportion of basin area, its absolute spatial extent often reached tens to more than seventy hectares, indicating a high level of impact. Mining in karst areas generates severe ecological and geomorphological impacts, altering the physicochemical properties of groundwater and degrading macroinvertebrate communities (MILIŠA et al., 2010). In the KASP province, cadmium concentrations in groundwater range from 0.001 µg/L to 15.63 µg/L, exceeding the threshold for human consumption (5 µg/L) in some cases (LUCON et al., 2020). Cadmium toxicity has been demonstrated at values as low as 16 µg/L in Ephemeroptera and even lower in salmonids (MEBANE et al., 2012), suggesting that current concentrations may already threaten subterranean fauna. Amphibious *Spelunconiscus* species, commonly associated with travertine dams, are especially vulnerable to water quality degradation, which can alter their biology and behavior and ultimately cause population declines. Moreover, many of these isopods migrate seasonally to the epikarst during dry periods, a compartment also susceptible to contamination from mining. Thus, even when macro-caves are not directly affected, their connected epikarst habitats may be significantly impacted.

Urban expansion also emerged as a notable driver of environmental degradation, with increases of 48.88% (~89 ha) in Isaías and 12.85% (~28 ha) in Éden. In karst systems, urbanization

ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

intensifies pollution, reduces groundwater quality, and generates irreversible impacts (DE WAELE; FOLLESA, 2004). According to Decree No. 6.640/2008 (BRASIL, 2008), caves harboring rare troglobitic species are considered of maximum relevance and should not be exposed to irreversible impacts. However, legislation primarily addresses easily measurable impacts, leaving uncertainties about the medium- and long-term consequences of sewage infiltration and soil impermeabilization on subterranean fauna. Previous studies have demonstrated a negative relationship between groundwater pollution and stygobitic richness (MALARD et al., 1996; SIMON; BUIKEMA, 1997).

Forestry expansion also imposes cumulative pressures. In some ottobasins, forestry plantations expanded by tens to hundreds of hectares, particularly in larger upstream basins such as Retiro II–Zeca da Mulata–Escorpião and CSN. By reducing evapotranspiration, tree plantations increase surface runoff, leading to erosion and nutrient leaching (URICH, 2002). Eucalyptus monocultures reduce organic matter input into aquatic systems (ABELHO; GRAÇA, 1999; MOLINERO; POZO, 2004). While they may temporarily alter soil organic carbon levels depending on pedological conditions (MONTERO; DELITTI, 2017), long-term declines in organic matter are expected (DEAN et al., 2017). Such changes reduce the quality and quantity of trophic resources entering subterranean ecosystems, with cascading effects on cave fauna (SCHNEIDER et al., 2011). Given that troglobitic populations are especially dependent on external trophic inputs (HUMPHREYS, 1991), forestry-related impacts may trigger population declines. Although total forest area increased in some ottobasins, upstream zones in Zizinho, Jardim Suspenso, Santuário–Brega, Peixe, Cavalinho, CSN, and Fazenda Amargoso experienced forest losses involving several to dozens of hectares due to anthropogenic expansion. These upstream alterations are particularly concerning, as disturbances propagate rapidly through karst systems and disproportionately affect downstream cave environments (URICH, 2002; VAN BEYNEN, 2011).

Deforestation exacerbates sedimentation, turbidity, nutrient infiltration, and flood pulses in subterranean ecosystems (URICH, 2002; FORD; WILLIAMS, 2007; GILLI, 2011). Because caves lack primary producers, adjacent vegetation is critical in supplying organic matter and energy to subterranean food webs (GIBERT; DEHARVENG, 2002). Reductions in these inputs, even when involving relatively small percentages but large absolute areas, likely intensify interspecific competition, with unknown but potentially severe consequences for *Spelunconiscus* and other troglobitic species. Given their low population densities and restricted distributions, such taxa are especially vulnerable to extinction. Landscape homogenization further amplifies these risks, as environmental heterogeneity is a major driver of biodiversity (SHMIDA; WILSON, 1985) and of cave community composition (PELLEGRINI et al., 2016).

Landscape metrics confirmed degradation of non-anthropogenic soil-cover classes, with upstream zones experiencing the most pronounced declines (Supplementary Material 3). Reductions in forest patch number and area, often involving tens to hundreds of hectares, decrease trophic input and water infiltration while also modifying habitat connectivity. The mean shape index (MSI) revealed increased edge effects, as irregular fragment shapes are more exposed to microclimatic variation (DAVIES-COLLEY et al., 2000). These effects reduce soil moisture and negatively affect soil fauna foraging activity (RIUTTA et al., 2016).

Looking ahead, mining concessions already registered in the National Mining Agency database (Figure 2) indicate that the long-term scenario will likely intensify pressures on karst ecosystems. Mining invariably results in vegetation removal, rock extraction, sedimentation, and

ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

air pollution, often involving large absolute areas, causing cascading impacts on subterranean biodiversity.

The ranking of ottobasins based on impact levels identified the most threatened areas, highlighting Éden as the most vulnerable site due to its high richness of troglobitic and endemic species. Protecting the seven most threatened ottobasins would safeguard approximately 52% (26 species) of all troglobites known in the province. However, the optimal scenario would involve mitigating impacts across all 14 ottobasins, which collectively shelter 17 undescribed *Spelunconiscus* species and approximately 76% of the province's troglobitic fauna. Given that the KASP province contains over 2,500 registered caves, the conservation of *Spelunconiscus* isopods as umbrella species (STOCH et al., 2009) is a promising strategy, as their protection would ensure the preservation of numerous co-occurring troglobitic, troglophilic, and trogloxenic species.

In summary, this study identified critical sources of anthropogenic pressure in the KASP province and demonstrated their negative consequences for subterranean biodiversity. Although some land-use changes appeared moderate in relative terms, they involved the conversion of extensive areas, often exceeding tens or hundreds of hectares, reinforcing the magnitude of human impacts. The current scenario is unfavorable for the long-term persistence of cave-restricted species, with some at risk of extinction due to their sensitivity and restricted ranges. Nevertheless, targeted conservation measures, particularly in priority ottobasins, could safeguard more than half of the province's troglobitic species. Further studies are urgently needed to clarify the ecological effects of land-use changes on subterranean communities and to guide effective mitigation and conservation strategies.

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### Author Contributions Statement

**V.M.M:** conceptualization, methodology, writing - original draft and visualization. **M.G.:** conceptualization, methodology and formal analysis, **R.L.F.:** conceptualization; methodology, writing – review & editing and supervision.

## REFERENCES

ABELHO, M.; GRAÇA, M. A. S. Effects of eucalyptus afforestation on leaf litter dynamics and macroinvertebrate community structure of streams in Central Portugal. **Hydrobiologia**, Dordrecht, v. 324, n. 3, p. 195-204, 1996. https://doi.org/10.1007/BF00016391

ANM. Sistema de Informações Geográficas da Mineração – SIGMINE. Brasília, 2021. Disponível em: http://www.anm.gov.br/assuntos/ao-minerador/sigmine.

BRASIL. Decreto nº 6.640 de 07 de novembro de 2008. Brasília, 2008.

ISSN 2179.4952- V.02 – Nº .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

CAVALCANTI, L. F.; LIMA, M. F.; MEDEIROS, R. C. S.; MEGUERDITCHIAN, I. **Plano de ação nacional para a conservação do patrimônio espeleológico nas áreas cársticas da bacia do rio São Francisco**. Brasília: Instituto Chico Mendes de Conservação da Biodiversidade, 2012. 140 p.

CECAV. Cadastro Nacional de Informações Espeleológicas. Brasília, 2021. Disponível em: https://www.icmbio.gov.br/cecav/canie.html.

CONAMA. Conselho Nacional do Meio Ambiente – Ministério do Meio Ambiente. Resolução nº 347, de 10 de setembro de 2004. Brasília, DF, 2004.

CONGALTON, R. G.; GREEN, K. **Assessing the accuracy of remotely sensed data: principles and practices**. Boca Raton: CRC Press, 2019.

COXON, C. **Agriculture and karst**. In: VAN BEYNEN, P. E. (ed.). Karst management. Dordrecht: Springer, 2011. p. 103-138.

CULVER, D. C.; PIPAN, T. **The biology of caves and other subterranean habitats**. Oxford: Oxford University Press, 2019.

DAVIES-COLLEY, R. J.; PAYNE, G. W.; VAN ELSWIJK, M. Microclimate gradients across a forest edge. **New Zealand Journal of Ecology**, Wellington, p. 111-121, 2000.

DE BARROS FERRAZ, S. F.; VETTORAZZI, C. A.; THEOBALD, D. M. Using indicators of deforestation and land-use dynamics to support conservation strategies: a case study of central Rondônia, Brazil. **Forest Ecology and Management**, Amsterdam, v. 257, n. 7, p. 1586-1595, 2009. https://doi.org/10.1016/j.foreco.2009.01.013

DE WAELE, J.; FOLLESA, R. Human impact on karst: the example of Lusaka (Zambia). **International Journal of Speleology**, Tampa, v. 32, n. 1, p. 5, 2003. http://dx.doi.org/10.5038/1827-806X.32.1.5

DEAN, C.; KIRKPATRICK, J. B.; FRIEDLAND, A. J. Conventional intensive logging promotes loss of organic carbon from the mineral soil. **Global Change Biology**, Oxford, v. 23, n. 1, p. 1-11, 2017. https://doi.org/10.1111/gcb.13387

DI MARZIO, W. D.; CASTALDO, D.; PANTANI, C.; DI CIOCCIO, A.; DI LORENZO, T.; SÁENZ, M. E.; GALASSI, D. M. P. Relative sensitivity of hyporheic copepods to chemicals. **Bulletin of Environmental Contamination and Toxicology**, New York, v. 82, n. 4, p. 488-491, 2009.

FIGUEIREDO, G. C.; VIEIRA, C. A. O. Estudo do comportamento dos índices de Exatidão Global, Kappa e Tau, comumente usados para avaliar a classificação de imagens do sensoriamento remoto. In: **Simpósio Brasileiro de Sensoriamento Remoto**, 13., 2007, Florianópolis. Anais [...]. São José dos Campos: INPE, 2007. p. 5755-5762.

FORD, D.; WILLIAMS, P. **Karst hydrogeology and geomorphology**. London: Wiley, 2007.

GIBERT, J.; DEHARVENG, L. Subterranean ecosystems: a truncated functional biodiversity. **BioScience**, Washington, v. 52, n. 6, p. 473-481, 2002. https://doi.org/10.1641/0006-568(2002)052[0473:SEATFB]2.0.CO;2

GILLI, E.; FANDEL, C. **Karstology: karst, caves and springs**. Boca Raton: CRC Press, 2011.

ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

GILLIESON, D.; THURGATE, M. Karst and agriculture in Australia. **International Journal of Speleology**, Tampa, v. 28, n. 1, p. 11, 1999. http://dx.doi.org/10.5038/1827-806X.28.1.11

GOLDSCHEIDER, N.; CHEN, Z.; AULER, A. S.; BAKALOWICZ, M.; BRODA, S.; DREW, D.; ... VENI, G. Global distribution of carbonate rocks and karst water resources. **Hydrogeology Journal**, Heidelberg, v. 28, n. 5, p. 1661-1677, 2020. https://doi.org/10.1007/s10040-020-02139-5

GOMES, M.; FERREIRA, R. L.; RUCHKYS, Ú. A. Landscape evolution in ferruginous geosystems of the Iron Quadrangle, Brazil: a speleological approach in a biodiversity hotspot. **SN Applied Sciences**, Heidelberg, v. 1, n. 9, p. 1-13, 2019. https://doi.org/10.1007/s42452-019-1139-3

GOOGLE. Google Earth. Mountain View, 2013.

GRIEBLER, C.; AVRAMOV, M. Groundwater ecosystem services: a review. **Freshwater Science**, Chicago, v. 34, n. 1, p. 355-367, 2014.

GRIEBLER, C.; STEIN, H.; KELLERMANN, C.; BERKHOFF, S.; BRIELMANN, H.; SCHMIDT, S.; ... HAHN, H. J. Ecological assessment of groundwater ecosystems – vision or illusion? **Ecological Engineering**, Amsterdam, v. 36, n. 9, p. 1174-1190, 2010.

HARDWICK, P.; GUNN, J. Soil erosion in cavernous limestone catchments. In: BOARDMAN, J.; FOSTER, I. D. L.; DEARING, J. A. (ed.). **Soil erosion on agricultural land**. Hoboken: Wiley, 1990. p. 301-310.

HUMPHREYS, W. F. Experimental re-establishment of pulse-driven populations in a terrestrial troglobite community. **The Journal of Animal Ecology**, London, v. 60, p. 609-623, 1991.

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Manual técnico de uso da terra**. Rio de Janeiro, 2013. Disponível em: https://biblioteca.ibge.gov.br/visualizacao/livros/liv81615.pdf

ICMBIO – INSTITUTO CHICO MENDES DE CONSERVAÇÃO DA BIODIVERSIDADE. **Anuário estatístico do patrimônio espeleológico brasileiro**. Brasília, 2020.

IGAM – INSTITUTO MINEIRO DE GESTÃO DAS ÁGUAS. Base hidrográfica ottocodificada de Minas Gerais. Belo Horizonte, 2019.

INPE – INSTITUTO DE PESQUISAS ESPACIAIS. **Introdução ao sensoriamento remoto**. São José dos Campos, 2001.

JAXA/METI. ALOS PALSAR L 1.0 – ALPSRP272776780. Disponível em: https://asf.alaska.edu

JENNINGS, J. N. **Karst**. Canberra: Australian National University Press, 1971.

LAMBECK, R. J. Landscape planning for biodiversity conservation in agricultural regions: a case study from the wheatbelt of Western Australia. **Biodiversity Technical Paper**, Canberra, v. 2, 1999.

LUCON, T. N.; COSTA, A. T.; GALVÃO, P.; LEITE, M. G. P. Natural background levels and seasonal influence on groundwater chemistry of the Upper São Francisco karst region, MG, Brazil. **Brazilian Journal of Geology**, São Paulo, v. 48, n. 4, p. 867-879, 2018. https://doi.org/10.1590/2317-4889201820180071

ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

LUCON, T. N.; COSTA, A. T.; GALVÃO, P.; LEITE, M. G. P. Cadmium behavior in a karst environment hydrological cycle. **Environmental Science and Pollution Research**, Heidelberg, v. 27, n. 9, p. 8965-8979, 2020. https://doi.org/10.1007/s11356-020-07894-2

LUIZ, C. H. P.; FARIA, S. D. Construção da base Otto-codificada em Minas Gerais: implementação da metodologia desenvolvida por Otto Pfafstetter (1989) para escalas 1:100.000 e 1:50.000. In: **Simpósio Brasileiro de Sensoriamento Remoto**, 16., 2013, Foz do Iguaçu. Anais [...]. São José dos Campos: INPE, 2013. p. 2455-2462.

MALARD, F.; PLENET, S.; GIBERT, J. The use of invertebrates in ground water monitoring: a rising research field. **Groundwater Monitoring & Remediation**, Hoboken, v. 16, n. 2, p. 103-113, 1996.

MARTINS, T. I. S.; RODRIGUES, S. C. Compartimentação geomorfológica da Folha Piumhi, região do alto São Francisco, Minas Gerais. **Revista Brasileira de Geomorfologia**, Uberlândia, v. 17, n. 1, p. 145-162, 2016.

MCGARIGAL, K. **Landscape pattern metrics**. Wiley StatsRef: Statistics Reference Online, Hoboken, 2014. https://doi.org/10.1002/9781118445112.stat07723

MEBANE, C. A.; DILLON, F. S.; HENNESSY, D. P. Acute toxicity of cadmium, lead, zinc, and their mixtures to stream-resident fish and invertebrates. **Environmental Toxicology and Chemistry**, Pensacola, v. 31, n. 6, p. 1334-1348, 2012. https://doi.org/10.1002/etc.1820

MELO, P. H. A. D.; LOMBARDI, J. A.; SALINO, A.; CARVALHO, D. A. D. Composição florística de angiospermas no carste do alto São Francisco, Minas Gerais, Brasil. **Rodriguésia**, Rio de Janeiro, v. 64, n. 1, p. 29-36, 2013. https://doi.org/10.1590/S2175-78602013000100004

MENEGASSE, L. N.; GONÇALVES, J. M.; FANTINEL, L. M. Disponibilidades hídricas na Província cárstica de Arcos-Pains-Doresópolis, Alto São Francisco, Minas Gerais, Brasil. **Águas Subterrâneas**, São Paulo, v. 16, n. 1, p. 1-19, 2002. https://doi.org/10.14295/ras.v16i1.1297

MILISA, M.; ŽIVKOVIĆ, V.; HABDIJA, I. Destructive effect of quarry effluent on life in a mountain stream. **Biologia**, Bratislava, v. 65, n. 3, p. 520-526, 2010. https://doi.org/10.2478/s11756-010-0044-4

MOLINERO, J.; POZO, J. Impact of a eucalyptus (Eucalyptus globulus Labill.) plantation on the nutrient content and dynamics of coarse particulate organic matter (CPOM) in a small stream. **Hydrobiologia**, Dordrecht, v. 528, n. 1, p. 143-165, 2004.

MONTERO, L. L.; DELITTI, W. Effects of *Eucalyptus* and *Pinus* forest management on soil organic carbon in Brazilian wooded-savanna. In: **Forest Biomass and Carbon**. London: IntechOpen, 2017.

PELLEGRINI, T.; SALES, L. P.; AGUIAR, P.; FERREIRA, R. L. Linking spatial scale dependence of land-use descriptors and invertebrate cave community composition. **Subterranean Biology**, Sofia, v. 18, p. 17-28, 2016.

REBOLERA, A. S. P.; ABRANTES, N.; OROMÍ, P.; GONÇALVES, F. Acute toxicity of copper sulfate and potassium dichromate on stygobiont Proasellus: general aspects of groundwater ecotoxicology and future perspectives. **Water, Air, & Soil Pollution**, Dordrecht, v. 224, n. 5, p. 1-9, 2013. https://doi.org/10.1007/s11270-013-1550-0

ISSN 2179.4952- V.02 – N° .14 – 2025.
Recebido: 29 de agosto de 2025. Aceito: 22 de dezembro de 2025. Publicado: 23 de dezembro de 2025.

RIUTTA, T.; CLACK, H.; CROCKATT, M.; SLADE, E. M. Landscape-scale implications of the edge effect on soil fauna activity in a temperate forest. **Ecosystems**, New York, v. 19, n. 3, p. 534-544, 2016. https://doi.org/10.1007/s10021-015-9939-9

ROBERGE, J. M.; ANGELSTAM, P. Usefulness of the umbrella species concept as a conservation tool. **Conservation Biology**, Malden, v. 18, n. 1, p. 76-85, 2004.

SCHNEIDER, K.; CHRISTMAN, M. C.; FAGAN, W. F. The influence of resource subsidies on cave invertebrates: results from an ecosystem-level manipulation experiment. **Ecology**, Washington, v. 92, n. 3, p. 765-776, 2011.

SHMIDA, A.; WILSON, M. V. Biological determinants of species diversity. **Journal of Biogeography**, Oxford, v. 12, n. 1, p. 1-20, 1985. https://doi.org/10.2307/2845026

SIMON, K. S.; BUIKEMA JR, A. L. Effects of organic pollution on an Appalachian cave: changes in macroinvertebrate populations and food supplies. **American Midland Naturalist**, Notre Dame, v. 138, n. 2, p. 387-401, 1997.

STOCH, F.; ARTHEAU, M.; BRANCELJ, A.; GALASSI, D. M.; MALARD, F. Biodiversity indicators in European ground waters: towards a predictive model of stygobiotic species richness. **Freshwater Biology**, Oxford, v. 54, n. 4, p. 745-755, 2009. https://doi.org/10.1111/j.1365-2427.2008.02143.x

URICH, P. B. **Land use in karst terrain: review of impacts of primary activities on temperate karst ecosystems**. Wellington: Department of Conservation, 2002.

VAN BEYNEN, P. E.; VAN BEYNEN, K. M. Human disturbance of karst environments. In: VAN BEYNEN, P. E. (ed.). **Karst management**. Dordrecht: Springer, 2011. p. 379-397.

VAN BEYNEN, P.; TOWNSEND, K. A disturbance index for karst environments. **Environmental Management**, New York, v. 36, n. 1, p. 101-116, 2005. https://doi.org/10.1007/s00267-004-0265-9

VAN BEYNEN, P.; BRINKMANN, R.; VAN BEYNEN, K. A sustainability index for karst environments. **Journal of Cave and Karst Studies**, Huntsville, v. 74, n. 2, p. 221-234, 2012. https://doi.org/10.4311/2011SS0217

ZAMPAULO, R. A. **Diversidade de invertebrados na província espeleológica de Arcos, Pains, Doresópolis (MG): subsídios para a determinação de áreas prioritárias para a conservação**. 2010. 190 f. Dissertação (Mestrado em Ecologia Aplicada) – Universidade Federal de Lavras, Lavras, 2010.

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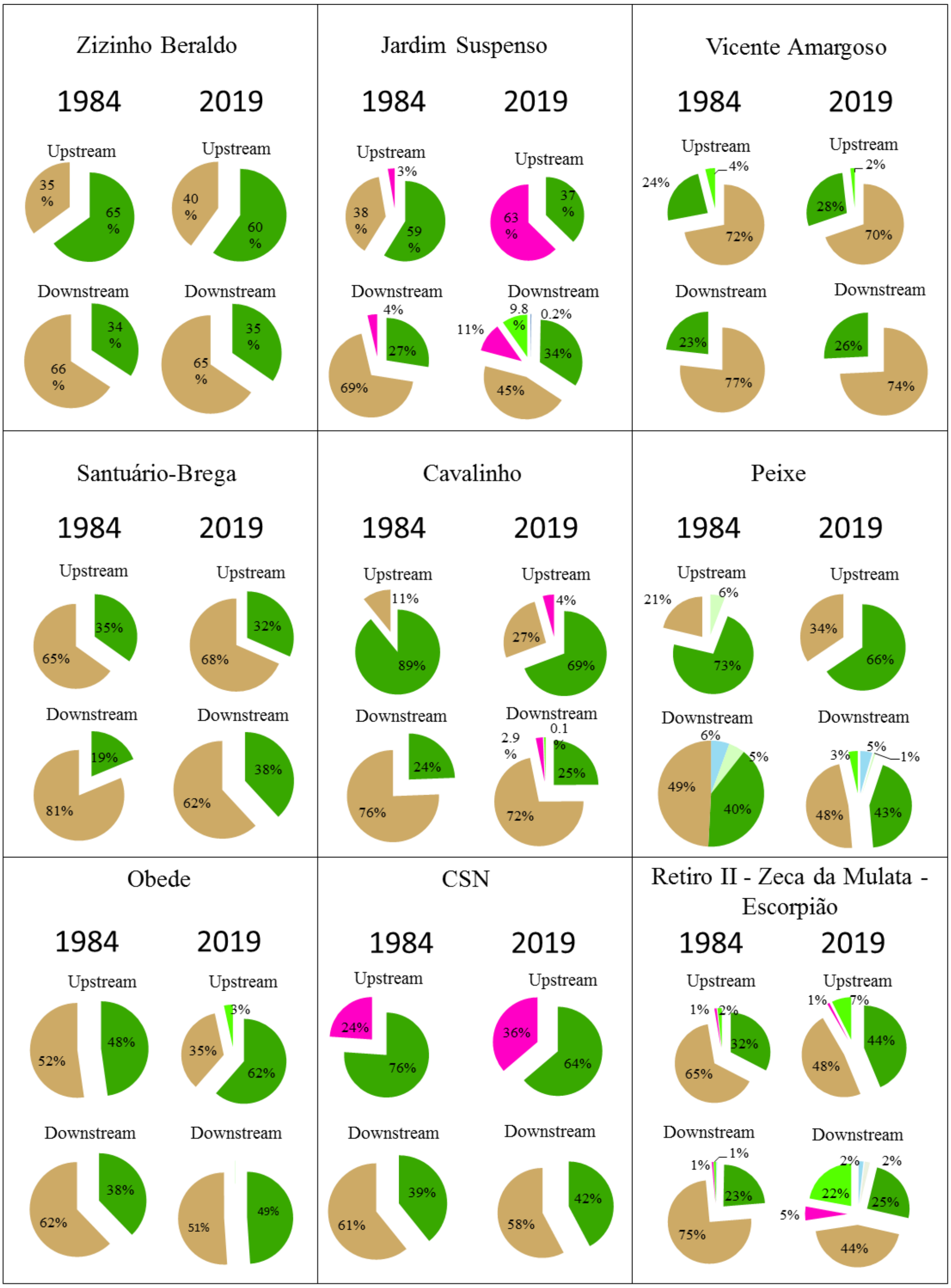
***Supplementary material 1***

Percentages of land use in each by ottobasin upstream and downstream related to the caves' positions on the landscape.



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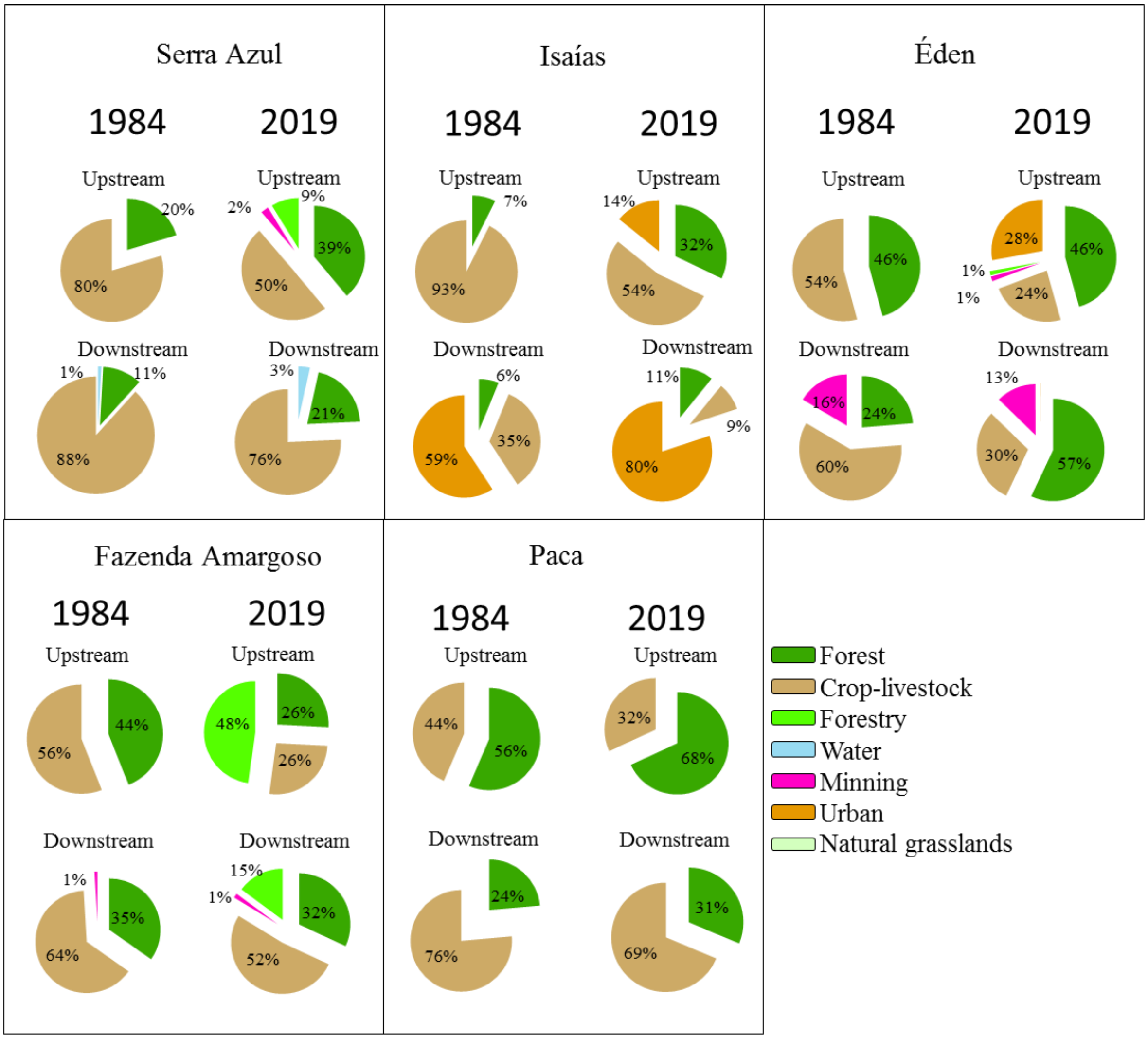


## *Supplementary material 2*

Kappa index generated for each ottobasin studied.

| Areas | Kappa |
|---|---|
| **Zizinho Beraldo** | 0.62 |
| **Jardim Suspenso** | 0.74 |
| **Vicente Amargoso** | 0.70 |
| **Santuário e Brega** | 0.64 |
| **Cavalinho** | 0.62 |
| **Peixe** | 0.69 |
| **Obede** | 0.90 |
| **CSN** | 0.76 |
| **Retiro II, Zeca da Mulata e Escorpião** | 0.85 |
| **Serra Azul** | 0.76 |
| **Isaías** | 0.94 |
| **Éden** | 0.69 |
| **Fazenda Amargoso** | 0.85 |
| **Paca** | 0.76 |

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***Supplementary material 3***

Landscape metrics for natural vegetation cover patches in the downstream portion of ottobasins (1984 and 2019).

| Ottobasins | Year | Classes | NP | CA | ACS | MSDC | TCA | ICA | MSI |
|---|---|---|---|---|---|---|---|---|---|
| Cavalinho | 1984 | Forest | 25 | 547699.40 | 21907.98 | 60070.30 | 20219.80 | 53.77 | 2297 |
| | 2019 | Forest | 18 | 559002.60 | 31055.7 | 83432.34 | 429347.20 | 76.81 | 1.405 |
| CSN | 1984 | Forest | 2 | 214009.7 | 107004.9 | 19578.37 | 171738.60 | 80.25 | 1.85 |
| | 2019 | Forest | 2 | 230518 | 115259 | 27807.60 | 186826.90 | 81.05 | 1.847 |
| Éden | 1984 | Forest | 9 | 279511 | 31056.77 | 32167.38 | 186809.70 | 66.83 | 1.742 |
| | 2019 | Forest | 3 | 672520.20 | 224173.40 | 297735.60 | 553982.30 | 82.37 | 2.419 |
| Fazenda Amargoso | 1984 | Forest | 25 | 715766.10 | 28630.64 | 103133.40 | 509451.60 | 71.18 | 1.616 |
| | 2019 | Forest | 13 | 660740.90 | 50826.22 | 88455.13 | 505814.10 | 76.55 | 1.647 |
| Isaías | 1984 | Forest | 2 | 92699.84 | 46349.92 | 36950.96 | 57953.65 | 62.52 | 2.317 |
| | 2019 | Forest | 2 | 162793.70 | 81396.87 | 70488.78 | 124671 | 76.58 | 2.214 |
| Jardim Suspenso | 1984 | Forest | 24 | 850178.50 | 35424.10 | 86406.64 | 600487.20 | 70.63 | 1.885 |
| | 2019 | Forest | 13 | 1048700 | 80669.26 | 119580.80 | 841864.40 | 80.28 | 1.743 |
| Obede | 1984 | Forest | 8 | 238106.80 | 29763.35 | 39929.91 | 155696.30 | 65.39 | 1.824 |
| | 2019 | Forest | 5 | 296946 | 59389.21 | 78592.1 | 237446.70 | 79.96 | 1.954 |
| Paca | 1984 | Forest | 22 | 488854 | 22220.64 | 25207.33 | 316198.40 | 64.68 | 1.578 |
| | 2019 | Forest | 11 | 655154.30 | 59559.48 | 72245.1 | 498707 | 76.12 | 1.865 |
| *Continuation* | | | | | | | | | |
| | 1984 | Natural grasslands | 4 | 134784.40 | 33696.10 | 28222.66 | 91962.01 | 68.23 | 1.688 |

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| Ottobasins | Year | Classes | NP | CA | ACS | MSDC | TCA | ICA | MSI |
|---|---|---|---|---|---|---|---|---|---|
| Peixe | | Forest | 27 | 1077596 | 39910.96 | 107250.50 | 796547.30 | 73.92 | 1.967 |
| | 2019 | Natural grasslands | 1 | 16806.22 | 16806.22 | 0 | 12012.28 | 71.48 | 1.112 |
| | | Forest | 13 | 1163916.00 | 89532.04 | 124470.60 | 916437.9 | 78.74 | 1.899 |
| Retiro II-Zeca da Mulata-Escorpião | 1984 | Forest | 73 | 5810803.00 | 79600.04 | 222095.60 | 4435926.00 | 76.34 | 1.955 |
| | 2019 | Natural grasslands | 1 | 91820.69 | 91820.69 | 0 | 72580.73 | 79.05 | 1.849 |
| | | Forest | 23 | 10135081 | 440655.70 | 1153368 | 8948206 | 88.29 | 2.13 |
| Serra Azul | 1984 | Forest | 14 | 163835.10 | 11702.51 | 19702.16 | 99894.14 | 60.97 | 1.538 |
| | 2019 | Forest | 6 | 302369.10 | 50394.85 | 73586.23 | 228135.70 | 75.45 | 1.891 |
| Santuário-Brega | 1984 | Forest | 13 | 81338.64 | 6256.82 | 11292.19 | 28974.56 | 35.62 | 2.305 |
| | 2019 | Forest | 6 | 137052.40 | 22842.06 | 22591.67 | 92475.94 | 67.47 | 1.694 |
| Vicente Amargoso | 1984 | Forest | 4 | 175085.30 | 43771.32 | 53214.18 | 117726.10 | 67.24 | 2.154 |
| | 2019 | Forest | 6 | 194128.70 | 32354.79 | 46511.84 | 143450.00 | 73.89 | 1.706 |
| Zizinho | 1984 | Forest | 5 | 31395.14 | 6279.03 | 5924.56 | 13289.00 | 42.33 | 2.187 |
| | 2019 | Forest | 5 | 31731.44 | 6346.29 | 5627.34 | 16925.49 | 53.34 | 1.535 |

NP: number of patches. CA: class area ($m^2$). ACS: average class size; MSDC: mean standard deviation of the class; TCA: total central area of the class; ICA: index in % of the central area of the class; MSI: mean shape index.