



Discussion

Environmental impact assessment in Brazilian Amazonia: Challenges and prospects to assess biodiversity



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ABSTRACT

Environmental Impact Assessment (EIA) has the goal of providing decision makers with an indication of the likely environmental consequences of planned actions risking environmental changes and, when necessary, allowing revision of these actions to mitigate adverse impacts. Here we provide an overview of the efficiency of EIA with emphasis on Brazilian Amazonia and discuss the problems and challenges with this type of assessment in highly diverse ecosystems. We concentrate on the methodology and performance of EIAs for three of the most recent and largest infrastructure projects in Amazonia: the Belo Monte hydroelectric dam, the BR-319 Highway, and the Juruti bauxite mine. We conclude that all of these EIAs fall short of properly assessing the expected impact of infrastructure development in situ, and that their results had little or no effect on policy decisions. To improve the reliability and usefulness of EIAs in biologically diverse ecosystems, we suggest three relatively fast and cost-effective complementary approaches for assessing biodiversity: remote sensing, reflectance spectroscopy, and DNA meta-barcoding. We discuss how these emerging cutting-edge techniques can help in identifying environmental threats and the consequences of different activities in Amazonia. The ability to monitor the state of the environment and the likely impacts of human activities on natural resources is fundamental to evidence-based decisions on development choices, to the design of appropriate management strategies, and to mitigate biological and ecological consequences.

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1. Background

Environmental Impact Assessment (EIA) can be defined as a technical and legal system for assisting in environmental management and for supporting sustainable development (Jay et al., 2007). The purpose of EIA is the systematic identification and evaluation of potential impacts of proposed projects, plans, programs, or legislative actions, with respect to the physical–chemical, biological, cultural, and socioeconomic environment's components. EIAs also provide mechanisms for amending development proposals when necessary and for mitigating likely adverse impacts (Canter, 1996). EIAs thus supply decision makers

with information based on systematic environmental studies as well as inform public opinion (included communicating through public hearings) on the potential environmental impacts of such projects (Jay et al., 2007). Brazilian EIAs are accompanied by the 'RIMA' (meaning "EIA Report" or *Relatório de Impacto Ambiental*, in Portuguese), which is written in a non-technical style addressed to non-specialists.

The purpose of the EIA is to ensure that decision makers account for environmental impacts when deciding whether or not to proceed with any project that may alter the natural environment of a place – such as the construction of a factory, road, or dam. In some cases, the EIA may lead to an outright rejection of a project or proposal, but the primary goal is to mitigate environmental impacts while allowing for economic development. Although EIAs are in a position to identify the main potential environmental impacts, in practice it is not uncommon that their influence on decision-making is limited (Jay et al., 2007).

Many approaches have been proposed for improving EIAs in order to make them more useful, robust, and efficient. Examples include further

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training of practitioners, guidance on best and alternative practices, and regular environmental monitoring (Jay et al., 2007; Toro et al., 2010). Ferraz (2012) introduced 12 guidelines to assess environmental impacts. He suggests the decisions about why, what, when and how to sample should be made on a case-by-case basis' (Ferraz, 2012). Other reviews, evaluations, and discussions have been made of EIAs in Brazilian settings (e.g., Fearnside, 2015a; Fearnside and Graça, 2009; MPE-RO, 2006; Nitta and Naka, 2015), as well as in other countries (e.g., Barker and Wood, 1999; Toro et al., 2010; Wang et al., 2003).

Brazil is the world's 5th largest country both in terms of area and human population size. It is furthermore the country with the largest number of extant species described (UNEP-WCMC, 2016). Brazil's 1989 environmental legislation (see Appendix 1 in the Supplementary online material for a more extensive historical account) requires an EIA for numerous potentially polluting activities, but it is surprisingly vague regarding the demands for licensing each of these activities. For example, the legislation that regulates the biotic environment requires consideration of the "...biological environment and natural ecosystems - the fauna and flora, highlighting the environmental quality indicator species, scientific and economic value, rare and endangered species and areas of permanent preservation" (Art. 6° CONAMA resolution 01/86: CONAMA, 1986). However, there are no clear definitions of these species' categorizations. In practice, the biological components of Brazilian EIAs are performed as rapid inventories of specific groups (usually vertebrates, vascular plants and, in some cases, arthropods). Focus is given to rare, endemic, and/or threatened species. These studies are perhaps appropriate in fragmented landscapes and in areas for which extensive biological information is already available, notably in some well-studied fragments of Brazil's Atlantic rainforest near populated areas. In contrast, such cursory approaches are inadequate in megadiverse environments and understudied areas, such as the Amazonian rainforest (Ferraz, 2012; Peres, 2005).

The Amazon Basin comprises the largest tropical forest in the world, encompassing 5.5 million km² and accounting for approximately 40% of the rainforests and possibly 40% of all extant species on the planet (Hansen et al., 2013). It also holds 15 to 20% of the global freshwater supply (Salati and Vose, 1984). Amazonia provides essential environmental services to the world such as maintenance of biodiversity, water cycling, and carbon stocks (Fearnside, 2008; Ojea et al., 2012). Finally, Amazonia is fragile: relatively small alterations may lead to major impacts (Malhi et al., 2008). Amazonia is therefore a relevant and important area for evaluating the current and potential role of EIAs at the interface between ecosystem management and human development.

2. Environmental impact assessment in Amazonia

Here we assess three of the most recent and largest infrastructure projects in Amazonia, with a particular focus on whether ecosystem threats and potential environmental impacts were properly assessed and in accordance with the EIA principles. We chose these projects because they included activities linked to some of the most significant threats in Amazonia and because these could have synergistic, detrimental effects. We also suggest faster and more cost-effective tools to aid in the identification and quantification of biodiversity in highly diverse ecosystems. For more information about biological sampling and impact assessment see Appendix 2 in the online Supplementary material.

2.1. BR-319 highway (Fig. 1A)

The BR-319 is an 870-km long road connecting the cities of Manaus and Porto Velho. The road was initially built in 1972 and 1973, but cheaper shipping alternatives (such as barges along the rivers) resulted in the road's traffic being insufficient to justify the high maintenance costs. Due to the difficult soil conditions (unstable clay, recurrent landslides), low economic importance, and high rainfall, the road quickly

degraded and was abandoned in 1988 (Fearnside and Graça, 2006). Sections of the road at the southern and northern ends of the highway were reconstructed and paved, but work on the central stretch was held up until April 2015 when the euphemistically termed "maintenance" was approved, amounting to the proposed reconstruction in all relevant aspects except the final paving.

In 2008, after the presentation of the first version of the EIA for the central stretch (between kilometers 250 and 656, a total of 406 km) by the National Department of Traffic Infrastructure (DNIT), the EIA was rejected due to non-compliance with the terms of reference established by the Brazilian Institute of Environment and Natural Resources (IBAMA). The Ministry of the Environment then created a working group to develop guidelines and to monitor the environmental licensing of BR-319 (Brazil, MMA, 2008).

2.1.1. Prediction of impacts

Roads constitute one of the main drivers of deforestation in Amazonia (Alves, 2010; Fearnside, 2015b). Studies indicate that 87% of the deforestation in Brazilian Amazonia occurs within 25 km of a highway (Alves, 2001). Soares-Filho et al. (2006) used the SimAmazonia model to estimate deforestation in the Amazon due to construction of the BR-319. Their main conclusion was that reconstructing and paving the highway would lead to deforestation of up to 39 million hectares of forest and CO₂ emissions exceeding 4.8 billion tons by 2050. In a more conservative study, Fearnside et al. (2009) estimated the deforestation caused by the road to be in the order of 5.1 million hectares, and the CO₂ emission to be up to 950 million tons. These studies only considered the area along the highway route – essentially the interfluvium between the Madeira and Purus Rivers. However, the highway's potential impact is much greater: a planned road (AM-366) branching off of BR-319 would give access to the large block of intact forest to the west of the Purus River, opening a new frontier to deforestation and biodiversity loss (Graça et al., 2014). Migration from Rondônia would presumably not stop in Manaus at the northern end of BR-319, but would continue along the existing road network in the states of Amazonas and Roraima. A simulation of deforestation in Roraima suggests that the impact there would be substantial (Barni et al., 2015).

According to National Environmental Council (CONAMA) Resolution 1/1986, the EIA must "define the extent of the geographical area to be directly or indirectly affected by the impacts, called the area of influence of the project, considering, in all cases, the hydrographic basin in which it is located". The direct influence area defined by the EIA (in this case 5 km on each side of the road, a total of 4057 km²) disregards important factors such as degradation by illegal logging, forest conversion to agriculture, and ranching due to the facilitation of access to areas that had been previously isolated.

The main area affected by BR-319 is the Madeira-Purus interfluvium. The area has one of the highest levels of species richness in all of Amazonia (Py-Daniel et al., 2007), outstandingly high levels of endemism (Ribas et al., 2011), and is still little perturbed. Indeed, even in the 21st century, new species in well studied groups such as mammals (Röhe et al., 2009) and birds (Cohn-Haft et al., 2013) have been described from this area. It is reasonable to assume that many more species, biological interactions, and ecological niches await discovery and formal scientific description. In the lower Madeira River region, more than 60% of the area is considered "very important," 39% is considered a "priority for establishing conservation units," and 19% as a "priority for conservation" (Câmara Legislativa, 2016).

The main arguments for the construction of this road are to facilitate production in the Manaus industrial pole, connecting Manaus to the rest of Brazil through a highway system (UFAM, 2009: Vol. 1). Counterarguments include increased deforestation, loss of natural resources and biodiversity, increased carbon emissions, impacts on indigenous populations, swelling human populations through migration, overload of urban services, and the high costs of road maintenance (Fearnside et al., 2009). The EIA does not present economic evidence to justify the

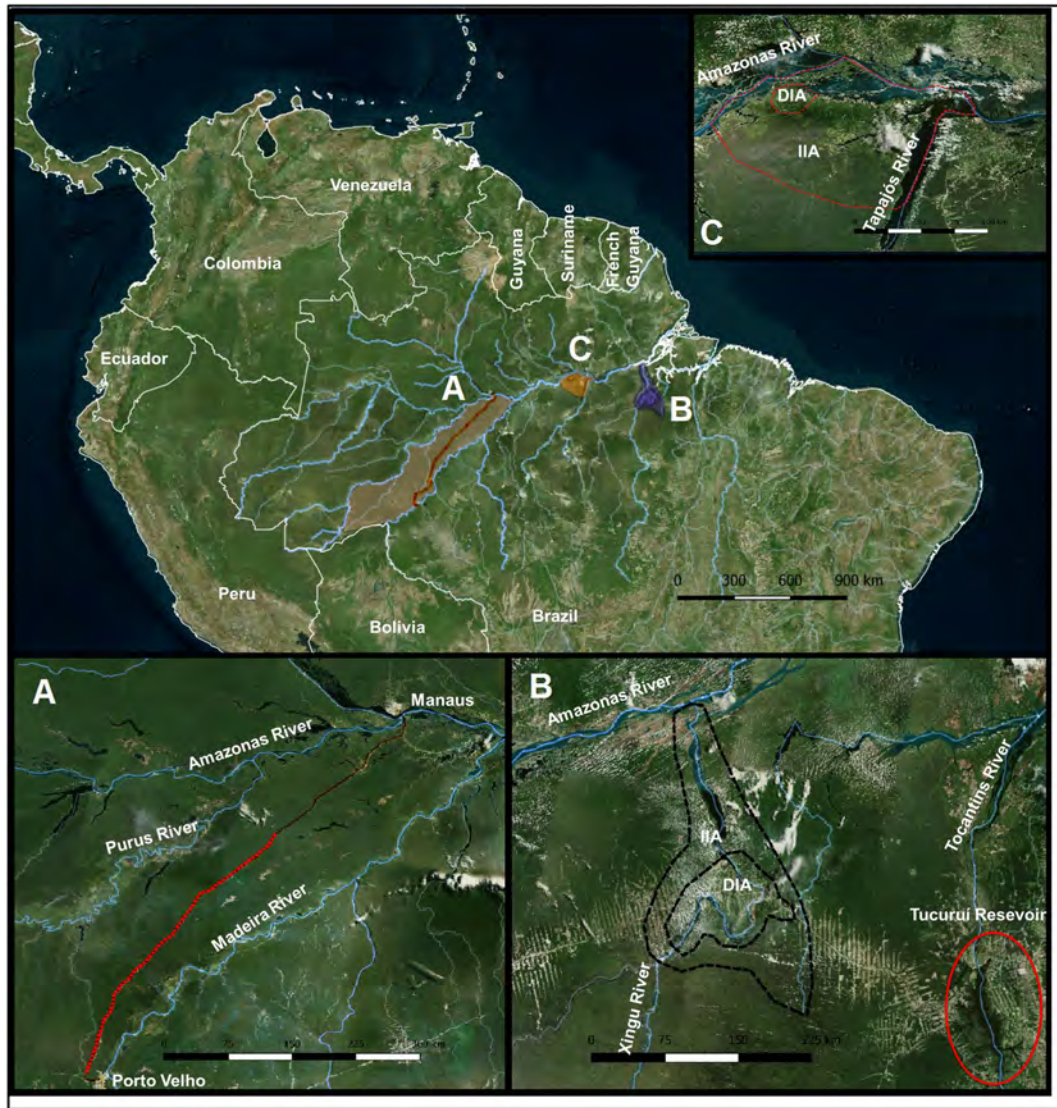


Fig. 1. Map showing the three large Amazonian infrastructure projects discussed here. A: The Madeira-Purus interfluvium, highlighting the portion of the BR-319 road that is proposed for reconstruction. B: The Direct Influence Area (DIA) and Indirect Influence Area (IIA) of the Belo Monte Dam; the circle shows the Tucuruí reservoir on the Tocantins River. C: The DIA and IIA of the Juruti bauxite mine site.

highway project in the context of the Manaus industrial pole. In fact, the cost of shipping containers from Manaus to São Paulo using the current system of barges carrying truck trailers to Belém followed by road transport on the existing highways to São Paulo is cheaper than their transport via the BR-319 would be (Fearnside and Graça, 2006).

2.2. Belo Monte Dam (Fig. 1B)

Originally named Kararaô, the Belo Monte Dam was planned already in the 1970s and 1980s by the Brazilian government, together with five other hydroelectric facilities to be installed in the Xingu River basin in southeastern Amazonia. In 1975, 14 possible damming locations were presented. Surprisingly, as stated in the EIA, social-environmental criteria were not used as a basis for the decision on where the dam should be placed. In 1989, the final environmental impact study was concluded for UHE Kararaô (CNEC/ELETRONORTE, 1989; Brazil, ELETRONORTE, s/d [2002]).

In 1994, the original plans for Kararaô were changed and a new Belo Monte Task Group was created to update and complement the feasibility and the environmental impact studies. Work on the EIA began in 2000, and a draft was completed in 2002 (Brazil, ELETRONORTE, s/d

[2002]). It was not until 2006 that the work on the EIA resumed again, and it was officially concluded and presented to IBAMA in 2009 (Brazil, ELETRONORTE, 2009). However, IBAMA considered the studies incomplete, and the same year the public attorney's office requested an injunction to "Declare as null and void the administrative act of acceptance of the EIA/RIMA delivered by IBAMA" (MPF, 2008). The licenses were granted despite non-compliance with IBAMA's requirements (Fearnside, 2012). The reservoir was filled in December 2015, and the 233-MW supplementary powerhouse and the first turbines of the 11,000-MW main powerhouse are now being used commercially. When the full capacity of 11,233 MW is reached, expected in 2019, Belo Monte will be the world's third largest hydroelectric dam.

The axis of the main dam is located on the Xingu River, some 40 km downstream of the city of Altamira. The electricity produced at Belo Monte will enter the National Interconnected System (SIN). Some of the power will be transmitted to users in northern Brazil through the Tucuruí-Macapá-Manaus transmission line (Brazil, ELETRONORTE, 2009), but most will be sent by two transmission lines to Brazil's southeastern region for use in the country's largest consuming centers, including São Paulo. The project triggered a heated debate, with numerous social movements and indigenous leaders in Amazonia opposing the EIA,

since they felt that the environmental and social impacts were not adequately addressed (Winemiller et al., 2016).

2.2.1. Prediction of impacts

The Belo Monte EIA is descriptive rather than predictive, and it falls short of proposing mitigating actions (Appendix 2 in online Supplementary material). The EIA further lacks analyses of synergistic effects, environmental effects due to the human population attracted to the area, increase in deforestation, and changes in the flood cycle. It is important to note that hydropower contributes to global warming by the large amounts of methane produced when running rivers are transformed into lakes with slow flow rates (Fearnside, 2011, 2015c; Fearnside and Pueyo, 2012). Additional indirect effects include deforestation in areas around the project due to the increase of human population. Furthermore, energy production could well be lower than expected due to the alteration of water flow rates (Coe et al., 2009). Reduction of water volume will also change the riverine flora composition, which, in turn, is likely to have a significant impact on various animal species (cf. Benchimol and Venticinque, 2014; Calaça et al., 2015) and other organisms that interact with the flora (Zeilinger et al., 2015).

The region of the Belo Monte Dam has rich biological and social diversity, including the Directly Affected Area (DAA). The DAA includes all of the terrain that will be completely or partially inundated by the primary reservoir and the adductor channels, and also includes the 100-km “reduced flow” river stretch between the main dam and the main powerhouse. These areas include caves (e.g., the Kararaô cave, the second largest cave considered in the EIA, which has the highest species richness) and the Tabuleiro do Embaú archipelago. Both of these have been recognized as sites of “extremely high biological importance” (Brazil, MMA, 2007). The same report considers the “Volta Grande” (“Big Bend”) area along the “reduced flow” stretch to have “extremely high biological importance”. This area was not officially considered as DAA, but it will also be directly impacted. The EIA points to the presence of many endemic species (Brazil, ELETROBRAS, 2009: Vols. 18 and 19). We argue that biological and social impacts of the dam should be reanalyzed and mitigation measures should be re-considered in light of the results.

The Direct Influence Area (DIA) for the physical and biotic environments corresponds to approximately 5% of the Xingu River basin, amounting to over 26,000 km² (Brazil, ELETROBRAS, 2009: Vol. 7.5, p. 3). The DIA also encompasses surrounding areas that may be directly affected by implementation and operation of the Belo Monte Dam (Brazil, ELETROBRAS, 2009: Vol. 6.1, p. 4). Most importantly, the DIA does not include the synergistic effects of others dams and activities that are likely to follow as a result of building Belo Monte (e.g., Fearnside, 2006).

Concerning social impact, the DIA underestimates the population in this area in that it considers the average number of inhabitants per square kilometer to be 3.14. This is a methodological mistake, and the average should be about twice as large – 5.5 to 7 people (Magalhães, 2009). In addition, the DIA should have been larger also for the reason that these populations inhabit various locations that were not considered in the initial estimates. For example, the “Juruna do Paquiçamba” and “Arara da Volta Grande” indigenous lands are not inside the DIA, but studies on the effects of river flow reduction indicate that the inhabitants of these areas will no longer be able to maintain their livelihoods (Dugan et al., 2010; Richter et al., 2010). Of the ten indigenous areas directly affected by the project, only two are within the DIA. The project will change the flow of the Xingu River in this stretch, causing biological impacts and affecting all human populations that depend on the river (Magalhães, 2009).

2.3. Juruti mine (Fig. 1C)

The Juruti bauxite project began in 2000, when Alcoa, a multinational corporation in the aluminum industry, acquired Reynolds Metals. In 2001, Alcoa started surveying mineral deposits in the municipalities of

Capiranga, Guarana, and Mauari (Alcoa, 2004). In 2005, the Federal Attorney's Office (MPF) and the State Attorney's Office of Pará (MPE-PA) issued a recommendation to the State Secretariat of Science, Technology and Environment (Sectam) to cancel the licenses of Omnia Ores, an Alcoa subsidiary, for mining bauxite in Juruti (MPF and MPE-PA, 2005). Problems in the EIA/RIMA were observed by the Federal Attorney's Office and by the technicians of Sectam itself, which issued an opinion pointing out gaps (SEMAS, 2005). In spite of all these complications, the State Environmental Council conceded preliminary authorization for installation licenses (SEMAS, 2005). Alcoa was subsequently accused of omitting and distorting information in the EIA/RIMA (MPF, 2005). However, Sectam has yet to enforce such a cancellation, and the document produced by the Federal Attorney's Office (MPF) lists 20 considerations that compelled the government to withdraw the company's right to extract bauxite in Juruti, at least until the licensing concerns had been addressed (MPF and MPE-PA, 2005).

Surprisingly, in 2009 Sectam issued the operation license to Alcoa. Being opposed to granting the Operation License, the State Attorney's Office of Pará (MPE-PA) and the Federal Attorney's Office (MPF) jointly initiated a civil lawsuit to cancel the license. They demanded a complete list of environmental protection measures as well as compensation for the local populations affected by the plans (MPF, 2005). The State Secretary of the Environment stated that there was no reason to cancel the licenses, and claimed to have made 54 requests for adjustments and new conditions for license maintenance (Wanderley, 2009). Bauxite extraction by the Alcoa group began in 2009. The goal was to meet the demand from “Consórcio de Alumínio do Maranhão” (Alumar), located in São Luís in the state of Maranhão, which produces both alumina and primary aluminum. The project involves an industrial complex with a mine, railway, and river port.

2.3.1. Prediction of impacts

Mineral exploitation causes environmental damage that is difficult to quantify. Because this kind of commodity is a non-renewable natural resource, the balance between economy and sustainable development is problematic, and the restoration of land after bauxite mining is complicated: even after 13 years of restoration another bauxite mine in Pará had reduced crown coverage, tree basal area, mean canopy high, average litter, humus depths, and wood density (Parrotta and Knowles, 1999). The planned activities at Juruti are likely to introduce significant and long-lasting environmental changes, including alteration of groundwater, air pollution, soil degradation, impacts on fauna and flora, changes in drainage, depletion of water resources, siltation, erosion, mass movement, slope instability, and land fragmentation (Barreto, 2001). In addition, there are subjective impacts that are difficult to quantify, such as the loss of a river considered as sacred by indigenous communities. Indirect impacts of the aluminum industry, especially electricity supplied to smelters from hydroelectric dams, are enormous (Fearnside, 2016a).

The fauna sampling of the Juruti project's EIA (CNEC, 2009) underestimates mammal, bird, and herpetofauna species due to a sampling design that was relatively limited in time and space; at least the double number of species reported would be expected for these groups (see Appendix 2 in the Supplementary Online Material). The EIA's surveys of species are problematic because most of the threatened species are likely to have small population sizes or to have restricted distributions (Gaston, 1994: Chapter 1, p. 2). A large sampling effort with spatial and temporal replication is necessary to register the rare species in an area (Cerqueira et al., 2013).

The Direct Influence Area (DIA) of the physical-biotic environment (Fig. 1C) comprises close to 173,000 ha and covers the following areas: (1) ore mining areas (open pit) located in the Capiranga, Mauari, and Guarana municipalities; (2) installation areas of the processing plant structures and the ore transportation system: crushing, washing plant, screening, filtering and drying, storage yard, ore transport system, water pipelines, and the line for transport and deposition of waste; (3)

local access infrastructure and internal circulation and flow of production; local road and port infrastructure system; (4) the Juruti Grande stream and tributaries from its dammed stretch to its confluence with the Amazon River; (5) the right bank of the Amazon River, the stretch between the Serra de Parintins, which is in the portion contained in Para state (upstream) and the urban seat of the municipality of Juruti (downstream); and (6) the urban area of the Juruti project and surroundings, including Lake Jará.

3. Improving EIAs: complementary strategies for biodiversity assessment

The three large infrastructure projects discussed above share similar problems regarding the proper assessment of biodiversity, which is one of the main components of EIAs. Hence, the development and validation of new methods for faster, more comprehensive, and more cost-effective biodiversity assessments is crucial. We selected three emerging and cost-effective methods that are being developed and tested for use in biological identification of taxa in different environments, including areas of high and poorly characterized biodiversity. Below follows a brief description of these techniques, their prospects and limitations, and how they could be applied in the EIA context.

3.1. Satellite remote sensing (SRS)

Satellite images allow researchers and practitioners to monitor the landscape in a relatively inexpensive way, once the satellite infrastructure is implemented and made available. With the combination of several kinds of data, stemming from sources such as Landsat, QuickBird, and Polar-orbiting Operational Environmental Satellite (POES), it is possible to access information captured by sensors on board satellites (Strand et al., 2007). Monitoring land cover, land-use dynamics and climate variables is straightforward using SRS. Over the past 30 years there has been a significant increase in the use of these tools by environmental professionals working with areas under increased anthropogenic pressure (Duro et al., 2007; Gillespie et al., 2008; Horning et al., 2010). Case studies to help identify ecological issues that can be informed by the use of SRS are accumulating (Pettorelli et al., 2014). SRS studies can monitor large areas in a consistent manner and may be updated regularly, typically several times per year (Strand et al., 2007). SRS has a variety of uses, such as identifying broadleaf species in urban forests (Pu, 2009), identifying some tropical rainforest trees at the species level (Clark et al., 2005), and assessing biochemical and physical characteristics related to key ecological processes such as carbon cycling, changes in land use, and fire (Goetz et al., 2015). It is even possible to monitor basic ecosystem dynamics (Ustin et al., 2004). Although these advantages render the use of SRS techniques promising, there are several limitations. These include low taxonomic resolution, differences in results depending on the technique applied, difficulties in locating small-scale changes over large areas, and the need for large computational resources for data analyses and storage (Bensana et al., 1999; Goetz et al., 2015).

3.2. Species spectral signature

Near-infrared reflectance spectroscopy (NIRS) offers an enormous but largely unrealized potential to identify plant species in a rapid and cost-effective way (Foley et al., 1998), since it is capable of discriminating herbarium samples at the level of species or even variety (Xu et al., 2009). Infrared spectroscopy has been used in a variety of research fields, including taxonomy and ecology. For example, Fan et al. (2010) correctly identified 83–91% of *Ephedra* species in this way. For Lecythidaceae, over 96% of the species were correctly identified in two *terra-firme* (unflooded upland) Amazon forests (Durgante et al., 2013). The technique was further validated in young and old trees of Lecythidaceae species with a precision of 75% (Lang et al., 2015). For

Eucalyptus species, the accuracy was 100% (Castillo et al., 2008). Further research is needed to determine accuracy at different taxonomic levels (e.g., families, genera, and species) in plant groups that have not yet been surveyed, including those with high morphological similarity among species.

3.3. DNA metabarcoding

Metabarcoding is a rapid method of biodiversity assessment that combines two technologies: DNA barcoding and high-throughput (also called 'next-generation') sequencing. This technique is becoming a popular and useful tool for taxonomic identification of species in diverse environments. Although significant success has been achieved for animal DNA barcoding (e.g., Hebert et al., 2003) and microorganisms in general (e.g., Chariton et al., 2010; Porazinska et al., 2009; Zinger et al., 2009), this method has yet to be validated in tropical megadiverse environments with many closely related species. Kress et al. (2009) identified tree and shrub species from a forest plot on Barro Colorado Island with 98% correct identification using a three-locus plant DNA barcode; however, this forest is composed mostly of distantly related species. In another study, Gonzalez et al. (2009) used an eight-locus barcode system for a species-rich tropical forest in French Guiana. They obtained a rate of correct species identification below 70%, showing the need for more studies in these areas and perhaps hinting at the need for improved plant barcoding protocols.

Although metabarcoding may occasionally suffer from issues with taxonomic identification of individual species, it allows us to describe and analyze patterns of species diversity within an ecosystem without relying on individual specimens or individual parts. Identification of plants is usually a time-consuming, above-ground exercise, but the information contained in the soil could both complement above-ground data and be used to estimate components of plant diversity over longer temporal scales (Yoccoz et al., 2012). Furthermore, with soil samples we can access with high precision the biodiversity of microorganisms such as bacteria (Zinger et al., 2009), nematodes (Porazinska et al., 2009), micro-invertebrates (Chariton et al., 2010), and fungi (Tedesoo et al., 2014), which together constitute a large proportion of the world's biodiversity (e.g., Amman et al., 1995; Hamilton et al., 2010).

Other shortcomings of traditional taxonomic inventories are the need to find organisms in adequate shape for identification at the time of sampling (e.g., plants with reproductive parts), and the fact that some species are rare and hard to find in short sampling periods (ter Steege et al., 2013). In comparison, DNA is more sensitive to small quantities of biomass and can linger in the environment for months after the organisms leave or die (Yoccoz et al., 2012). A biodiversity assessment approach based on soil DNA could be potentially applied over large areas or at high densities, forming a highly standardized sampling effort that would make the studies and sites inter-comparable. Even without a complete reference database for species in a region, this approach would yield directly comparable molecular operational taxonomic units (MOTUs) (Stahlhut et al., 2013).

4. Future prospects

Reviewing priorities for conservation and making EIAs more stringent are essential for the maintenance of Brazilian and Amazonian biodiversity. Unfortunately, instead of improving EIA policies and methodology, a committee of the federal senate in Brazil approved a Constitutional Amendment Proposal (PEC 65/2012) stating that no project should be suspended or cancelled once an EIA has been submitted (Senado Federal, 2016a). The proposal has been returned to the committee, but could be released for a vote of the full senate at any time. In addition, a proposed law (PL 654/2015) that would essentially eliminate EIAs for "strategic" projects has also been approved in committee and awaits a full senate vote (Senado Federal, 2016b; Fearnside, 2016b).

Economic pressure is the biggest obstacle to effective implementation of EIAs. Companies often consider the EIA merely as a bureaucratic step, and several lobbying projects are currently attempting to reduce requirements and shorten the execution of EIAs in Brazil. As an example, it took less than a month after the biggest environmental disaster in Brazil's history - the rupture of a mine-tailings dam in Mariana, Minas Gerais, which in November 2015 released approximately 60 million m³ of iron ore tailings into the Doce River - before the state government approved a project to reduce the EIA requirements for mineral exploitation (*Câmara dos Deputados*, 2011, 2013).

It is clearly necessary to undertake a sampling effort in the area to be affected to achieve a reliable sampling of biodiversity data, since our current knowledge of the distribution of biodiversity is highly spatially and taxonomically biased (e.g., *Maldonado et al.*, 2015; *Meyer et al.*, 2016), precluding a simple taxon occurrence information download from databases as a substitute for a physical sampling effort. Sampling efforts are, however, usually constrained by the available time, by logistical difficulties, and by costs. The sampling design needs to be appropriate for the specific goal and for the study area (*Ferraz*, 2012). These sampling programs need to include experts on different taxonomic groups and the programs need to include a variety of techniques in order to sample as much of the local biodiversity as possible. However, these differences in sampling techniques also imply that results across studies will be difficult to compare, and their reliability is difficult to assess a posteriori. The results from EIAs need to be analyzed in the light of knowledge from the literature and to be peer-reviewed by unbiased independent experts. Finally, the use of emerging technological tools to complement biological assessments could help to produce more comparable and biologically reliable results, greatly improving the use of EIAs to promote environmentally sustainable development.

5. Conclusions

The current EIA system in Brazil is very general and imprecise in its requirements. Usually EIAs are extremely limited in their spatial and temporal scopes. Furthermore, many Brazilian environments are in urgent need of biological characterization, not only for assessing and documenting biodiversity but also to provide suitable baselines for comparison between essentially pristine and altered environments. EIAs often fail to deliver a proper description of the species composition and the characterization of the abiotic environment such as the quality of the soil and water. EIAs in Brazil are still descriptive, and little is done to identify potential impacts and suggest mitigation strategies.

Many aspects should be considered to improve the quality of EIAs in Brazil: improving the capacity of researchers and practitioners, making the formal requirements in EIAs more specific and biologically sound, providing an improved definition of the terms of reference (the document that sets the minimal assessment necessary in each project), and requiring a more thorough inventory of the species in the areas to be directly and indirectly affected by new infrastructure projects. With these improvements, future studies are likely to become more analytical, less descriptive, and of enhanced usefulness.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.biocon.2016.12.031>.

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Appendix 1: A brief overview of environmental studies in Brazil ... p. 2

Appendix 2: Environmental Impact Assessment in Amazoniap. 6

Appendix 1: A brief of overview of environmental studies in Brazil:

EIAs were introduced in the 1960s, as part of increasing environmental awareness. The first country to institutionalize the EIA process was the United States of America in 1970 (National Environmental Policy Act of 1969). Soon after, the EIA was adopted by other countries, notably France, Canada, the Netherlands, Great Britain, and Germany (Marques, 2001). The International Organization for Standardization (ISO) Standard 14011, which covers EIA, advises that as many environmental aspects as possible should be identified in an EIA, including general requirements, environmental policy, planning, implementation and operation, pre-emptive and corrective action, and management review (International Organization for standardization, 1996a, 4.2.2). However, how these requirements should be assessed is not stated explicitly. In addition, the spatiotemporal boundaries of the proposal's effects are typically not specified. In practice, almost all EIA studies merely deal with direct and *in situ* effects (Lezen et al., 2003).

Brazil's modern environmental legislation was formally launched in 1989, but the first legal steps to protect the environment in Brazil started in the 1930's, when the government began to regulate the use of some natural resources. The first initiatives to protect the environment were the Codes of the Water and Mining and the first Forest Code created in 1934, the Protection of Cultural Heritage in 1937, and the Fisheries Code in 1938. In 1965 the Land Act and the second Forest Code were created, which gave the opportunity for the Government to interfere in economic activities that affected the environment. Within the aforementioned framework of the United Nations Conference on the Human Environment, the Brazilian government created the Special Environmental Secretariat (SEMA) in 1973 (Câmara do Deputados, 1973). Among other responsibilities, SEMA coordinated the actions of government agencies related to environmental protection and use of natural resources. The first EIAs in Brazil were established as a response to requirements of multilateral funding agencies, namely the Inter-American Development Bank (IDB) and the World Bank (WB). Due to international demands, some projects financed by the IDB and WB were subjected to environmental studies such as the Sobradinho hydroelectric dam. A similar study was prepared for the Tucuruí Dam, although the World Bank did not fund the project (see Fearnside, 1999, 2001). These projects followed the international requirements because Brazil did not have national environmental requirements to produce an EIA (Luz, 2013). The first

regulation to use an EIA in Brazil occurred in Rio de Janeiro state, in 1977 by means of an administrative order (Governo do Rio de Janeiro, 1977).

The year 1981 saw the establishment of the National Policy Environment and the National Environmental System (SISNAMA) and the National Environmental Council (CONAMA). This law reorganized environmental management focusing on environmental quality and sought to find a balance between societal development and environmental protection. It was furthermore the first law to specifically incorporate the EIA concept in Brazil, defining the need for EIA in the context of potentially polluting activities. Since 1986, EIAs are mandatory in Brazil for any project with potentially harmful effects on wildlife or local human populations. This was incorporated into the constitution in 1988. In 1989, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) was created. It took over the responsibilities of SEMA, the Brazilian Institute of Forest Development (IBDF) and the Superintendence of rubber development and of fisheries. IBAMA can be thought of as something of an environmental police agency. Among other tasks, it follows up on national environmental policies related to federal responsibilities, it monitors issues related to environmental licensing, and oversees permissions and licensing to use natural resources.

In 2007, the Chico Mendes Institute for Biodiversity Conservation (ICMBio) was launched. ICMBio is a part of the National Environmental System (SISNAMA) and was assigned the responsibility for proposing, deploying, managing, protecting, supervising, and monitoring all federally protected areas. It also promotes and implements research programs, manages conservation of biodiversity, and exercises the power of environmental police for the protection of biodiversity in Brazil (Casa Civil, 2007). ICMBio arose from a restructuring of IBAMA, which previously was in charge of these actions.

Although this historical overview of environmental protection in Brazil portrays a picture of good laws for environmental conservation, the regulatory framework is in fact very general. Brazil is a country with continental dimensions and has a very high environmental, cultural, and social diversity. Beginning with the federal constitutional reform of 1988, some municipalities have incorporated environmental licensing into their local or complementary laws (e.g., Lei Orgânica do Município de Salvador). In 1997, CONAMA established guidelines for the decentralization of environmental licensing. Decentralization policies have been adopted in some states, but, due to economic pressures, many municipalities and states

have relaxed their environmental licensing processes, and even at the federal level there are trends to this effect. For example, the new Forest Code, which has been in effect since 2012, granted amnesty to deforesters and downplayed basic concepts of preservation of legal reserve and permanent preservation areas (Forest Code, 1934; 2012). There is therefore reason for concern that proper, sustainable use of natural resources may not occur as quickly as the original intentions stipulated.

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Appendix 2: Environmental Impact Assessment in Amazonia

Here we assess the biological impact assessment of three of the most recent and largest infrastructure projects in Amazonia (i.e., those discussed in the manuscript). Although EIAs also cover geological, historical and social, aspects of planned projects, here we focus on the biological component.

1. BR-319 Highway: Impact Assessment: We argue that the EIA for BR-319 suffers from insufficient information compared to previous environmental studies in the region. It informs its readers about the number of species and individuals for a very limited number of taxa, showing just general information about each group. In the EIA, it is possible to trace the methods used to sample the different groups:

Plant sampling – Fieldwork to survey biological data was carried out in two distinct seasons; the first season was from October to December 2007 (transition from dry to rainy season; note that the EIA does not report the number of man-hours spent on this campaign). The second season was between 16 and 26 January 2008 with 10 days of collections and field observations in the rainy season. The sampling scheme consisted of 17 plots, randomly distributed on both sides of the road, each 2.5 km in length (east to west) and of 10 m in width, such that the total area of sampling was 85 ha.

The “Characterization of vegetation observed for each sample unit” (UFAM, 2009: Vol. 3, pp. 55-56, Table 9) shows only a small fraction of species as “non-identified,” implying that almost all individual samples were identified to the species level. Considering the fact that many species can be identified only by examining the reproductive parts of the plant, and given the difficulty of finding plants that are flowering or fruiting at the time of sampling in the Amazon (Gomes et al., 2012), it is very unlikely that all plants were identified correctly (cf. Gomes et al., 2012; Pitman et al., 2008). Furthermore, the areas closest to the road had been previously occupied and deforested. By comparing the data in the tables (plant typologies studied and characterization of vegetation observed for each sample unit (UFAM, 2009a: Vol. 3, pp. 55-56), we conclude that the majority of plots were installed in degraded areas (“*capoeiras*,” or secondary vegetation) in different stages of regeneration. Hence, it is highly unlikely that these plots sampled the original vegetation of the Madeira-Purus interfluve. The results also appear to be surprisingly species-poor from a taxonomic point of view. In a study in the same region, Carvalho (2006) sampled 36 plots of 500 m² (a total of 1.8 ha) at two sites, finding a total of 53 species of Araceae and 37 species of Marantaceae, while the EIA only found four species in each family despite surveying an area that was 56 times larger.

The impacts of the road on the original (pre-road) vegetation are likely to have been underestimated, and many direct and indirect impacts seem to have been disregarded. Impacts that were more difficult to quantify but potentially just as ecologically important, such as genetic erosion of populations, loss of pollinators and/or dispersers, changes in the soil hydrological regime, and microclimatic changes, were similarly not accounted for in the EIA. The increased human settlement in the area will result in the introduction of domestic and exotic species of flora and fauna, which among other impacts, increases the risk of fires and competitive exclusion.

Similar to the situation with biodiversity, the estimate of the areas of vegetation that will be removed was inappropriate since it considered only the road's paved area and not the direct influence area. The EIA also dismissed anthropogenic areas in its estimate of the extent of vegetation suppression, without a clear definition of "anthropogenic areas." Indeed, the definition applied probably included secondary forests. The anthropogenic areas formed a total of 2 271 ha in the EIA, such that the EIA defines the area with vegetation suppression to be a mere 0.014% of the road's paved area. Most importantly, the estimate of vegetation suppression does not include the synergistic effects of providing access to the municipalities located along the road and the expected increase in human occupation.

Fauna sampling design – The method for sampling fauna was the "RAPELD" system (PPBio, 2016). This was carried out using U-shaped modules perpendicular to the road. The area is 5 km long and 1 km wide between two transects 500 m from the road margin. The modules were placed between the 300-km and 450-km road marks (marks represent km south of Manaus), with 50 km between modules, and another two modules were located at the 539-km and 615-km marks. The total number of sampled modules was six (UFAM, 2009). Each module had 12 transects of 250 m, six on each trail, spaced 1 km from each other.

The sampling of *invertebrates* was undertaken in August 2008. Sampling was done in 16 transects of 250 m that followed the terrain's isocline and were spaced every 500 m (eight in Module 1 and eight in Module 2). This design samples only the first 50 km of BR-319 and does not cover different types of vegetation such as *várzea* (white-water floodplain) and *campinas* (oligotrophic vegetation on white-sand soil). In addition, the sampling was done during a short time frame without considering the season-dependent occurrence of species. Only three arthropod orders were sampled: butterflies, which account for some 13% of the order Lepidoptera and approximately 0.006% to 0.012% of the insects

(Hamilton et al., 2010); ants, with only 12% of the samples identified to the genus level; and scorpions, also underestimated with six species from two families. Interestingly, this total is comparable to the number of new scorpion species described from the Amazon between 2005 and 2007 (Lourenço, 2005a, b; Lourenço et al., 2005a, b, 2007). In the invertebrate sampling, none of the richness-collection effort curves reached an asymptote, demonstrating that a greater effort must be employed to obtain even basic accuracy in the description of the diversity of these three groups (Magurran, 2004).

The sampling of *vertebrates* was also insufficient. The short sampling period and the limitation to six plots without the comprehensiveness of the many different vegetation types that were about to be affected by the project did not give a complete picture of the impacts on the fauna. The groups were sampled in the dry season in some places and in the wet season in others, making robust comparison impossible. The results presented were not sufficient to characterize the fish fauna of the area but nevertheless comprised 465 individuals from 95 species. The number of species estimated for the Amazon is approximately 2 000 (Agostinho et al., 2005). The Brazilian portion of the Madeira River has over 800 fish species (de Queiroz et al., 2013). In addition, there was wide variation in catches from different rivers, ranging from 10 to 135 individuals and from 4 to 29 species (UFAM, 2009: Vol. 3, p. 228, Table 39). This may be due to differences in water characteristics in the water bodies (e.g., turbidity, pH, and quality), but no analysis in this regard was presented. As an example of the seemingly suboptimal nature of the sampling effort, 10 fish species were recovered from a total of five streams. In comparison, dos Anjos (2007) reported 65 species in nine streams in the municipality of Manaus (377 km²). Quantification of the herpetofauna suffered from several problems, and no rarefaction curve reached an asymptote. Sampling was only done in the dry season for two modules (total of 15 days). One module was sampled in different places for the dry and wet season, respectively. Moreover, some 11% of the animal specimens defied identification to the species level, hinting at the presence of new or perhaps endemic species. For the sampling of mammals, bats were sampled for six days, one day per module, only in the rainy season. Six hours of sampling with 10 nets per module must be seen as a small sampling effort. For example, Bergallo et al. (2003) estimated the minimum sampling effort to represent bats in Atlantic forest to require more than 5 000 net-hours or 1 000 registers/locality. The list of species for Highway BR-319 shows an underestimation of bats, with a number of species much lower than that found in comparable studies (Martins et al., 2003). For non-flying small mammals, sampling was done in modules, seven days in the dry season and five days in the wet season. The identification of species was not finished in time for the publication of the EIA. For medium and large mammals, the sampling design was more robust, although the considerations of the impact of the road lack essential information such as the rate of road kills on non-asphalted versus asphalted stretches (paved roads have approximately nine times higher road kill rates than unpaved

roads in Brazil; Figueiredo et al., 2013). For the avian assessment, the EIA lists occurrence of 740 species, corresponding to 60% of all Amazonian species. This remarkably high number calls into question how many of these were computed from the previous literature and databases (e.g., based on locality), as compared to how many species were recorded during the EIA inventories. This crucial information was not provided in the report.

In summary, we feel that the BR-319 EIA should not be seen as particularly reliable, as it not only has methodological shortcomings in the biodiversity assessment, but also disregards factors such as illegal activities and agribusiness (Fearnside and Laurance, 2002). The models (and the EIA itself) also do not take into account synergistic effects with other activities, such as the construction of the Jirau and Santo Antônio Dams on the Madeira River (Fearnside, 2014a,b).

2. Belo Monte Dam: Impact Assessment: *Flora sampling design:* For the field campaign, which occurred from October through December 2007 (that is, in a single season), sixty-four sampling points of 0.25 ha were used. A total of 20 531 plant specimens were collected, from which 1 067 plant species in 105 families were identified. Some 10% (112) of the specimens were identified to the genus level, and the rest were identified to the species level. The study did not consider the seasonal communities and, as in the BR-319 EIA, most plants were reported as identified to the species level, which is unlikely in the Amazon (Gomes et al., 2012; Pitman et al., 2008).

Faunal Sampling: Two rounds of sampling – one in the dry season and another in the transition to the flooded season – were carried out for several taxonomic groups. Most of the rarefaction curves did not reach an asymptote, suggesting an under-sampling of species. Nevertheless, the formal report states that the sampling effort was “sufficient” (Avila-Pires et al., 2007; Brazil, ELETROBRAS, 2009: Vol. 18). The EIA fails to infer the environmental impact due to flooding alterations, plant community changes, and landscape modifications that will follow as a result of the dam. There is limited discussion on the effects of isolating wild populations on islands once the reservoir is created. Isolating hilltops by surrounding them with water creates a landscape that very few species may be able to traverse (Wolfe et al., 2015). Alteration of the landscape is known to change population dynamics, something that has already been observed in connection with the Balbina Dam north of Manaus (e.g., Benchimol and Venticinque, 2014; Calaca et al., 2015). For birds, a total of 456 species were identified in the Belo Monte region, of which 45 are probably extinct in the area of the Tucuruí Reservoir on the Tocantins River; both dams affect the Xingu-Tocantins interfluvium (Fig. 1B) (Brazil, ELETROBRAS, 2009: Vol. 18).

The Xingu basin consists of two ecoregions with distinct biological compositions separated by rapids in the Volta Grande do Xingu. Geographic species differentiation and isolation of populations were established between these two ecoregions for fish and aquatic mammals (Brazil, ELETROBRAS, 2009: Vol. 20). The Belo Monte Dam now breaks this barrier, which is likely to have major repercussions on the biota, such as the introduction of species outside their areas of distribution, and may lead to species extinctions (Carlton and Geller, 1993). Introduction of species from other regions is the most prominent cause of aquatic species extinctions (Carlton and Geller, 1993), and this is certainly something one would expect the EIA to discuss. Surprisingly, the mitigation measure proposed is the building of channels to facilitate migration of species. In effect, this will allow the passage of non-intended species, thereby compounding the species invasion problem. Construction of channels makes sense in rivers that have continuous populations, which is not the case in the Xingu. The mitigating measures proposed thus lack a scientific basis and were, presumably, presented just to meet formal bureaucratic requirements (Santos and Hernandez, 2009).

3. Juruti Mine: Impact Assessment: The Juruti project's EIA has not been made available online, which compromises the transparency of the licensing process.

Flora: The vegetation sampling was carried out on only one occasion (14 to 31 of August, 2002). The sampling design consisted of six plots of 10×1.000 m (1 ha), which is a tiny fraction of the impacted area (0.000004% of the DIA). In total, 849 plant species with diameter at breast height ≥ 10 cm were recorded, including three threatened species.

Fauna: The sampling occurred in two periods, 19 days in September 2002 sampling three points and 16 days in August 2004 sampling four points, both in the dry season. The locations included *varzea* (floodplain), *terra-firme* (unflooded upland), and an *igarapé* (stream) areas without any replication. The studies focused on vertebrates and on invertebrates, the latter with an emphasis on spiders (CNEC, 2009). Birds were sampled at three localities, and reptiles and amphibians were sampled in a modest two localities. With a sampling design limited in time, space, and target groups, the species composition can be hypothesized to be severely underestimated, and the conclusions on the impact on fauna can, as a consequence, be expected to be very incomplete. Sixty-two mammal species were reported, which corresponds to one-third of the area's expected richness (including seven threatened species of small mammals). The protocol emphasizes endemic, rare, and threatened species (and to

some extent economically relevant species), which limits the evaluation of the ecological impact on mammals. A modest 14 specimens of small mammals were found in the first campaign and 4 in the second (capture success around 1%), showing the clear need for a more thorough sampling effort. Birds were represented by 376 observed species without reaching asymptote in the species accumulation curves. The birds species count of the area are estimated to be up to 450 (CNEC, 2009). The known geographical distribution of seven species was increased through this effort, which also found one threatened species. The reported herpetofauna included 30 species of frogs, 25 of lizards, 25 of snakes, 3 of turtles, and 3 of alligators. At least twice this number of species is expected for all of these groups if one compares it to studies done in similar areas (Avila-Pires et al., 2007), although there may be confounding differences in sampling effort. A total of 241 fish species was collected in six localities. A low degree of overlap of fish species among the localities hints at the importance of the small tributaries, rivers, and *várzeas*. One new species of fish in a new family was found, and it seems probable that the region holds many more undescribed species (CNEC, 2009). Among invertebrates, a new scorpion species and at least two new harvestmen spider species were found. Forty-six spider families were recorded, including one family new to Brazil.

Planktonic and benthonic communities: The sampling was carried out at two localities on two occasions, first from 28 April to 2 May and the second from 14 to 22 November (both in 2002). In spite of the limitation in time and space with respect to the sampling design, the study found a high richness of phytoplankton, zooplankton, and benthos. However the discussion does not consider the impact of mining on these communities.

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