



Discussion

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



Camila D. Ritter^{a,b,*}, Gabriel McCrate^c, R. Henrik Nilsson^{a,b}, Philip M. Fearnside^{d,e}, Ulrika Palme^f, Alexandre Antonelli^{a,b}

^a Department of Biological and Environmental Sciences, University of Gothenburg, Box 463, 405 30 Göteborg, Sweden

^b Gothenburg Global Biodiversity Centre, Box 461, SE-405 30 Göteborg, Sweden

^c R. dos Cedroramas, 85, Manaus, Amazonas CEP 69000-000, Brazil

^d National Institute for Research in Amazonia (INPA), Av. André Araújo, 2936, Manaus, Amazonas CEP 69067-0375, Brazil

^e Brazilian Research Network on Climate Change (Rede Clima), Brazil

^f Energy & Environment, Division of Environmental Systems Analysis, Chalmers University of Technology, Göteborg, Sweden

ARTICLE INFO

Article history:

Received 17 August 2016

Received in revised form 9 December 2016

Accepted 23 December 2016

Available online 8 January 2017

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.

© 2017 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

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

* Corresponding author at: Carl Skottsbergs gata 22B, P.O. Box 461, SE 405 30 Göteborg, Sweden.

E-mail addresses: kmicaduarte@gmail.com, camila.ritter@gu.se (C.D. Ritter).

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. 6º 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

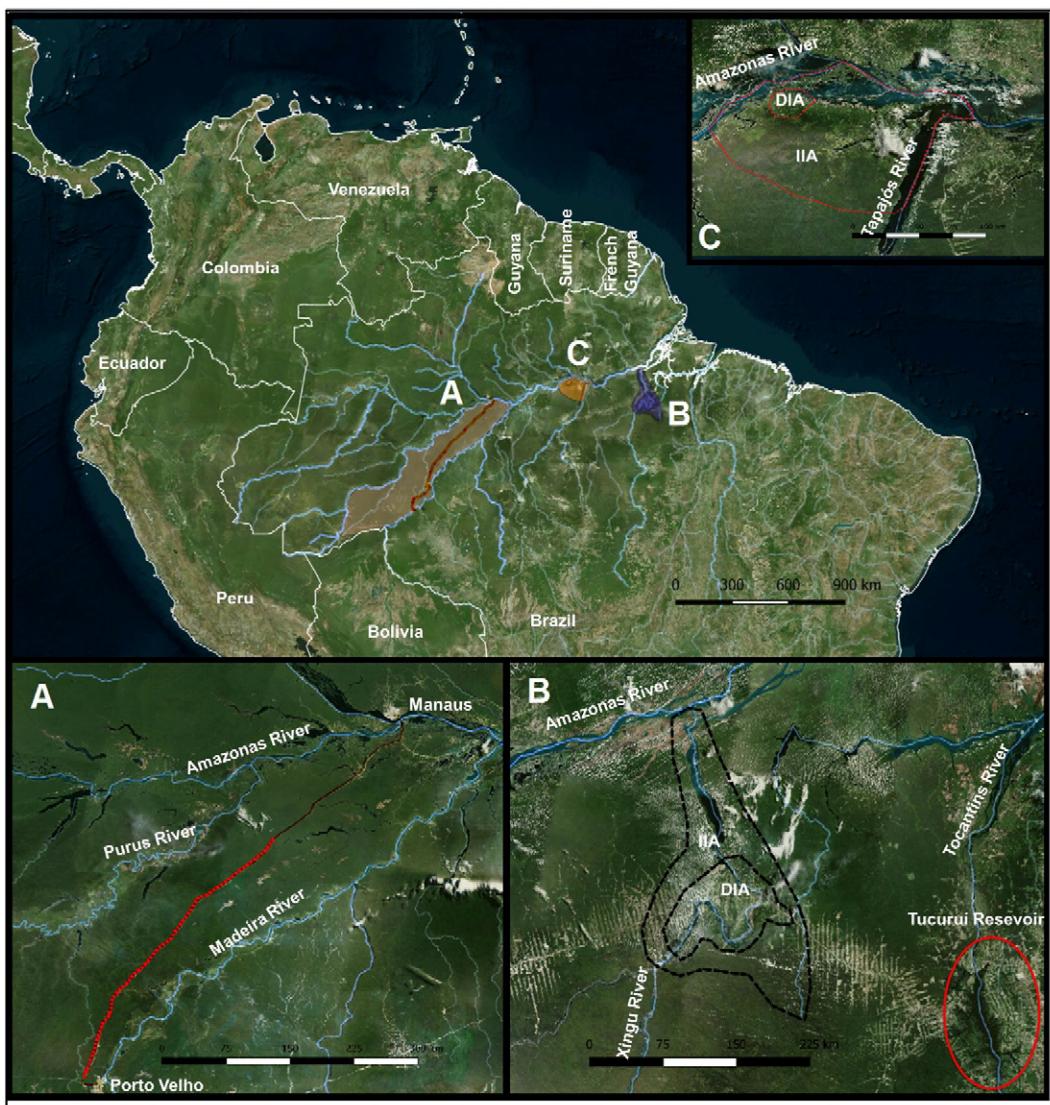


Fig. 1. Map showing the three large Amazonian infrastructure projects discussed here. A: The Madeira-Purus interfluvium, highlighting the portion of the BR-319 road that is proposed for reconstruction. B: The Direct Influence Area (DIA) and Indirect Influence Area (IIA) of the Belo Monte Dam; the circle 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, ELETROBRAS, 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, ELETROBRAS, 2009), but most will be sent by two transmission lines to Brazil's southeast 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 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 (Zelinger 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 (Cerdeira 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., Charlton 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 (Charlton et al., 2010), and fungi (Tedesco 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.

Acknowledgments

This study had financial support from CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico – Brazil: 249064/2013-8), the Swedish Research Council (B0569601), the European Research Council under the European Union's Seventh Framework Programme (FP/2007-2013, ERC Grant Agreement n. 331024), the Swedish Foundation for Strategic Research and a Wallenberg Academy Fellowship to A.A. P.M.F. thanks CNPq (305880/2007-1; 304020/2010-9; 573810/2008-7; 575853/2008-5), Fundação do Amparo à Pesquisa do Estado do Amazonas (FAPEAM: 708565), Instituto Nacional de Pesquisas da Amazônia (INPA: PRJ15.125) and the Brazilian Research Network on Climate Change (Rede Clima).

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>.

References

- Alcoa, 2004. Projeto Juriti. São Paulo, SP, Brazil. <http://www.alcoa.com/brazil/pt/environment/pdfs/folder.pdf> (accessed 14.06.16).
- Alves, D.S., 2001. O processo de desmatamento na Amazônia. Parcerias Estratégicas 6 (12), 259–275.
- Amman, R., Ludwig, W., Schleifer, K.H., 1995. Phylogenetic identification and in situ detection of individual microbial cells without cultivation. *Microbiol. Rev.* 59, 143–169.
- Barker, A., Wood, C., 1999. An evaluation of EIA system performance in eight EU countries. *Environ Impact Assess* 19 (4), 387–404.
- Barni, P.E., Fearnside, P.M., Graça, P.M.L.A., 2015. Simulating deforestation and carbon loss in Amazonia: impacts in Brazil's Roraima state from reconstructing highway BR-319 (Manaus-Porto Velho). *Environ. Manag.* 55 (2):259–278. <http://dx.doi.org/10.1007/s00267-014-0408-6>.
- Barreto, M.L. (Ed.), 2001. Mineração e Desenvolvimento Sustentável: Desafios para o Brasil. Centro de Tecnologia Mineral (CETEM). Rio de Janeiro, RJ, Brazil (215 pp.). <http://pubs.iied.org/pdfs/G00580.pdf> (accessed 14.06.16).
- Benchimol, M., Venticinque, E.M., 2014. Responses of primates to landscape change in Amazonian land-bridge islands—a multi-scale analysis. *Biotropica* 46 (4), 470–478.
- Bensana, E., Lemaitre, M., Verfaillie, G., 1999. Earth observation satellite management. *Constraints* 4 (3), 293–299.
- Brazil, ELETROBRAS (Centrais Elétricas do Brasil), 2009. Aproveitamento Hidrelétrico Belo Monte: Estudo de Impacto Ambiental. Fevereiro de 2009. 36. ELETROBRAS, Rio de Janeiro, RJ, Brazil. <http://licenciamento.ibama.gov.br/Hidreletricas/Belo%20Monte/EIA/> (accessed 14.06.16).
- Brazil, ELETRONORTE (Centrais Elétricas do Norte do Brasil), s/d, 2002. Complexo Hidrelétrico Belo Monte: Estudo de Impacto Ambiental- EIA. Versão preliminar. 6. ELETRONORTE, Brasília, DF, Brazil Available at: http://philip.inpa.gov.br/publ_livres/Dossie/BM/BELO%20MONTE.htm (accessed 14.06.16).
- Brazil, MMA (Ministério do Meio Ambiente), 2007. Portaria nº 9/MMA, de 23 de janeiro de 2007. http://www.icmbio.gov.br/portal/images/stories/portaria_mma_092007.pdf (accessed 14.06.16).
- Brazil, MMA (Ministério do Meio Ambiente), 2008. Portaria N° 295, de 22 de setembro de 2008. <http://www.rcamambiental.com.br/Atos/ver/PORT-MMA-295-2008> (accessed 14.06.16).
- Calaça, A.M., Faedo, O.J., de Melo, F.R., 2015. Hydroelectric dams: the first responses from giant otters to a changing environment. *IUCN Otter Spec. Group Bull* 32 (1), 48–58.
- Câmara dos Deputados, 2011. PL 37/2011. http://www.camara.gov.br/proposicoesWeb/prop_mostrarIntegra?codteor=837280 andfilename = PL + 37/2011 (accessed 14.06.16).
- Câmara dos Deputados, 2013. PL. <http://www.camara.gov.br/proposicoesWeb/fichadetramitacao?idProposicao=581696>.
- Câmara Legislativa, 2016. Áreas prioritárias para a conservação, utilização sustentável e repartição de benefícios da biodiversidade brasileira. <http://www.camara.leg.br/internet/comissao/index/perm/capr/listadasareas.htm> (accessed 14.06.16).
- Canter, L.W., 1996. *Environmental Impact Assessment*. second ed. McGraw-Hill, New York.
- Castillo, R., Contreras, D., Freer, J., Ruiz, J., Valenzuela, S., 2008. Supervised pattern recognition techniques for classification of eucalyptus species from leaves NIR spectra. *J. Chil. Chem. Soc.* 53 (4), 1709–1713.
- Cerdeira, M.C., Cohn-Haft, M., Vargas, C.F., Nader, C.E., Andretti, C.B., Costa, T.V., Sberze, M., Hines, J.E., Ferraz, G., 2013. Rare or elusive? A test of expert knowledge about rarity of Amazon forest birds. *Divers. Distrib.* 19 (7), 710–721.
- Charlton, A.A., Court, L.N., Hartley, D.M., Colloff, M.J., Hardy, C.M., 2010. Ecological assessment of estuarine sediments by pyrosequencing eukaryotic ribosomal DNA. *Front. Ecol. Environ.* 8 (5), 233–238.
- Clark, M.L., Roberts, D.A., Clark, D.B., 2005. Hyperspectral discrimination of tropical rain forest tree species at leaf to crown scales. *Remote Sens. Environ.* 96 (3), 375–398.
- CNEC (Conselho Nacional de Engenheiros Consultores Engenharia S.A.), 2009a. Estudo de Impacto Ambiental (EIA) do Projeto Juruti. CNEC, São Paulo, SP, Brazil.
- CNEC/ELETRONORTE (Conselho Nacional de Engenheiros Consultores/Centrais Elétricas do Norte do Brasil), 1989t. Estudo de Impacto Ambiental (EIA) (Brasília).
- Coe, M.T., Costa, M.H., Soares-Filho, B.S., 2009. The influence of historical and potential future deforestation on the stream flow of the Amazon River–land surface processes and atmospheric feedbacks. *J. Hydrol.* 369 (1), 165–174.
- Cohn-Haft, M., Santos Jr., M., Fernandes, A.M., Ribas, C.C., 2013. A New Species of *Cyanocorax* Jay From Savannas of the Central Amazon. *Handbook of the Birds of the World. Special volume. New Species and Global Index*, pp. 306–310.
- CONAMA (Conselho Nacional do Meio Ambiente), 1986. Resolução CONAMA N° 001, de 23 de Janeiro de 1986. <http://www.mma.gov.br/port/conama/res/res86/res0186.html> (accessed 14.06.16).
- Dugan, P.J., Barlow, C., Agostinho, A.A., Baran, E., Cada, G.F., Chen, D., Cowx, I.G., Ferguson, J.W., Jutagate, T., Mallen-Cooper, M., Marmulla, G., 2010. Fish migration, dams, and loss of ecosystem services in the Mekong basin. *Ambio* 39 (4), 344–348.
- Durgante, F.M., Higuchi, N., Almeida, A., Vicentini, A., 2013. Species spectral signature: Discriminating closely related plant species in the Amazon with near-infrared leaf-spectroscopy. *Forest Ecol. Manag.* 291, 240–248.
- Duro, D.C., Coops, N.C., Wulder, M.A., Han, T., 2007. Development of a large area biodiversity monitoring system driven by remote sensing. *Prog. Phys. Geog.* 31 (3), 235–260.

- Fan, Q., Wang, Y., Sun, P., Liu, S., Li, Y., 2010. Discrimination of ephedra plants with diffuse reflectance FT-NIRs and multivariate analysis. *Talanta* 80 (3), 1245–1250.
- Fearnside, P.M., 2006. Dams in the Amazon: Belo Monte and Brazil's hydroelectric development of the Xingu River basin. *Environ. Manag.* 38 (1):16–27. <http://dx.doi.org/10.1007/s00267-005-00113-6>.
- Fearnside, P.M., 2008. Amazon forest maintenance as a source of environmental services. *An. Acad. Bras. Ciênc.* 80 (1):101–114. <http://dx.doi.org/10.1590/S0001-37652008000100006>.
- Fearnside, P.M., 2011. Gases de efeito estufa no EIA-RIMA da Hidrelétrica de Belo Monte. 14(1). Novos Cadernos NAEA:pp. 5–19. <http://www.periodicos.ufpa.br/index.php/nca/article/view/596/848> (accessed 14.06.16).
- Fearnside, P.M., 2012. Belo Monte Dam: A Spearhead for Brazil's Dam Building Attack on Amazonia? GWF Discussion Paper 1210. Global Water Forum, Canberra, Australia (6 pp.). http://www.globalwaterforum.org/wp-content/uploads/2012/04/Belo-Monte-Dam-A-spearhead-for-Brazils-dam-building-attack-on-Amazonia_-GWF-1210.pdf.
- Fearnside, P.M., 2015a. Brazil's São Luiz do Tapajós dam: the art of cosmetic environmental impact assessments. *Water Alternatives* 8 (3):373–396. <http://www.water-alternatives.org/index.php/all/doc/articles/vol8/v8issue3/297-a8-3-5/file> (accessed 14.06.16).
- Fearnside, P.M., 2015b. Highway construction as a force in destruction of the Amazon forest. In: van der Ree, R., Smith, D.J., Grilo, C. (Eds.), *Handbook of Road Ecology*. John Wiley and Sons Publishers, Oxford, UK, pp. 414–424 (552 pp.).
- Fearnside, P.M., 2015c. Tropical hydropower in the clean development mechanism: Brazil's Santo Antônio dam as an example of the need for change. *Clim. Chang.* 131 (4):575–589. <http://dx.doi.org/10.1007/s10584-015-1393-3>.
- Fearnside, P.M., 2016a. Environmental and social impacts of hydroelectric dams in Brazilian Amazonia: Implications for the aluminum industry. *World Dev.* 77:48–65. <http://dx.doi.org/10.1016/j.worlddev.2015.08.015>.
- Fearnside, P.M., 2016b. Brazilian politics threaten environmental policies. *Science* 353, 746–748.
- Fearnside, P.M., Graça, P.M.L.A., 2006. BR-319: Brazil's Manaus–Porto Velho highway and the potential impact of linking the arc of deforestation to central Amazonia. *Environ. Manag.* 38 (5):705–716. <http://dx.doi.org/10.1007/s00267-005-0295-y>.
- Fearnside, P.M., Graça, P.M.L.A., 2009. BR-319: A rodovia Manaus–Porto Velho e o impacto potencial de conectar o arco de desmatamento à Amazônia central. 12(1). Novos Cadernos NAEA:pp. 19–50. <http://www.periodicos.ufpa.br/index.php/nca/article/viewFile/241/427> (accessed 14.06.16).
- Fearnside, P.M., Pueyo, S., 2012. Underestimating greenhouse-gas emissions from tropical dams. *Nat. Clim. Chang.* 2 (6):382–384. <http://dx.doi.org/10.1038/nclimate1540>.
- Fearnside, P., Graça, P.M.L.A., Keizer, E.W.H., Maldonado, F.D., Barbosa, I.R. and Nogueira, E.M., 2009. Modelagem de desmatamento e emissões de gases de efeito estufa na região sob influência da Rodovia Manaus–Porto Velho (BR-319). *Rev. Bras. Meterorol.*, 24(2), pp. 208–233. doi: 10.1590/S0102-77862009000200009 [English translation available at: http://philip.inpa.gov.br/publ_livres/mss%20and%20in%20press/RBMET-BR-319_-engl.pdf (accessed 14.06.16)].
- Ferraz, G., 2012. Twelve guidelines for biological sampling in environmental licensing studies. *Nat Conservação* 10 (1), 20–26.
- Foley, W.J., McElwee, A., Lawler, I., Aragones, L., Woolnough, A.P., Berding, N., 1998. Ecological applications of near infrared reflectance spectroscopy—a tool for rapid, cost-effective prediction of the composition of plant and animal tissues and aspects of animal performance. *Oecologia* 116 (3), 293–305.
- Gaston, K.J., 1994. *Rarity*, first ed. Chapman and Hall, London.
- Gillespie, T.W., Foody, G.M., Rocchini, D., Giorgi, A.P., Saatchi, S., 2008. Measuring and modelling biodiversity from space. *Prog. Phys. Geog.* 32 (2), 203–221.
- Goetz, S.J., Hansen, M., Houghton, R.A., Walker, W., Laporte, N., Busch, J., 2015. Measurement and monitoring needs, capabilities and potential for addressing reduced emissions from deforestation and forest degradation under REDD+. *Environ. Res. Lett.* 10 (12), 123001.
- Gonzalez, M.A., Baraloto, C., Engel, J., Mori, S.A., Pétronelli, P., Riéra, B., Roger, A., Thébaud, C., Chave, J., 2009. Identification of Amazonian trees with DNA barcodes. *PLoS One* 4 (10), e7483.
- Graça, P.M.L.A., dos Santos Jr., M.A., Rocha, V.M., Fearnside, P.M., Emilio, T., Menger, J.S., Marciente, R., Bobrowiec, P.E.D., Venticinque, E.M., Antunes, A.P., Bastos, A.N., Rohe, F., 2014. Cenários de desmatamento para região de influência da rodovia BR-319: perda potencial de habitats, status de proteção e ameaça para a biodiversidade. In: Emilio, T., Luizão, F. (Eds.), *Cenários para a Amazônia: Clima, Biodiversidade e Uso da Terra*. Editora-INPA. Manaus, Amazonas, Brazil, pp. 91–101 (194 pp.).
- Hamilton, A.J., Basset, Y., Benke, K.K., Grimbacher, P.S., Miller, S.E., Novotní, V., Samuelson, G., Stork, A., Weiblen, N.E., Yen, G.D., JD, 2010. Quantifying uncertainty in estimation of tropical arthropod species richness. *Am. Nat.* 176, 90–95.
- Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R., Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. *Science* 342, 850–853.
- Hebert, P.D., Cywinski, A., Ball, S.L., 2003. Biological identifications through DNA barcodes. *PLoS Bio.* 270 (1512), 313–321.
- Horning, N., Robinson, J., Sterling, E., Turner, W., Spector, S., 2010. *Remote Sensing for Ecology and Conservation*. Oxford University Press.
- Jay, S., Jones, C., Slinn, P., Wood, C., 2007. Environmental impact assessment: Retrospect and prospect. *Environ. Impact Assess.* 27 (4), 287–300.
- Kress, W.J., Erickson, D.L., Jones, F.A., Swenson, N.G., Perez, R., Sanjur, O., Bermingham, E., 2009. Plant DNA barcodes and a community phylogeny of a tropical forest dynamics plot in Panama. *Proc. Natl. Acad. Sci.* 106 (44), 18621–18626.
- Lang, C., Costa, F.R.C., Camargo, J.L.C., Durgante, F.M., Vicentini, A., 2015. Near infrared spectroscopy facilitates rapid identification of both young and mature Amazonian tree species. *PLoS One* 10 (8) (p.e0134521).
- Magalhães, A.C., 2009. Análise do estudo do impacto ambiental. pp. 61–69. In: Santos, S.M.S.B.M. and Hernandez, F.M. (eds.), *Painel de Especialistas: Análise Crítica do Estudo de Impacto Ambiental do Aproveitamento Hidrelétrico de Belo Monte. Painel de Especialistas sobre a Hidrelétrica de Belo Monte, Belém, Pará, Brazil*. 230 pp. Available at: http://www.xingu vivo.org.br/wp-content/uploads/2010/10/Belo_Monte_Painel_especialistas_EIA.pdf (accessed 14.06.16).
- Maldonado, C., Molina, C.I., Zizka, A., Persson, C., Taylor, C.M., Albán, J., ... Antonelli, A., 2015. *Estimating species diversity and distribution in the era of Big Data: to what extent can we trust public databases?* *Global Ecol. Biogeogr.* 24 (8), 973–984.
- Malhi, Y., Roberts, J.T., Betts, R.A., Killeen, T.J., Li, W., Nobre, C.A., 2008. *Climate change, deforestation, and the fate of the Amazon*. *Science* 319, 169–172.
- Meyer, C., Weigert, P., Kreft, H., 2016. Multidimensional biases, gaps and uncertainties in global plant occurrence information. *Ecol. Lett.* 19 (8):992–1006. <http://dx.doi.org/10.1111/ele.12624>.
- MPE-RO (Ministério Público do Estado de Rondônia), 2006. *Pareceres Técnicos dos Especialistas Setoriais—Aspectos Físicos/Bióticos. Relatório de Análise do Conteúdo dos Estudos de Impacto Ambiental (EIA) e do Relatório de Impacto Ambiental (RIMA) dos Aproveitamentos Hidrelétricos de Santo Antônio e Jirau no Rio Madeira, Estado de Rondônia*. MPE-RO, Porto Velho, Rondônia, 2 Vols. (Available at: http://philip.inpa.gov.br/publ_livres/Dossie/Mad/Documentos%20Oficiais/Madeira_COBRAPE/11118-COBRAPE-report.pdf (accessed 14.06.16)).
- MPF (Ministério Público Federal), 2005. <http://www.mpf.mp.br/pgr/noticias-pgr/mp-quer-obrigar-licenciamento-federal-do-projeto-juruti-20051111> (accessed 01.08.16).
- MPF (Ministério Público Federal), 2008. Ação Civil Pública, Ministério Público Federal, n° 2008.39.03.000071- <http://ptdocz.com/doc/117762/processos-caso-belo-monte> (accessed 01.08.16).
- MPF and MPE (Ministério Público Federal and Ministério Públco Estadual do Pará), 2005. Ação Civil Pública com Pedido de Liminar: Licenciamento ambiental Projeto Juruti/Alcoa. Santarém. http://www.mpf.mp.br/atuacao-tematica/ccr6/dados-da-atuacao/acao-civil-publiva-1/mineracao-garimpo-1/acp_licenciamento_juruti_pa.pdf (accessed 01.08.16).
- Nitta, R. and Naka, L.N. (eds.), 2015. Barragens do rio Tapajós: Uma avaliação crítica do Estudo e Relatório de Impacto Ambiental (EIA/RIMA) do Aproveitamento Hidrelétrico São Luiz do Tapajós. Greenpeace Brasil, São Paulo, SP, Brazil. 99 pp. Available at: <http://greenpeace.org.br/tapajos/docs/analise-EIA-rima.pdf> (accessed 14.06.16).
- Ojea, E., Martin-Ortega, J., Chiabai, A., 2012. Defining and classifying ecosystem services for economic valuation: the case of forest water services. *Environ. Sci. Pol.* 19, 1–15.
- Parrotta, J.A., Knowles, O.H., 1999. Restoration of tropical moist forests on bauxite-mined lands in the Brazilian Amazon. *Restor. Ecol.* 7 (2), 103–116.
- Peres, C.A., 2005. Why we need megareserves in Amazonia. *Conserv. Biol.* 19, 728–733.
- Pettorelli, N., Laurance, W.F., O'Brien, T.G., Wegmann, M., Nagendra, H., Turner, W., 2014. Satellite remote sensing for applied ecologists: opportunities and challenges. *J. Appl. Ecol.* 51 (4), 839–848.
- Porazinska, D.L., Giblin-Davis, R.M., Faller, L., Farmerie, W., Kanzaki, N., Morris, K., Powers, T.O., Tucker, A.E., Sung, W.A.Y., Thomas, W.K., 2009. Evaluating high-throughput sequencing as a method for metagenomic analysis of nematode diversity. *Mol. Ecol. Resour.* 9 (6), 1439–1450.
- Pu, R., 2009. Broadleaf species recognition with in situ hyperspectral data. *Mol. Ecol. Resour.* 30 (11), 2759–2779.
- Py-Daniel, L.R., de Deus, C.P., Henriques, A.L., Pimpao, D.M., Ribeiro, O.M., 2007. *Biodiversidade do Médio Madeira. Bases Científicas para Propostas de Conservação*. Manaus: INPA and Brasília: MMA and MCT.
- Ribas, C.C., Aleixo, A., Nogueira, A.C., Miyaki, C.Y., Cracraft, J., 2011. A palaeobiogeographic model for biotic diversification within Amazonia over the past three million years. *PLoS Bio.* 279:681–689. <http://dx.doi.org/10.1098/rspb.2011.1120>.
- Richter, B.D., Postel, S., Revenga, C., Scudder, T., Lehner, B., Churchill, A., Chow, M., 2010. Lost in development's shadow: The downstream human consequences of dams. *Water Alternatives* 3 (2), 14.
- Röhle, F., Silva Jr., E., JDS, Sampaio, R., Rylands, A.B., 2009. A new subspecies of *Saguinus fuscicollis* (Primates, Callitrichidae). *Int. J. Primatol.* 30 (4), 533–551.
- Salati, E., Vose, P.B., 1984. Amazon basin: a system in equilibrium. *Science* 225 (4658), 129–138.
- SEMAS, 2005. Secretário do Meio Ambiente e Sustentabilidade, Pará. <https://www.semias.para.gov.br/2005/06/21/10026/> (accessed 14.06.16).
- Senado Federal, 2016a. Proposta de Emenda à Constituição nº 65, de 2012. <http://www25.senado.leg.br/web/atividade/materias/-/materia/109736> (accessed 14.06.16).
- Senado Federal, 2016b. Projeto de Lei do Senado nº 654, de 2015. <http://www25.senado.leg.br/web/atividade/materias/-/materia/123272> (accessed 14.06.16).
- Soares-Filho, B.S., Nepstad, D.C., Curran, L.M., Cerqueira, G.C., Garcia, R.A., Ramos, C.A., Voll, E., McDonald, A., Lefebvre, P., Schlesinger, P., 2006. Modelling conservation in the Amazon basin. *Nature* 440, 520–523.
- Stahlhut, J.K., Fernández-Triana, J., Adamowicz, S.J., Buck, M., Goulet, H., Hebert, P.D., ... Smith, M.A., 2013. DNA barcoding reveals diversity of Hymenoptera and the dominance of parasitoids in a sub-arctic environment. *BMC Ecol.* 13 (1), 1.
- Strand, H., Höft, R., Strittholt, J., Miles, L., Horning, N., Fosnight, E., Turner, W., 2007. Sourcebook on remote sensing and biodiversity indicators. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 32 (203 pp.).
- Tedersoo, L., Bahram, M., Pöhlme, S., Köljalg, U., Yorou, N.S., Wijesundera, R., Ruiz, L.V., Vasco-Palacios, A.M., Thu, P.Q., Suija, A., Smith, M.E., 2014. Global diversity and geography of soil fungi. *Science* 346 (6213) (p.1256688).
- ter Steege, H., Pitman, N.C., Sabatier, D., Baraloto, C., Salomão, R.P., Guevara, J.E., ... Monteagudo, A., 2013. Hyperdominance in the Amazonian tree flora. *Science* 342, 1243092.

- Toro, J., Requena, I., Zamorano, M., 2010. Environmental impact assessment in Colombia: critical analysis and proposals for improvement. *Environ Impact Asses* 30 (4), 247–261.
- UFAM (Universidade Federal do Amazonas), 2009. Estudo de Impacto Ambiental – EIA: Obras de reconstrução/pavimentação da rodovia BR-319/AM, no segmento entre os km 250,0 e km 655,7. UFAM, Manaus, Amazonas. 6 Vols. + Annexes. <http://licenciamento.ibama.gov.br/Rodovias/BR%20319%20AM%20segmento%20entre%20os%20km%20250%20e%20km%20655/EIARIMA/> (accessed 14.06.16).
- UNEP-WCMC (United Nations Environmental Programme-World Conservation Monitoring Centre), 2016n. Assessing the Contribution of Brazil's Forest Code to Biodiversity Conservation. http://wcmc.io/REDD-PAC_Brazil_Biodiversity_Policy_Brief (Accessed 07.07.16).
- Ustin, S.L., Roberts, D.A., Gamon, J.A., Asner, G.P., Green, R.O., 2004. Using imaging spectroscopy to study ecosystem processes and properties. *Bioscience* 54, 523–534.
- Wang, Y., Morgan, R.K., Cashmore, M., 2003. Environmental impact assessment of projects in the People's Republic of China: new law, old problems. *Environ. Impact Asses.* 23 (5), 543–579.
- Wanderley, L.J.D.M., 2008. Conflitos e impactos ambientais na exploração dos recursos minerais na Amazônia. Rio de Janeiro: UFRJ.
- Winemiller, K.O., McIntyre, P.B., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., Baird, I.G., Darwall, W., Lujan, N.K., Harrison, I., Stiassny, M.L.J., 2016. Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science* 351 (6269), 128–129.
- Xu, H.R., Yu, P., Fu, X.P., Ying, Y.B., 2009. On-site variety discrimination of tomato plant using visible-near infrared reflectance spectroscopy. *Journal of Zhejiang University Science B* 10 (2), 126–132.
- Yoccoz, N.G., Bráthen, K.A., Gielly, L., Haile, J., Edwards, M.E., Goslar, T., Von Stedingk, H., Brysting, A.K., Coissac, E., Pompanon, F., Sønstebo, J.H., 2012. DNA from soil mirrors plant taxonomic and growth form diversity. *Mol. Ecol.* 21 (15), 3647–3655.
- Zeilinger, S., Gupta, V.K., Dahms, T.E., Silva, R.N., Singh, H.B., Upadhyay, R.S., Gomes, E.V., Tsui, C.K.M., 2015. Friends or foes? Emerging insights from fungal interactions with plants. *FEMS Microbiol. Rev.*, p.fuv045
- Zinger, L., Shahnavaaz, B., Baptist, F., Geremia, R.A., Choler, P., 2009. Microbial diversity in alpine tundra soils correlates with snow cover dynamics. *The ISME Journal* 3 (7), 850–859.