Brazilian obligatory subterranean fauna and threats to the hypogean environment

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Abstract

The subterranean environment harbors species that are not capable of establishing populations in the epigean environment, i.e., the obligatory subterranean species. These organisms live in a unique selective regime in permanent darkness and usually low food availability, high air humidity in terrestrial habitats, and low temperature range allied to other unique conditions related to lithologies and past climatic influences. The pressure to increase Brazil’s economic growth relies on agricultural/pastoral industries and exporting of raw materials such as iron, limestone, ethanol, soybean, cotton, and meat, as well as huge reservoir constructions to generate electricity. Mining (even on a small scale), agricultural expansion, and hydroelectric projects are extremely harmful to subterranean biodiversity, via the modification and even destruction of hypogean habitats. The Brazilian subterranean species were analyzed with respect to their distributions, presence on the IUCN Red List, and current and potential threats to hypogean habitats. A map and three lists are presented, one with the described obligatory subterranean species, one with undescribed taxa, and one with the current and potential threats to the hypogean environment. To date, 150 obligatory subterranean species have been recorded in Brazil, plus at least 156 undescribed troglobiotic taxa, totaling 306 Brazilian troglobites/obligatory cave fauna. We also analyzed the current and potential cave threats and the conservation actions that are underway to attempt to compensate for loss of these habitats. In according to the Brazilian legislation (Decree 6640) only caves of maximum relevance are fully protected. One strategy to protect the subterranean fauna of Brazil is the inclusion of these species in the IUCN Red List (one of attributes that determines maximum relevance for caves); however, one of the IUCN assumptions is that the taxa must be formally described. It is clear that the description and proposed protection of Brazilian subterranean biodiversity depends on more systematics studies.

Keywords
caves, Neotropical region, IUCN Red list, troglobites
Introduction

The most obvious intrinsic feature of subterranean environments is the absence of light, which results in energy restriction (Poulson and White 1969, Poulson and Lavoie 2000). Furthermore, subterranean environments tend to be environmentally stable in terms of low temperature, high relative humidity, and complete darkness (Moore and Sullivan 1997). Consequently, few organisms are capable of effectively colonizing these environments (Barr 1968).

Obligatory subterranean species have evolved in isolation under particular selective conditions, such as complete darkness, low food quantity (with exceptions), and high and constant air humidity for terrestrial species. Obligatory subterranean species have accumulated specializations that are not present in their epigean relatives, which have culminated in exclusively subterranean populations that are no longer capable of colonizing the epigean realm (Trajano 2012).

The importance and fragility of hypogean environments was acknowledged when subterranean species were placed on the IUCN Red List by the environmental government agency in 2004 (IBAMA) and 2014 (ICMBio) (Machado et al. 2008, ICMBio 444 2014 and ICMBio 445 2014). The inclusion of obligatory subterranean species in the IUCN Red List elevates caves to the maximum relevance level (out of four levels of relevance - maximum, high, median, and low), meaning that the cave habitat must be protected (Decree 6640 from November 7, 2008 (Brasil 2008), Normative Instruction [NI] number 2 from August 20, 2009; Normative Instruction [NI] number 2 from August 30, 2017). The biological attributes present in the Normative Instructions that elevates caves to maximum relevance are species included in official Red Lists; presence of endemic or relict troglobites; presence of rare troglobites; and occurrence of unique ecological interactions.

The hypogean environment is fragile and, thus, highly vulnerable to environmental changes; it typically presents high endemism and small population sizes with low restoration capacity, which implies that obligatory subterranean fauna is sensitive to habitat changes, such as chemical pollution, eutrophication, deforestation close to the outcrops and drainages, uncontrolled tourism, mining, dams, etc. (Poulson 1964, Culver and Pipan 2009).

Extinction rates and disturbances caused by human activities are significant (Pimm et al. 1995), thus the knowledge of biodiversity becomes a fundamental tool to recognize threats to biodiversity. Financial resources for documenting biodiversity must be prioritized, as they are essential to establishing and developing best conservation policies (Brooks et al. 2006).

Knowledge of the geographical distribution of obligatory subterranean fauna in Brazil is fragmented compared to Europe and Asia, where a higher level of knowledge has been achieved (Botosaneanu 1986, Juberthie and Decu 2001, Deharveng et al. 2009, Stoch et al. 2009, Brancelj et al. 2013). The first list of obligatory subterranean fauna of Brazil was published in the 1980s and comprised five areas (Dessen et al. 1980). Since then, these lists have been constantly reviewed (Trajano 1987, Trajano
and Gnaspini-Netto 1991, Gnaspini and Trajano 1994, Pinto-da-Rocha 1995, Trajano and Bichuette 2010a). Herein we update and elaborate on the list of Brazilian obligatory subterranean fauna, mapping in detail the areas/regions with this fauna and its main threats.

**Materials and methods**

To construct the list, species descriptions, literature data, and sampling conducted by our group were utilized. The undescribed taxa were confirmed by specialists and are deposited in Brazilian collections (Museu Nacional do Rio do Janeiro/Universidade Federal do Rio de Janeiro, Instituto Butantan, Museu de Zoologia da Universidade de São Paulo). The information contained in two existing faunistic lists is expanded upon: one with the formally described obligatory subterranean fauna and the other containing the troglomorphic taxa (possible obligatory subterranean fauna detailed to as accurate taxonomic level as possible).

The purpose of the inclusion of undescribed troglomorphic taxa was to propose potential areas for conservation (since they are not included in the IUCN Red List). To avoid overestimation of taxa, we did not use data from environmental impact assessment reports.

The geomorphologic units used follow Karmann and Sanchez (1979). Groups: main uninterrupted limestone rocks (Una-Irecê, Corumbá, Bambuí, Açungui, Rio Pardo, Araras, Brusque, Apodi); superfamilies: main interrupted limestone rocks (Canudos); sandstone: main sandstone rocks (Altamira-Itaituba, Chapada Diamantina); formation: main iron ore rocks (Carajás, Quadrilátero Ferrífero). Since the Bambuí group is huge, we divided it into regions, based on municipalities (Presidente Olegário, Mambaí, São Domingos, São Desidério, Itacarambi, Jaíba, Montes Claros, Cordisburgo, Unaí, Distrito Federal) or based on continuous outcrops (Serra da Canastra, Serra do Ramalho). Other minor geomorphological units used are Serra do Mar and Serra da Mantiqueira (quartzitic), Vargem Alta (marble), and Itirapina (sandstone).

The threats listed herein are those that directly disturb the hypogean environment and its fauna, such as small and large hydroelectrical projects, mining projects, deforestation, uncontrolled tourism, chemical pollution, and lowering of the water table due to extraction of water; and indirect threats such as roads, land conflicts and gas extraction. The main threats were listed for municipalities and for some Brazilian geomorphologic units.

The map was created on QuantumGis Essen 2.14 with shapefiles of South America and Brazil. Besides these, we used the shapefile of Brazilian karst areas, available at the CECAV/ICMBIO website. Circle size is proportional to the number of species occurring in each area and was plotted using Adobe Illustrator CS6.

To evaluate the addition of Brazilian subterranean species in the IUCN Red lists, we compared the number of species presented in the 2004 IUCN Red List (Machado et al. 2008) and the 2014 IUCN Red List (ICMBio 444 2014 and ICMBio 445
We distinguished between the species not rated in the IUCN Red List as “not reported” and “not included”. “Not reported” refers to species that were not revised and “not included” are species that were revised and do not fit into any threat category: vulnerable (VU), endangered (EN), and critically endangered (CR). The term IUCN Red List used herein correspond to the Brazilian List of Threatened Fauna.

Results

Presently, Brazil has 150 described obligatory subterranean species, distributed over 12 states and located in different lithologies and geomorphologic groups (Figure 1, Table 1). The majority of these species occur in limestone rocks (123 species), mainly owing to the vast size of limestone geomorphologic units and the higher sampling effort in this lithology. Even with the high number of impact reports (mainly mining) regarding iron ore lithologies, and the increase in studies and inventories over the last ten years after publication of Decree 6640, there has been few described species (twelve species). In the other lithologies, sandstone contains less described species than does iron ore (ten species); for quartzitic and marble lithologies, we recorded only two obligatory subterranean species, one for each. Besides, there are two hyporheic fishes, one from Pará State and another from Rondônia State.

At least 156 troglomorphic/stygomorphic taxa are undescribed (Figure 1, Table 2), representing possible obligatory subterranean populations; these collections, deposited in different museums, await further taxonomic studies. Most of these specimens have not been identified to even a generic taxonomic level. In total, we listed approximately 306 obligatory and potentially obligatory subterranean species for Brazil (Tables 1 and 2). The Brazilian states with the highest number of species are Bahia (Serra do Ramalho karst area and São Desidério region, part of the Bambuí group, the Una-Irecê and Rio Pardo groups, the Canudos supergroup and the sandstone Chapada Diamantina; at least 90 obligatory subterranean species) and São Paulo (including part of the Açungui group, with at least 66 obligatory subterranean species) (Figure 1). Considering the geomorphologic units used here, the Bambuí group is the richest with 100 obligatory subterranean species followed by the Açungui group with 73 obligatory subterranean species.

In total, eight threats are identified in the Bahia State (Table 3) and the majority of the caves in this State are outside conservation units (natural areas liable for protection by law owing to special features), the exception being in the Andaraí and Lençóis regions, where the sandstone caves are recorded inside a conservation unit. For São Paulo State, the amount of threats are fewer (five, Table 3), but there is a concentration of them in areas that contain a high number of subterranean species, e.g., the Alto do Ribeira region – deforestation, land conflicts, pollution of subterranean drainage, small hydroelectric power-stations buildings (SHPS) and uncontrolled tourism.

The most common threat to the hypogean environment (Figure 1, Table 3) was miscellaneous impacts, with historical threats (e.g., deforestation related to agriculture/pastures and mining). For example, from the 29 impacted regions, deforestation for
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Figure 1. Map of Brazil with main rock groups, karst areas, and formations with obligatory cave-dwelling species. Threats are indicated by letters as follows: A Minig B Reservoir construction C Deforestation for pastures D Deforestation for agriculture E Pollution of subterranean drainages F Tourism G Land conflict H Road construction, I Lowering of water table J Small hydroelectric power station buildings, K Pesticides L Natural gas and oil exploration. For Bambuí group, we grouped as follows (see Table 1 for distinction):

- Mambaí region - Mambaí and Posse municipalities; Distrito Federal region - Distrito Federal region plus Formosa and Padre Bernardo municipalities; Presidente Olegário region - Presidente Olegário and Vazante municipalities; Serra da Canastra region - São Roque de Minas, Arcos and Pains municipalities; Cordisburgo region - Cordisburgo, Matozinhos, Sete Lagoas, Morro do Pilar, Monjolos and Lagoa Santa municipalities; Montes Claros region - Montes Claros, Coração de Jesus and Luislândia municipalities.

agricultural and/or pastures occurred in 17 (58.6 %); mining in 15 (51.7 %), uncontrolled tourism in six, as is also the case for pollution (20.7 % each); hydroelectric projects are present in five (17.2 %). Roads, land conflicts, gas extraction, and lowering of the water table are more widespread and are present in five regions (17.2 %). Caves included in conservation units are not fully protected - for example, the Açungui group in southeastern Brazil (where there are three State Parks) is under five different threats (Figure 1, Table 3). Specifically, considering the Carajás region in North Brazil, we observed that only mining had an impact that would deplete the entire subterranean environment and lead to the total destruction of landscapes and caves (by mining), with the possible pollution of soil and drainage ways.

Considering the described subterranean species up to the end of 2003, only 33 were included in the Brazilian Red List of 2004 and another 30 species were “not re-
Table 1. Obligatory subterranean fauna described in Brazil (149 species) and IUCN Red List threatened species categories. VU – vulnerable; EN – endangered; CR – critically endangered; LC – least concern; DD – data deficient. SNR – still not rated, see text for explanations. States: BA – Bahia, GO – Goiás, MG – Minas Gerais, MS – Mato Grosso do Sul, MT – Mato Grosso, PA – Pará, PR – Paraná, RO – Rondônia, RN – Rio Grande do Norte, SP – São Paulo.

| Higher taxon | Species | Lithology / Geomorphological Unit / Karstic area or Region (State) | Category 2004 | Category 2014 |
|-------------|---------|-------------------------------------------------------------|---------------|---------------|
| Phylum Platyhelminthes | | | | |
| Class Turbellaria | | | | |
| Order Tricladida | | | | |
| Dimarcusidae | *Hausera hauseri* Leal-Zanchet & Souza, 2014 | Limestone / Apodi group / Felipe Guerra region (RN) | – | SNR |
| Dugesiidae | *Girardia multidiverticulata* Souza, Morais, Condeiro & Leal-Zancheti, 2015 | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | – | SNR |
| | *Girardia desiderensis* Souza & Leal-Zancheti, 2016 | Limestone / Bambuí group / São Desidério region (BA) | – | SNR |
| Phylum Porifera | | | | |
| Class Demospongiae | | | | |
| Order Haplosclerida | | | | |
| Spongillidae | *Racekiela cavernicola* Volkmer-Ribeiro, Bichuette & Machado, 2010 | Limestone / Una-Irecê group / Morro do Chapéu region (BA) | – | CR |
| Phylum Arthropoda | | | | |
| Class Malacostraca | | | | |
| Order Amphipoda | | | | |
| Hyalellidae | *Hyalella caeca* Pereira, 1989 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | SNR |
| | *Hyalella spelaea* Bueno & Cardoso, 2011 | Sandstone / Itirapina region (SP) | – | SNR |
| | *Hyalella veredae* Cardoso & Bueno, 2014 | Limestone / Bambuí group / Vazante formation / Presidente Olegário region (MG) | – | SNR |
| | *Hyalella formosa* Cardoso & Araujo, 2014 | Limestone / Açungui group / Alto do Ribeira karst area (PR) | – | SNR |
| | *Hyalella epikarstica* Rodrigues, Bueno & Ferreira, 2014 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | – | SNR |
| Artesiidae | *Megagidiella azul* Koemenann & Holsinger, 1999 | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | “Not reported” | SNR |
| | *Spelaeogammarus bahiensis* Brum, 1975 | Limestone / Una-Irecê group / Curaxá region (BA) | “Not reported” | SNR |
| | *Spelaeogammarus unitanensis* Koemenann & Holsinger, 2000 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | “Not reported” | SNR |
| | *Spelaeogammarus spinilacertus* Koemenann & Holsinger, 2000 | Limestone / Una-Irecê group / Iraquara region (BA) | “Not reported” | SNR |
| Mesogammaridae | *Spelaeogammarus trinacronae* Koemenann & Holsinger, 2000 | Limestone / Una-Irecê group / Campo Formoso region (BA) | “Not reported” | SNR |
| | *Spelaeogammarus titan* Senna, Andrade, Castelo-Branco & Ferreira, 2014 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | – | SNR |
| | *Spelaeogammarus sanctus* Bastos-Pereira & Ferreira, 2015 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | – | SNR |
| | *Spelaeogammarus natut* Bastos-Pereira & Ferreira, 2017 | Limestone / Bambuí group / Itaparicambi region (MG) | – | – |
| Seborgiidae | *Pseibera praesauropoda* Fiser, Zagmajter & Ferreira, 2013 | Limestone / Apodi group / Felipe Guerra region (RN) | – | SNR |
| | *Seborgia potiaguara* Fiser, Zagmajter & Ferreira, 2013 | Limestone / Apodi group / Governador Dix-Sept Rosado region (RN) | – | SNR |
| Aeglidae | *Aegla cavernicola* Turkay, 1972 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
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| Higher taxon | Species | Lithology / Geomorphological Unit / Karstic area or Region (State) | Category 2004 | Category 2014 |
|--------------|---------|---------------------------------------------------------------|---------------|---------------|
| **Aeglida**  | *Aegla leptochaeta* Bond-Buckup & Buckup, 1994               | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU            | CR            |
|              | *Aegla micropthalma* Bond-Buckup & Buckup, 1994             | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU            | CR            |
| **Order Isopoda** |                                                 |                                                             |               |               |
| **Calabozoidae** |                                                 |                                                             |               |               |
|              | *Pongycarcinia xiphioidea* Messana, Baratti & Benvenuti, 2002 | Limestone / Una-Irecê group / Campo Formoso region (BA) | "Not reported" | SNR           |
| **Brasilinriinae** |                                                 |                                                             |               |               |
|              | *Brazilinrinus canaliculus* Pryorominick, Ferreira & Sket, 2011 | Limestone / Canudos supergroup / Paripiranga region (BA) | –             | SNR           |
| **Oedopoidea** |                                                 |                                                             |               |               |
| **Philoscidiidae** |                                                 |                                                             |               |               |
|              | *Benthana spongiogena* Lima & Serejo, 1993                  | Limestone / Açungui group / Alto do Ribeira karst area (SP) | "Not reported" | SNR           |
|              | *Leonardossia basalli* Campos-Filho, Araujo & Taiti, 2014   | Sandstone / Altamira-Iaituha group / Altamira region (PA) | –             | SNR           |
| **Pudeoniscidae** |                                                 |                                                             |               |               |
|              | *Iansaoniscus georginae* Campos-Filho, Araujo & Taiti, 2017 | Limestone / Una-Irecê group / Campo Formoso region (BA) | –             | –             |
|              | *Iansaoniscus iraquara* Campos-Filho, Araujo & Taiti, 2017  | Sandstone / Altamira-Iaituha group / Altamira region (PA) | –             | –             |
| **Order Scleropoda** |                                                 |                                                             |               |               |
| **Scleropactidae** |                                                 |                                                             |               |               |
|              | *Amazoniscus eleonorae* Souza, Ferreira & Araujo, 2006      | Limestone / Altamira-Iaituha group / Altamira region (PA) | –             | SNR           |
|              | *Amazoniscus leistikowi* Campos-Filho, Araujo & Taiti, 2014 | Sandstone / Altamira-Iaituha group / Altamira region (PA) | –             | SNR           |
|              | *Cirrinitus buchelli* Campos-Filho & Araujo, 2011           | Iron ore / Carajás formation / Parauapebas region (PA) | –             | SNR           |
|              | *Cirrinitus camptoaenius* Campos-Filho & Araujo, 2011       | Iron ore / Carajás formation / Canção dos Carajás region (PA) | –             | SNR           |
| **Styloniscidae** |                                                 |                                                             |               |               |
|              | *Spelunconiscus castroi* Campos-Filho, Araujo & Taiti, 2014 | Limestone / Bambuí group / Matozinhos region (MG) | –             | SNR           |
|              | *Xangoniscus aganju* Campos-Filho, Araujo & Taiti, 2014     | Limestone / Bambuí group / Matozinhos region (MG) | –             | SNR           |
|              | *Xangoniscus itacarambeiensis* Bastos-Pereira, Souza & Ferreira, 2017 | Limestone / Bambuí group / Parauapebas region (PA) | –             | –             |
| **Order Styloniscidae** |                                                 |                                                             |               |               |
|              | *Iuiuniscus iuiuensis* Souza, Ferreira & Senna, 2015       | Limestone / Bambuí group / Matozinhos region (MG) | –             | SNR           |
| **Order Spelaeogriphacea** |                                                 |                                                             |               |               |
| **Spelaeogriphidae** |                                                 |                                                             |               |               |
|              | *Potiicoara brasiliensis* Pires, 1987                       | Limestone / Corumbá and Araras groups / Serra da Bodoquena karst area (MS) and Rosário Oeste region (MT) | "Not reported" | SNR           |
| **Class Chelicerata** |                                                 |                                                             |               |               |
| **Order Amblypygi** |                                                 |                                                             |               |               |
| **Charinidae** |                                                 |                                                             |               |               |
|              | *Charinus troglodytus* Baptista & Giupponi, 2002            | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | CR            | CR            |
|              | *Charinus eleonore* Baptista & Giupponi, 2003              | Limestone / Bambuí group / Itacarambi region (MG) | "Not reported" | CR            |
|              | *Charinus caatingae* Vasconcelos & Ferreira, 2016          | Limestone / Una-Irecê group / Várzea Nova region (BA) | –             | –             |
|              | *Charinus tabua* Vasconcelos, Giupponi & Ferreira, 2016    | Limestone / Bambuí group / Sete Lagoas region (MG) | –             | SNR           |
|              | *Charinus ferreus* Giupponi & Miranda, 2016               | Iron ore / Carajás formation / Serra de Carajás (PA) | –             | SNR           |
|              | *Charinus spelaeus* Vasconcelos & Ferreira, 2017           | Limestone / Bambuí group / Presidente Juscelino region (MG) | –             | –             |
| **Order Araneae** |                                                 |                                                             |               |               |
| **Theraphosidae** |                                                 |                                                             |               |               |
|              | *Timexiphanthos hypogaeus* Bertani, Bichuette & Pedrasso, 2013 | Sandstone / Chapada Diamantina region (BA) | –             | CR            |
| **Dipluridae** |                                                 |                                                             |               |               |
|              | *Harmonicon cerberus* Pedrasso & Baptista, 2014            | Iron ore / Carajás formation / Parauapebas region (PA) | –             | CR            |
| **Ctenidae** |                                                 |                                                             |               |               |
|              | *Isotetus corymbulus* Polotow, Brescovit & Pellegatti-Franco, 2005 | Limestone / Bambuí group / São Domingos karst area (GO) | –             | CR            |
| **Ochyroceratidae** |                                                 |                                                             |               |               |
|              | *Spencera eleonore* Baptista, 2003                        | Limestone / Bambuí group / Serra da Bodoquena karst area (MS) | "Not reported" | EN            |
| Higher taxon              | Species                                           | Lithology / Geomorphological Unit / Karstic area or Region (State) | Category 2004 | Category 2014 |
|--------------------------|---------------------------------------------------|--------------------------------------------------------------------|---------------|---------------|
| Ochyroceratidae          | Ochyroceras ibitipoca Baptista, Gonzalez & Tourinho, 2008 | Quartzitic / Serra da Mantiqueira / Lima Duarte (MG)                | –             | EN            |
| Pholcidae                | Metagonia diamantina Machado, Ferreira & Brescovit, 2011 | Limestone / Una-Irecê group / Itaeté region (BA)                   | –             | CR            |
|                          | Metagonia potiguar Ferreira, Souza, Machado & Brescovit, 2011 | Limestone / Apodi group / Felipe Guerra region (RN)                  | –             | CR            |
| Prodidomidae             | Lysogennes yaguenae Rheims & Brescovit, 2004       | Limestone / Bambuí group / Cordisburgo region (MG)                  | –             | CR            |
| Symphytognathidae        | Anapistula guyri Rheims & Brescovit, 2003         | Limestone / Bambuí group / São Domingos karst area (GO)             | VU            | LC            |
| Order Opiliones          |                                                   |                                                                    |               |               |
| Gerdesiidae              | Gonyoxenus plato Bragagnolo, Hara & Pinto-da-Rocha, 2015 | Limestone / Bambuí group / Morro do Pilár region (MG)               | –             | –             |
|                          | Pachylaepeles strinatus Silhavy, 1974              | Limestone / Açungui group / Alto do Ribeira karst area (SP)         | VU            | EN            |
|                          | Landosomaeta uiti Pinto-da-Rocha, 1996             | Limestone / Bambuí group / Itacarambi region (MG)                   | CR            | CR            |
|                          | Landosomaeta smegel Pinto-da-Rocha, Fonseca-Ferreira & Bichuette, 2015 | Limestone / Bambuí group / Monjolos region (MG)                     | –             | –             |
|                          | Landosomaeta siringapucu Hara & Pinto-da-Rocha, 2008 | Limestone / Bambuí group / Coração de Jesus region (MG)             | –             | EN            |
|                          | Giupponia chagasi Pérez & Kury, 2008              | Sandstone / Chapada Diamantina region (BA)                          | CR            | CR            |
|                          | Discocyrtus pedrului Kury, 2008                   | Limestone / Bambuí group / Serra do Ramalho karst area (BA)         | CR            | CR            |
|                          | Enacrus elinae Kury, 2008                         | Limestone / Una-Irecê group / Iraquara region (BA)                  | –             | EN            |
|                          | Spinopilar moria Kury & Pérez-González, 2008      | Limestone / Bambuí group / Cordisburgo region (MG)                  | –             | CR            |
| Escadabiidae             | Spelaeoleptes spaeleus Soares, 1966               | Limestone / Bambuí group / Cordisburgo region (MG)                  | EN            | EN            |
| Kimulidae                | Relictopus galadriel Pérez-González, Monte & Bichuette, 2017 | Limestone / Bambuí group / Itacarambi region (MG)                   | –             | –             |
| Order Palpigradi         |                                                   |                                                                    |               |               |
| Eukoeneniidae            | Eukoenenia maqueenii Souza & Ferreira, 2010       | Limestone / Bambuí group / Cordisburgo region (MG)                  | –             | CR            |
|                          | Eukoenenia spelunc Souza & Ferreira, 2011         | Marble / Vargem Alta region (ES)                                    | –             | CR            |
|                          | Eukoenenia virgindalapa Souza & Ferreira, 2012    | Limestone / Bambuí group / Vazante formation / Vazante region (MG)  | –             | EN            |
|                          | Eukoenenia sagarana Souza & Ferreira, 2012        | Limestone / Bambuí group / Cordisburgo region (MG)                  | –             | CR            |
|                          | Eukoenenia jequitinhonha Souza & Ferreira, 2016   | Granitic / Carai region (MG)                                        | –             | –             |
|                          | Eukoenenia cavaticta Souza & Ferreira, 2016       | Limestone / Bambuí group / Arcos region                             | –             | –             |
| Order Pseudoscorpiones   |                                                   |                                                                    |               |               |
| Bochicidae               | Spelaeobochica allidentatus Mahnert, 2008          | Limestone / Una-Irecê group / Palmeiras region (BA)                 | “Not reported” | CR            |
|                          | Spelaeobochica muchuneri Andrade & Mahnert, 2003  | Limestone / Açungui group / Alto do Ribeira karst area (SP)         | “Not reported” | EN            |
|                          | Spelaeobochica inui Ratton, Mahnert & Ferreira, 2012 | Limestone / Bambuí group / Serra do Ramalho karst area (BA)        | –             | CR            |
| Chthoniidae              | Mascherina ipomongae Mahnert & Andrade, 1998      | Limestone / Açungui group / Alto do Ribeira karst area (SP)         | EN             | CR            |
|                          | Pseudochthonius striatit Beier, 1969               | Limestone / Açungui and Bambuí groups / Alto do Ribeira karst area (SP-PR) and Sete Lagoas region (MG) | VU             | DD            |
|                          | Pseudochthonius biseriatus Mahnert, 2001          | Limestone / Bambuí group / Itacarambi region (MG)                   | “Not reported” | CR            |
| Ideorncidae              | Ideorncus cavica Mahnert 2001                     | Limestone / Açungui group / Alto do Ribeira karst area / Ipomarã (SP) and Rio Branco do Sul regions (PR) | “Not reported” | VU            |
| Higher taxon | Species | Lithology / Geomorphological Unit / Karstic area or Region (State) | Category 2004 | Category 2014 |
|-------------|---------|---------------------------------------------------------------|---------------|---------------|
| Order Scorpionidae | Troglorhopalurus translucidus Lourenço, Baptista & Giupponi, 2004 | Sandstone / Chapada Diamantina region (BA) | – | EN |
| | Troglorhopalurus lacrus (Lourenço & Pinto-da-Rocha, 1997) | Limestone / Una-Irecê group / Itacét region (BA) | “Not reported” | EN |
| Class Chilopoda | | | | |
| Order Scolopendromorpha | Cryptops (Trygonocryptops) iporanguensis Ázara & Ferreira, 2013 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | – | EN |
| | Cryptops (Cryptops) spelaeoptor Ázara & Ferreira, 2014 | Limestone / Una-Irecê group / Campo Formoso region (BA) | – | VU |
| | Scolecoptops troylacaudatus Chagas-Jr. & Bichuette, 2015 | Sandstone / Chapada Diamantina region (BA) | – | SNR |
| Class Diplopoda | | | | |
| Order Glomeromorpha | Pseudonannolene lundi Ázara & Ferreira, 2015 | Limestone / Bambuí group / Luislândia region (MG) | – | SNR |
| Class Entognatha | Oncinocampa trajanoae Condé, 1997 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | “Not reported” | SNR |
| Order Collembola | Arrhopalites amori / Palacios-Vargas & Zeppelini, 1995 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
| | Arrhopalites gnaspini / Palacios-Vargas & Zeppelini, 1995 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
| | Arrhopalites laurencii / Palacios-Vargas & Zeppelini, 1995 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
| | Arrhopalites adulteratus Zeppelini, 2006 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | – | CR |
| | Arrhopalites boesenbergii Zeppelini, 2006 | Limestone / Brusque group / Botuverá region (SC) | – | CR |
| | Arrhopalites heteroculatus Zeppelini, 2006 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | – | CR |
| | Arrhopalites pantanalensis Zeppelini, 2006 | Limestone / Açungui group / Alto do Ribeira karst area (PR) | – | CR |
| Class Hypogastruridae | Acherontides eisenowi Palacios-Vargas & Gnaspini-Neto, 1992 | Limestone / Açungui group / Alto do Ribeira karst area / Iporanga (SP) and Rio Branco do Sul regions (PR) | “Not reported” | EN |
| Higher taxon | Species | Lithology / Geomorphological Unit / Karstic area or Region (State) | Category 2004 | Category 2014 |
|-------------|---------|------------------------------------------------------------------|---------------|---------------|
| Paronellidae | Troglobius brasilienis Palacios-Vargas & Zeppelini, 1995 | Sandstone / Altamira-Itaituba region / Medicilândia region (PA); Limestone / Açungui group / Alto do Ribeira karst area (SP) | "Not reported" | CR |
| | Troglobius ferricus Zeppelini, Silva & Palacios-Vargas, 2014 | Iron ore / Quadrilátero Ferrífero formation / Itabirito region (MG) | – | CR |
| | Trogolaphys aelleni Yossi, 1988 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | VU |
| | Trogolaphys basleri Yossi, 1989 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | VU |
| Sminthuridae | Panarrhopalites wallacei (Palacios-Vargas & Zeppelini, 1995) | Limestone / Açungui group / Campo Formoso region (BA) | "Not reported" | SNR |
| | Troglobius brasiliensis Palacios-Vargas & Zeppelini, 1995 | Sandstone / Altamira-Itaituba region / Medicilândia region (PA); Limestone / Açungui group / Alto do Ribeira karst area (SP) | "Not reported" | CR |
| | Troglobius ferroicus Zeppelini, Silva & Palacios-Vargas, 2014 | Iron ore / Quadrilátero Ferrífero formation / Itabirito region (MG) | – | CR |
| | Trogolaphys aelleni Yossi, 1988 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | VU |
| | Trogolaphys basleri Yossi, 1989 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | VU |
| | Panarrhopalites wallacei (Palacios-Vargas & Zeppelini, 1995) | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
| | Panarrhopalites papaveroi (Zeppelini & Palacios-Vargas, 1999) | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | VU |
| Class Insecta | | | | |
| | Class Insecta | | | |
| | Order Zygentoma | | | |
| | Nicoletiidae | Cobacubana spelaea Galán, 2001 | Limestone / Una-Irecê group / Campo Formoso region (BA) | "Not reported" | SNR |
| | Order Blattaria | | | |
| | Blattellidae | Litobolatta canaryoi Gutierrez, 2005 | Limestone / Una-Irecê group / Iraquara region (BA) | – | SNR |
| | Order Coleoptera | | | |
| | Sphindidae | | | |
| | Carabidae | Schizophorus ocellatus Whitehead, 1972 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | EN |
| | | Coenazaphium tessai (Godoy & Vanin, 1990) | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | VU | CR |
| | | Coenazaphium bexerrn Gnaspini, Vanin & Godoy, 1998 | Limestone / Bambuí group / Sáo Domingos karst area (GO) | VU | VU |
| | | Coenazaphium cesaiima Gnaspini, Vanin & Godoy, 1998 | Limestone / Una-Irecê group / Itacét region (BA) | VU | CR |
| | | Coenazaphium painis Alves & Ferreira, 2002 | Limestone / Bambuí group / Pains region (MG) | VU | EN |
| | | Coenazaphium fornsos Pellegrini & Ferreira, 2011 | Limestone / Una-Irecê group / Campo Formoso region (BA) | – | VU |
| | | Coenazaphium tapiauaaua Pellegrini & Ferreira, 2011 | Iron ore / Carajás formation / Curionópolis region (PA) | – | CR |
| | | Coenazaphium cassuing Pellegrini & Ferreira, 2014 | Limestone / Una-Irecê group / Campo Formoso region (BA) | – | EN |
| | | Coenazaphium ricardoi Bená & Vanin, 2014 | Limestone / Açungui group / Alto do Ribeira karst area (PR) | – | CR |
| | | Coenazaphium amazonicus Pellegrini & Ferreira, 2017 | Iron ore / Carajás formation / Curionópolis region (PA) | – | – |
| | | | | |
| | Dytiscidae | Capelatus cesaiima Caetano, Bená & Vanin, 2013 | Iron ore / Carajás formation / Parauapebas region (PA) | – | CR |
| | | Metopius patennis Asenjo, Ferreira & Zampaulo, 2017 | Limestone / Bambuí group / Pains region (MG) | – | – |
| | Staphylinidae | | | |
| | | | | |
| | Order Hemiptera | | | |
| | Cixiidae | Ferricixius davidi Hoch & Ferreira, 2012 | Iron ore / Quadrilátero Ferrífero formation / Itabirito region (MG) | – | SNR |
| | | Kinnaridae | Limestone / Apodi group / Felipe Guerra and Governador Dix-Sept Rosado regions (RN) | – | SNR |
| | | Bixia caeca Hoch & Ferreira, 2016 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | – | SNR |
| | | | | |
| | Order Orthoptera | | | |
| | Phalangopsidae | Endevou aelpern Bolfarini & Souza-Dias, 2013 | Limestone / Una-Irecê group / Iruçu region (BA) | – | SNR |
| | | Endevou persuasense Bolfarini, 2015 | Limestone / Bambuí group / Itacarumbi region (MG) | – | – |
### Brazilian obligatory subterranean fauna and threats to the hypogean environment

| Higher taxon | Species | Lithology / Geomorphological Unit / Karstic area or Region (State) | Category 2004 | Category 2014 |
|--------------|---------|-------------------------------------------------------------------|---------------|---------------|
| Phylum Mollusca | Potamolithus troglobius Simone & Moracchiolli, 1999 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
| Class Gastropoda | Spiripokia punctata Simone, 2012 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | – | EN |
| Order Caenogastropoda | Potamolithus troglobius Simone & Moracchiolli, 1999 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
| Phylum Chordata | Potamolithus troglobius Simone & Moracchiolli, 1999 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | VU | CR |
| Order Characiformes | Stygichthys typhlops Brittan & Böhlke, 1965 | Limestone / Bambuí group / Jaíba region (MG) | VU | EN |
| Order Gymnotiformes | Eigenmannia vicentespelaea Tríques, 1996 | Limestone / Bambuí group / São Domingos karst area (GO) | VU | VU |
| Order Siluriformes | Heptapteridae | | | |
| Loricariidae | Ancistrus cryptophthalmus Reis, 1987 | Limestone / Bambuí group / Posse region (GO) | “Not reported” | EN |
| | Ancistrus formoso Sabino & Trajano, 1997 | Limestone / Córumbá group / Serra da Bodoquena karst area (MS) | VU | VU |
| | Trichomycterus itacarambis Trajano & de Pinna, 1996 | Limestone / Bambuí group / Itacarambi region (MG) | VU | CR |
| | Trichomycterus ruddi Rizzato, Costa-Jr, Trajano & Bichuette, 2011 | Limestone / Córumbá group / Serra da Bodoquena karst area (MS) | – | VU |
| | Ituglanis naembi Bichuette & Trajano, 2008 | Limestone / Bambuí group / Posse region (GO) | – | EN |
| | Ituglanis bambui Bichuette & Trajano, 2004 | Limestone / Bambuí group / São Domingos karst area (GO) | – | CR |
| | Ituglanis paesii Fernandez & Bichuette, 2002 | Limestone / Bambuí group / São Domingos karst area (GO) | “Not reported” | VU |
| | Ituglanis ramiroi Bichuette & Trajano, 2004 | Limestone / Bambuí group / São Domingos karst area (GO) | – | VU |
| | Ituglanis botucatu Rizzato & Bichuette, 2011 | Limestone / Bambuí group / Mambaí region (GO) | – | SNR |
| | Glaophyropoma spinosum Bichuette, de Pinna & Trajano, 2008 | Sandstone / Chapada Diamantina region (BA) | – | VU |
| Incertae sedis | Phreatobius cisternarum Goeldi, 1905 | Hyporheic / Ilha de Marajó (PA) | – | “Not reported” |
| | Phreatobius deuncensudus Shibata, Muriel-Cunha & de Pinna, 2007 | Hyporheic / Rio Pardo basin (RO) | – | “Not reported” |
**Table 2.** Obligatory subterranean undescribed. References: A – Dessen et al. 1980; B – Chaimowicz 1984; C – Trajano 1987; D – Trajano and Gnasini-Netto 1991; E – Trajano and Moreira 1991; F – Gnasini and Trajano 1994; G – Trajano and Sanchez 1994; H – Pinto-da-Rocha 1995; I – Bichuette 1998; J – Lourenço et al. 2004; K – Deharveng 2005; L – Trajano and Bichuette 2010a; M – Cordeiro et al. 2014; TS – this study. spp – widespread taxa possibly meaning several species. States: BA-Bahia, GO-Goiás, MG-Minas Gerais, MS-Mato Grosso do Sul, MT-Mato Grosso, PA-Pará, PR-Paraná, RJ-Rio de Janeiro, RN-Rio Grande do Norte, SC-Santa Catarina, SP-São Paulo.

| Taxon | Lithology / Geomorphological Unit / karst area or region | References |
|-------|----------------------------------------------------------|------------|
| Phylum Annelida |                                         |            |
| Class Clitellata |                                             |            |
| Subclass Oligochaeta | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M          |
| Phylum Platyhelminthes |                                         |            |
| Order Tricladida |                                         |            |
| Dugesiidae indet. 1 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS         |
| Dugesiidae indet. 2 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | L          |
| Phylum Onychophora |                                         |            |
| Order Eunonychophora |                                         |            |
| Peripatidae indet. | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M          |
| Phylum Arthropoda |                                         |            |
| Order Amphipoda |                                         |            |
| Bogidiellidae |                                         |            |
| Megagidiella sp. | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | L          |
| Hyaliellidae |                                         |            |
| Hyalella aff. pernix | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, G, H |
| Hyalella sp. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | A, D, G, H |
| Order Isopoda |                                         |            |
| Indet. 1 | Limestone / Bambuí group / Montes Claros region (MG) | A, B, H |
| Indet. 2 | Limestone / Araras group / Nobres region (MT) | L          |
| So. Oniscidea | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M          |
| Armadillidae |                                         |            |
| Veneziello sp. 1 | Magnesita / Padre Bernardo region (GO) | F, H |
| Veneziello sp. 2 | Limestone / Bambuí group / Distrito Federal region (GO) | L          |
| Bathytropidae |                                         |            |
| Neotroponiscus sp. | Iron ore / Quadrilátero Ferrífero formation / Brumadinho region (MG) | Cardoso & Araujo pers. comm. |
| Philiscidae indet. 1 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Philiscidae indet. 2 | Sandstone / Chapada Diamantina region (BA) | TS         |
| Benthabana sp. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, G, H |
| Platyarthridae |                                         |            |
| Trichobrata spp. | Limestone / Bambuí group / several regions (BA, MG, SP, PR); Iron ore / Quadrilátero Ferrífero (MG) | H, L |
| Scleropactidae indet. 1 | Sandstone / Altamira-Itainaba group / Altamira region (PA) | E, F, G, H, L |
| Styloiscidae indet. 1 | Limestone / Bambuí group / Itacarambi region (MG) | TS         |
| Styloiscidae indet. 2 | Limestone / Bambuí group / Itacarambi region and Serra do Ramalho karst area (MG and BA) | L, TS |
| Styloiscidae indet. 3 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS         |
| Styloiscidae indet. 4 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS         |
| Styloiscidae indet. 5 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | F, G, H |
| Styloiscidae indet. 6 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Styloiscidae indet. 7 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Styloiscidae indet. 8 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | B, G, H |
| Taxon                             | Lithology / Geomorphological Unit / karst area or region                                      | References |
|----------------------------------|------------------------------------------------------------------------------------------------|------------|
| Styloniscidae indet. 9           | Sandstone / Chapada Diamantina region (BA)                                                  | TS         |
| *Pectenoniscus* sp. 1            | Limestone / Brusque group / Botuverá region (SC)                                             | L          |
| *Pectenoniscus* sp. 2            | Limestone / Bambuí group / Serra do Ramalho karst area (BA)                                 | TS         |
| *Pectenoniscus* sp. 3            | Limestone / Bambuí group / Lagoa Santa region (MG)                                           | L          |
| *Pectenoniscus* sp. 4            | Limestone / Açungui group / Alto do Ribeira karst area (SP)                                 | H, L       |
| **Order Decapoda**               |                                                                                                |            |
| **Palaeomorphaeidae**            |                                                                                                |            |
| *Macrolebias* indet.             | Sandstone / Aliazam-Itaituba group / Prainha region (PA)                                     | E, G, H    |
| Subclass *Acari* indet. 1        | Sandstone / Chapada Diamantina region (BA)                                                   | TS         |
| Subclass *Acari* indet. 2        | Sandstone / Chapada Diamantina region (BA)                                                   | TS         |
| **Order Amblypygi**              |                                                                                                |            |
| *Charinus* sp.                   | Limestone / Bambuí group / Serra do Ramalho karst area (BA)                                 | L, TS      |
| **Order Araneae**                |                                                                                                |            |
| *Euryphantes* sp.                | Sandstone / Chapada Diamantina region (BA)                                                   | J, L       |
| **Subclass Acariidae**           |                                                                                                |            |
| *Ochyroceratidae* indet. 1       | Limestone / Açungui group / Alto do Ribeira karst area (SP)                                 | J, L       |
| *Ochyroceratidae* indet. 2       | Limestone / Açungui group / Alto do Ribeira karst area (SP)                                 | J, L       |
| *Ochyroceratidae* indet. 3       | Limestone / Açungui group / Alto do Ribeira karst area (SP)                                 | J, L       |
| *Ochyrocera* sp. 1               | Limestone / Bambuí group / Serra do Ramalho karst area (BA)                                 | L, TS      |
| *Ochyrocera* sp. 2               | Limestone / Bambuí group / Serra do Ramalho karst area (BA)                                 | L, TS      |
| *Eusarcus* sp. 1                 | Limestone / Una-Irecê group / Chapada Diamantina region (BA)                                 | L          |
| *Nesticus* sp. 1                 | Limestone / Una-Irecê group / Chapada Diamantina region (BA)                                 | L          |
| *Nesticus* sp. 2                 | Limestone / Una-Irecê group / Chapada Diamantina region (BA)                                 | L          |
| **Order Opiliones**              |                                                                                                |            |
| *Eusarcus* sp. 1                 | Limestone / Una-Irecê group / Chapada Diamantina region (BA)                                 | L          |
| *Eusarcus* sp. 2                 | Limestone / Una-Irecê group / Chapada Diamantina region (BA)                                 | L          |
| **Order Pseudoscorpiones**       |                                                                                                |            |
| *Eukoenenia* sp.                 | Sandstone / Chapada Diamantina region (BA)                                                   | TS         |
| *Eukoenenia* sp.                 | Sandstone / Chapada Diamantina region (BA)                                                   | TS         |
| **Order Pseudoscorpiones**       |                                                                                                |            |
| *Chernetidae* indet.             | Sandstone / Chapada Diamantina region (BA)                                                   | TS         |
| **Order Palpigradi**             |                                                                                                |            |
| *Eukoenenia* sp.                 | Sandstone / Chapada Diamantina region (BA)                                                   | TS         |
| *Eukoenenia* sp.                 | Sandstone / Chapada Diamantina region (BA)                                                   | TS         |
| Taxon | Lithology / Geomorphological Unit / karst area or region | References |
|-------|--------------------------------------------------------|------------|
| Chthoniidae indet. 1 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Chthoniidae indet. 2 | Sandstone / Chapada Diamantina region (BA) | TS |
| Chthoniidae indet. 3 | Iron ore / Quadrilátero Ferrífero (MG) | L |
| Class Diplopoda indet. 1 | Limestone / Una-Irecê group / Chapada Diamantina region (BA) | F, H |
| Diplopoda indet. 2 | Limestone / Bambuí group / Unaí region (MG) | D, H |
| Order Polydesmida indet. 1 | Limestone / Bambuí group / Formosa region (GO) | F, G, H |
| Polydesmida indet. 2 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Polydesmida indet. 3 | Iron ore / Quadrilátero Ferrífero (MG) | L |
| Polydesmida indet. 4 | Limestone / Bambuí group / Itacarambi region (MG) | K, TS |
| Chelodesmidae indet. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Aleodesmus sp. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Cryptodesmus indet. | Limestone / Açungui group / Adrianópolis region (PR) | H |
| Cryptodesmus sp. 1 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | L |
| Cryptodesmus sp. 2 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | L |
| cf. Cryptodesmidae indet. | Limestone / Una-Irecê group / Chapada Diamantina region (BA) | F, H |
| Oniscodesmidae indet. 1 | Limestone / Una-Irecê group / Chapada Diamantina region (BA) | F, H |
| Oniscodesmidae indet. 2 | Granitic / Serra do Mar / Ribeirão Pires region (SP) | F, H |
| Oniscodesmidae indet. 3 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Crypturodesmus sp. 1 | Limestone / Corumbá group / Serda da Bodoquena karst area (MS) | L, M |
| Crypturodesmus sp. 2 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | L |
| Crypturodesmus sp. 3 | Limestone / Brusque group / Botuverá region (SC) | L |
| Katandodesmus spp. | Limestone / Açungui group / several regions (PR and SP) | F, G, H |
| Katandodesmus sp. | Limestone / Corumbá group / Serda da Bodoquena karst area (MS) | F, G, H, M |
| Paradoxosomatidae indet. | Limestone / Corumbá group / Serda da Bodoquena karst area (MS) | M |
| Pyrgodesmidae indet. | Limestone / Una-Irecê group / Chapada Diamantina region (BA) | TS |
| Order Spirostreptida | | |
| Pseudonannolenidae indet. | Sandstone / Chapada Diamantina region (BA) | TS |
| Class Chilopoda | | |
| Order Geophilomorpha | | |
| Geophilidae indet. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | L |
| Order Scolopendromorpha | | |
| Cryptopidae | | |
| Cryptops sp. | Iron ore / Carajás Formation / Carajás region (PA) | L |
| Scolopendridae indet. | Sandstone / Chapada Diamantina region (BA) | TS |
| Order Lithobiomorpha indet. | Iron ore / Quadrilátero Ferrífero (MG) | L |
| Class Pauropoda indet. | Sandstone / Altamira-Itaituba group / Altamira region (PA) | TS |
| Class Symphyida indet. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | L |
| Scutigerellidae indet. | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS |
| cf. Hanseniella sp. | Limestone / Rio Pardo group (BA) | L |
| Class Entognatha | | |
| Order Collembola indet. | Limestone / Bambuí group / Itacarambi region (MG) | K, TS |
| Aribhopalitidae indet. | Limestone / Corumbá group / Serda da Bodoquena karst area (MS) | F, G, H |
| Aribhopalites sp. | Iron ore / Quadrilátero Ferrífero (MG) | L |
| Hypogastruridae | | |
| Acherontides spp. | Limestone / Brusque and Rio Pardo groups (SC and BA) | L |
| Onychiuridae indet. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, H |
| Isotomidae spp. | Granitic, Limestone and Iron ore / Serra do Mar, Bambuí group and Quadrilátero Ferrífero / several regions (SP and MG) | D, F, G, H, L |
| Taxon | Lithology / Geomorphological Unit / karst area or region | References |
|-------|--------------------------------------------------------|------------|
| Entomobryidae spp. | Limestone and Sandstone / Açungui, Bambuí, Corumbá groups and Chapada Diamantina region (BA, GO, MS, PR and SP) | F, G, H, L, M |
| Heteromurera sp. | Sandstone / Chapada Diamantina region (BA) | TS |
| Vertueella sp. | Sandstone / Chapada Diamantina region (BA) | TS |
| Cyphoderidae spp. | Granitic and Limestone / Serra do Mar, Bambuí and Corumbá groups / several regions (BA, GO, MS and SP) | F, G, H, M |
| Cyphoderus sp. | Limestone / Bambuí group / Montes Claros region (MG) | F, H |
| Paronellidae spp. | Limestone / Açungui, Una-Itacai and Corumbá groups / Alto do Ribeira karst area, Chapada Diamantina region and Serra da Bodoquena karst area (SP, BA and MS) | D, F, H, G |
| Trogolaphysa sp. | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M |
| Troglopedetes sp. 1 | Sandstone / Chapada Diamantina region (BA) | TS |
| Troglopedetes sp. 2 | Limestone / Bambuí group / São Domingos karst area (GO) | F, H, L |
| Troglobius sp. 1 | Sandstone / Altamira-Itaituba / Prainha region (PA) | E, F, H |
| Troglobius sp. 2 | Sandstone / Chapada Diamantina region (BA) | TS |
| Class Insecta | | |
| Order Blattaria | | |
| Blattellidae indet. | Sandstone / Chapada Diamantina region (BA) | TS |
| Order Coleoptera | | |
| Carabidae indet. | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS |
| Oxytreptopus sp. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, G, H, L |
| Dytiscidae indet. | Sandstone / Chapada Diamantina region (BA) | TS |
| Staphylinidae | | |
| Pselaphinae indet. 1 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, G, H |
| Pselaphinae indet. 2 | Limestone / Bambuí group / São Domingos karst area (GO) | TS |
| Pselaphinae indet. 3 | Sandstone / Chapada Diamantina region (BA) | TS |
| Arthimius sp. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, G, H, L |
| Syrbus sp. 1 | Limestone / Bambuí group / Pains region (MG) | F, H, L |
| Syrbus sp. 2 | Granitic / Serra do Mar / Rio de Janeiro region (RJ) | F, H, L |
| cf. Strombopsis sp. | Limestone / Açungui group / Alto do Ribeira karst area (SP) | F, G, H, L |
| Tenebrionidae indet. | Granitic / Serra do Mar / Rio de Janeiro region (RJ) | F, H, L |
| Order Hemiptera | | |
| Dipsoecoridae indet. | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M |
| Enicocephalidae indet. | Iron ore / Quadrilátero Ferrífero (MG) | L |
| Ortheziidae indet. | Iron ore / Quadrilátero Ferrífero (MG) | L |
| Hydrometridae indet. | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS |
| Order Hymenoptera | | |
| Formicinae indet. | Limestone / Bambuí group / São Desidério karst area (BA) | TS |
| Ponerinae indet. | Limestone / Bambuí group / São Domingos karst area (GO) | F, G, H, L |
| Order Orthoptera | | |
| Phalangopsidae indet. | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | TS |
| Phylum Mollusca | | |
| Order Caenogastropoda | | |
| Pomatiopsidae | | |
| cf. Spirosockia sp. | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M |
| Order Mesogastropoda | | |
| Potamolithus sp. 1 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | I |
| Potamolithus sp. 2 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | I |
| Potamolithus sp. 3 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | I |
| Potamolithus sp. 4 | Limestone / Açungui group / Alto do Ribeira karst area (SP) | I |
| Taxon                  | Lithology / Geomorphological Unit / karst area or region | References          |
|-----------------------|----------------------------------------------------------|---------------------|
| **Potamolithus sp. 5** | Limestone / Açungui group / Alto do Ribeira karst area (SP) | D, F, H             |
| **Potamolithus sp. 6** | Limestone / Açungui group / Alto do Ribeira karst area (SP) | I, M.E. Bichuette pers. obs. |
| cf. *Potamolithus*     | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | L                   |
| Order Pulmonata        |                                                          |                     |
| Endodontidae indet.    | Limestone / Açungui group / Alto do Ribeira karst area (SP) | L                   |
| Systrophiidae          |                                                          |                     |
| *Hapnia* sp.           | Sandstone / Chapada Diamantina region (BA)               | TS                  |
| Phylum Chordata        |                                                          |                     |
| Order Siluiformes       |                                                          |                     |
| Loricariidae           |                                                          |                     |
| *Ancistrus* sp.        | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M                   |
| Trichomycteridae       |                                                          |                     |
| Trichomycteridae indet.| Limestone / Bambuí group / Pains region (MG)              | TS                  |
| *Trichomycterus* sp. 1 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS                  |
| *Trichomycterus* sp. 2 | Limestone / Bambuí group / Serra do Ramalho karst area (BA) | TS                  |
| *Copeionodon* sp.      | Sandstone / Chapada Diamantina region (BA)               | TS                  |
| Heptapteridae           |                                                          |                     |
| Heptapteridae indet.   | Limestone / Bambuí group / Posse region (GO)              | TS                  |
| *Rhambdus* sp.         | Limestone / Corumbá group / Serra da Bodoquena karst area (MS) | M                   |
| *Rhamdopsis* sp. 1     | Limestone / Bambuí group / Cordisburgo region (MG)        | E. Trajano pers. comm. |
| *Rhamdopsis* sp. 2     | Limestone / Una-Irecê group / Chapada Diamantina region (BA) | E. Trajano pers. comm. |

**Table 3.** Threats recorded for different Brazilian regions with subterranean taxa. Highlighted in bold, intense degradation activities nowadays; highlighted in italics, potential threats in the near future. SHPS – small hydroelectric power-station buildings.

| State / Region          | Municipality | Lithology / Geomorphological Unit | Threats                                                                 |
|-------------------------|--------------|-----------------------------------|------------------------------------------------------------------------|
| Pará / North Brazil     | Altamira     | Sandstone / Altamira-Itaituba group | Reservoir construction (Belo Monte) / Deforestation for pastures        |
| –                       | Parauapebas, Carunholópolis and Canaã dos Carajas region | Iron ore / Carajás Formation | Mining                                                                 |
| Mato Grosso do Sul / Central Brazil | Bonito and Jardim regions | Limestone / Corumbá group | Deforestation for pastures / Mining projects                           |
| Mato Grosso / Central Brazil | Nobres region | Limestone / Araras group | Hydroelectric project / Mining / Deforestation for agriculture         |
| Rio Grande do Norte / Northeastern Brazil | Felipe Guerra and Governador Dix-Spet Rosado regions | Limestone / Apodi group | Mining / Natural gas and oil exploration                                |
| Bahia / Northeastern Brazil | Morro do Chapéu region | Limestone / Una-Irecê group | Pollution of subterranean drainages / Deforestation for agriculture / Mining projects |
| –                       | Iraquara     | Limestone / Una-Irecê group       | Lowering of the water table / Uncontrolled tourism                     |
| State / Region | Municipality | Lithology / Geomorphological Unit | Threats |
|---------------|--------------|-----------------------------------|---------|
| Brazil        | Carinhanha, Coribe, Santana and Santa Maria da Vitória regions | Limestone / Bambuí group - Serra do Ramalho karst area | Deforestation for charcoal production and agriculture / Mining projects |
|               | São Desidério region | Limestone / Bambuí group | Road construction (collapses of rock) / Pollution of subterranean drainage |
|               | Itaeté region | Limestone / Una-Irecê group | Uncontrolled tourism / Deforestation for pastures and agriculture |
|               | Andaraí and Lençóis regions | Sandstone / Chapada Diamantina | Illegal garimpo / Uncontrolled tourism |
|               | Paripiranga region | Limestone / Canudos supergroup | Mining projects |
| Goiás / Central Brazil | São Domingos region | Limestone / Bambuí group - São Domingos karst area | Uncontrolled tourism / Illegal mining / Deforestation for pastures and charcoal production |
|               | Posse and Mambai regions | Limestone / Bambuí group | Deforestation for pastures, agriculture and charcoal production |
|               | Distrito Federal region | Limestone / Bambuí group | Mining projects |
| Tocantins / Central Brazil | Aurora do Tocantins | Limestone / Bambuí group | Deforestation for pastures and agriculture / Mining projects |
| Minas Gerais / Southeastern Brazil | São Roque de Minas | Limestone / Bambuí group - Serra da Canastra region | Uncontrolled tourism / Deforestation for pastures |
|               | Jaíba region | Limestone / Bambuí group | Lowering of the water table / Pollution of subterranean drainage |
|               | Presidente Olegário region | Limestone / Bambuí group | SHPS / Deforestation for pastures |
|               | Caeté, Moeda and Brumadinho regions | Iron ore / Quadrilátero Ferrifero | Mining |
|               | Itacarambi and Januária regions | Limestone / Bambuí group | Deforestation for pastures and charcoal production. |
|               | Córdisburgo region | Limestone / Bambuí group | Uncontrolled tourism (Maquiné cave) / Deforestation for pastures and agriculture |
|               | Sete Lagoas region | Limestone / Bambuí group | Mining |
|               | Pains region | Limestone / Bambuí group | Mining |
|               | Serra da Mantiqueira region | Quartizitic | Deforestation for agriculture / Pollution by pesticides |
| São Paulo / Southeastern Brazil | Iporanga, Aplaí and Eldorado regions | Limestone / Açungui group - Alto do Ribeira karst area | Uncontrolled tourism / Land conflicts / Pollution of subterranean drainage due to illegal mining and tomatoes plantation / SHPS |
|               | Itirapina region | Sandstone | Deforestation for pastures and agriculture / Pollution of subterranean darinages |
|               | Serra do Mar region | Quartizitic | Deforestation for agriculture / Pollution by pesticides |
| Paraná / South Brazil | Adrianópolis and Rio Branco do Sul regions | Limestone / Açungui group - Alto do Ribeira karst area | SHPS / Deforestation for pastures and agriculture |
ported”. This corresponds to 53% of the known described subterranean species being included in the IUCN Red List at that time. From 2004 to 2014 we observe augmentation of the Red List, from 33 to 83 species, as well as an increase in the number of described obligatory subterranean species. The majority of these are in the Endangered (EN) or Critically Endangered (CR) categories, compared with the previous Red List, corroborating the fragility of this fauna. Besides there are many species that have not been evaluated (Table 1).

**Discussion**

Considering the small number of Brazilian subterranean species recorded to date (150 species plus 156 troglomorphic taxa), we highlight the extreme difficulty in effectively protecting these species. Taxonomic impediment (Linnean shortfall - most of the species have not been described and catalogued (Brown and Lomolino 1998)) is reflected in our results, including specimens of known taxa that have been stored for over 20 years that still are undescribed (e.g., Pseudoscorpiones and Diplopoda). Thus, there is an urgent need for training new taxonomists, since they can accelerate the descriptions, conduct revisionary works, and then include obligatory subterranean species in the IUCN Red List.

As observed in other studies, São Paulo and Bahia States have the highest numbers of obligatory subterranean species, since the São Paulo cave fauna is the best studied in Brazil (Dessen et al. 1980, Trajano 1987, Trajano and Gnaspini-Netto 1991). Regarding the Bahia State, the extended limestone area associated with the current semi-arid climate conditions and the history of past climates has allowed many possibilities for faunistic isolations (Trajano 1995, Trajano et al. 2016). Indeed, it is in this state that we recorded the highest number of obligatory subterranean species occurring also in other kinds of previously neglected lithologies, such as sandstone (Gallão and Bichuette 2015).

Publication of Decree 6640 and the corresponding Normative Instructions (2009, 2017), which classifies caves in terms of relevance degrees, resulted in suppression of Brazilian cave listings. The NIs recommend that subterranean studies for environmental impact assessment reports (for commercial use of the cave/subterranean habitat, such as mining) include two cave sampling campaigns, one in the dry season and one in the rainy season. Highlighting conceptual problems of the NIs, Deharveng et al. (2009) show that even after 110 samplings in European karstic areas, obligatory subterranean species were found. Subterranean fauna inventories may be so inadequate that many species become extinct, before they are discovered and identified (Schneider and Culver 2004, Zagmajster et al. 2014). Thus, adequate sampling methods in different habitats are extremely relevant (Brancelj 2002, Bichuette et al. 2015). Poor subterranean studies represent another problem considering cave conservation. Trajano and Bichuette (2010b) and Trajano et al. (2012) stressed that inadequate sampling designs for evaluation of taxonomic and ecological characteristics leads to biased conclusions, and consequently compromises the conservation of these habitats.
According to Primack and Rodrigues (2001), some species are especially vulnerable to extinction and occur in the following categories: limited occurrence area; one or few known populations; small populations; declining populations; low population density; need huge habitats; large species; species that are not effective dispersers; seasonal migrants; low genetic variability; species that require special niches; species that occur in stable environments; permanent or temporary aggregations species; and hunting or consumed species. Among these fourteen categories, obligatory subterranean fauna fit at least eight of them (highlighted in italics), revealing the fragility and vulnerability of this fauna.

Although the extent and intensity of deforestation have been relatively high in our study area, reservoir construction for hydroelectric power stations and mining projects are worse threats because these can cause total destruction or irreversible impacts (total removal or flooding) of subterranean habitats, which could lead to fauna extinction as a result of physical destruction of the habitat (Culver 1986). According to Groombridge (1992), habitat loss is the most harmful threat to vertebrates as well as invertebrates, reinforcing the harm caused by the above activities, which can decimate cave fauna.

Recognition of the importance and fragility of subterranean environments by government agencies is becoming apparent with inclusion of obligatory subterranean fauna in threatened species lists. Gallão and Bichuette (2012) stressed the importance of the IUCN Red List for the protection of obligatory subterranean fauna in Brazil. When there is such inclusion, the cave is categorized as ‘maximum totally avoiding cave destruction/suppression’, thus, the IUCN Red List becomes one of the most important tools for protecting caves in Brazil. The IUCN Red List is also an important tool for obligatory subterranean species conservation, since it is one element (among others, see Trajano and Bichuette (2010b) for a review) that includes hypogean habitats as having maximum relevance according to the new Brazilian speleological laws (Decree 6640; see Trajano 2010, 2013, Trajano and Bichuette 2010b). Another relevant and critical point is that, with the inclusion of subterranean species in the IUCN Red List, the whole habitat is being protected. Despite caves with several subterranean species being existing conservation priorities, inclusion of a single subterranean species should be enough to protect the entire cave. However, it is important that we try to protect the entire system, i.e., the cave itself, the surroundings, and the hydrographic basin and/or landscape (Gallão and Bichuette 2012).

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