Biodiversity Research Consortium (BRC): A technical and scientific partnership in search of "State of the Art" Mined Area Recovery

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Abstract

Hydro Paragominas is a bauxite mining company that operates in the municipality of Paragominas, in Pará State, Brazil. To carry out environmental restoration activities as close as possible to what was before or with superior environmental quality, Hydro has an initiative to create the Brazil-Norway Biodiversity Research Consortium (BRC), aiming to achieve existing, and create a new "State of Art in Environmental Restoration "in areas of bauxite mining. Of this initiative, 26 projects were approved and are in the implementation phase (be it budgetary or technical). Of these, three are presented with their main results. These projects are: Terrestrial Mammal Monitoring Project (25 species were recorded, 11 of conservation interest); Evaluation of chemical components of stored wood (favorable results in increasing organic matter in soil); Biodiversity of Birds, where 240 species were registered, 146 in the forest areas, 53 species in the Natural Regeneration technique, 49 species in the Traditional Planting technique and 37 in the Nucleation technique. For the academy, these four studies assisted in the development of 5 master's degrees; one graduation, with 14 students involved. In total the BRC's projects have at least 100 researchers and students working on surveys, 10 master's degrees concluded (and more in progress), 9 graduation's degree concluded, and several papers and articles produced. During the studies 3 new species of fungi, a new species of lichen and a new species of bug was discovered.

Keywords: Biodiversity, BRC, Hydro Paragominas, Amazon, Research.

1. Introduction

Hydro Paragominas is a project located in municipality of Paragominas, in the state of Pará, Brazil, which mines and beneficiates bauxite ore, transforming it into pulp (50% water and 50% ore), that is sent by pipeline to the municipality of Barcarena (244 km), to transform into alumina and later aluminium.

Mining activities have as the first step the removal of vegetation before the excavation of topsoil and overburden to reach the bauxite deposit. After this last stage, the organic rich topsoil, which is removed and stored, is returned to the mined area after contour reshaping with overburden to initiate forest recovery. Three different techniques are used for reforestation: Traditional Planting; Natural Regeneration; and a third and innovative technique, Nucleation.

On its own initiative, Norsk Hydro ASA (Hydro) invited four academic institutions to research and study three different scientific themes. This work had the purpose of establishing a model of environmental restoration proposed by scientific criteria integrating the academy and the technical operation, along with fostering the knowledge of Amazonian biodiversity and the exchange of technical-scientific learning, to achieve the State of the Art in Environmental Restoration after bauxite mining.

2. The Biodiversity Research Consortium Brazil-Norway (BRC)

In January 2012, Hydro issued the technical report "Reforestation and Wildlife Program, Hydro, Paragominas, Pará, Brazil", prepared by researchers Rafael Salomão & Silvio Brienza. This report contained a technical assessment of the Fauna and Flora Programs, as well as suggestions for improvement of the biodiversity program carried out at Mineração Paragominas S.A (MPSA). According to the researchers' analysis, the following can be observed in the report:

"*Due to the unique conditions of the project in a heavily anthropogenic area close to the city of Paragominas, associated with the high production of the MPSA, it is urgent to establish a broad research program in forest restoration that supports the consolidation of the new vision that Hydro wishes to implant in the company. The establishment of a research-based forest restoration model should be pursued to enable HYDRO to generate a genuine forest restoration model that could be applied to other degraded areas of the Amazon under similar conditions.*" [1]

According to the griffons on text, the report recommends that Hydro Paragominas establish a Forest Restoration program for new restoration activities that is based on scientific and academic research.

In response to the recommendations of this report, Hydro and the Natural History Museum (NHM) of the University of Oslo (UIO) signed a Memorandum of Understanding in May 2012, related to an intention to do research on environmental themes in Paragominas, Brazil. As a goal of this cooperation, Hydro aims to develop relevant knowledge, applied to biological diversity and climate change, to support and develop activities, among others, in the monitoring and rehabilitation program of Hydro's bauxite mine in Brazil.

Figure 1. Event held in October 2017 in Belém (State of Pará, Brazil) to extend the BRC Consortium until 2023. Source: Hydro.

In November 2013, the Brazil-Norway Biodiversity Research Consortium (BRC) was formally created. In addition to Hydro and UiO, the BRC consists of the Federal Universities of Pará (UFPA) and Rural da Amazônia (UFRA) and the Museu Paraense Emílio Goeldi (MPEG). In

October 2017, the consortium was renewed for another five years, having then extended the partnership until October 2023.

3. Objectives

The BRC Consortium's main objective is define a new State of the Art in recovery of areas mined for bauxite, through scientific research, covering the diverse subjects of the natural sciences (fauna, flora, microorganisms, fungi, soil, greenhouse gases, among others), increasing the knowledge of Amazonian biodiversity, fomenting high impact education and sharing knowledge among several institutions of different countries.

4. Area of Study

Hydro Paragominas is currently composed of two bauxite deposits located on the contiguous plateaus called Miltonia 3 (M3) and Miltonia 5 (M5), in the municipality of Paragominas, in the northeastern region of the State of Pará. The current production capacity is 11.1 Million Tons Per Year (MTPY), which is concentrated only in M3, located between longitudes 47 ° 30 'W and latitudes 3 ° S and 3 ° 30' S. The company is however, licensed to produce 14.85 MTPA.

Hydro Paragominas' operation involves the mining, processing, tailings disposal in dikes (tailing dams) and bauxite concentrate transportation in pulp form. The bauxite in pulp transport is by a 24 "diameter pipeline with a total length of 244 km, - the first bauxite pipeline in the world. It also has an electricity transmission line of 236 km to supply the energy demands of the industrial plant in the Miltônia 3 plateau and a second Pumping Station located in the municipality of Tomé-Açu.

Figure 2. Hydro Paragominas mining geographical location. Source: Hydro.

5. Methods

For the preparation of this article, documents related to the BRC Consortium were consulted, such as Work Plans, Scientific Proposals, Reports (Biannual and Annual), from which the necessary technical information was extracted.

5.1. BRC Consortium Research Lines

To meet the suggestions of reports referenced in the previous section, as well as to fulfill the aspirations and objectives of Hydro, three lines of research were established, in which the projects and their research scopes are aimed:

a) Biodiversity research and monitoring in mined and surrounding areas;
b) Greenhouse gas and carbon footprint flows related to mining operations; and
c) Restoration of tropical forests, including restoration of biodiversity and forest soils.

5.2 Approved Projects

Currently, the BRC Consortium has 26 approved research projects, with approximately 15 being completed or in progress, as seen in the Table 1 below. In December 2018, 11 new projects were approved and are currently in stage of agreements celebration, to begin in the second half of 2019 and the first half of 2020.

As noted in Table 1, since 2014 the projects are being approved and developed in Hydro Paragominas area. Of these, three were approved in 2014, eight in 2015, two in 2016, two in 2017 and 11 in 2018.

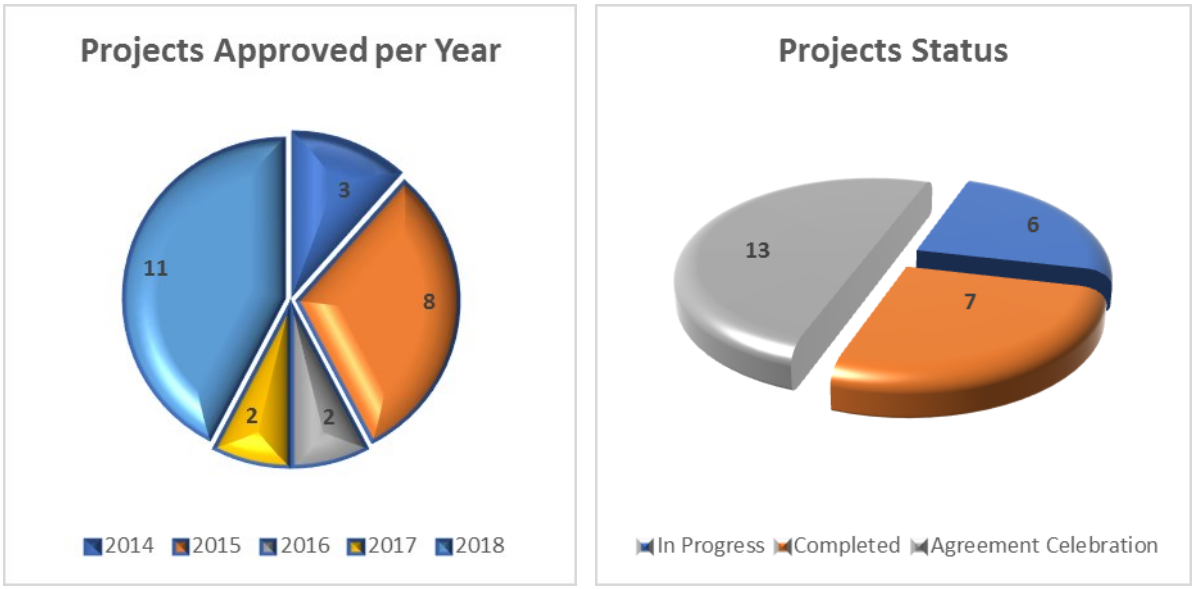

Figure 3. Number of biodiversity research projects approved from 2014 to 2018 and status of studies progress. Source: Hydro.

As for the projects' status, seven projects have already completed the surveys, six are in progress and 13 are in administrative stage of agreement, starting in the second half of 2019 and the first half of 2020, as can be seen in Table 1 below.

Table 1. Project names, approval year and progress status. Source: Hydro.

Project	Year	Status	People Envolved
BRC 01/2014 - Fungos Micorrízicos	2014	In Progress	10
BRC 02/2014 – Emissons	2014	In Progress	03
BRC 03/2014 – Plants Biodiversity, Soil and Biomass	2014	Completed	30
BRC 04/2015 – Entomology	2015	In Progress	08
BRC 05/2015 - Cameras Trap	2015	In Progress	04
BRC06/2015 – Chemicals Compounds by timber storage	2015	Completed	14
BRC 07/2015 – Vectors Insects	2015	Completed	10
BRC 08/2015 – Birds Diversity	2015	Completed	16
BRC 09/2015 – Wood-Decay Funghi	2015	Completed	03
BRC 10/2015 - Aquatic Biota	2015	Completed	23
BRC 11/2015 – Herbivorous Insects	2015	Completed	07
BRC 12/2016 – Biologicals Interactions	2016	In Progress	24
BRC 13/2016 – Tracking Jaguars	2016	In Progress	06
BRC 14/2017 - Herpetofauna	2017	Agreement Celebration	07
BRC 15/2017 – Topsoil Study	2017	Agreement Celebration	03
BRC 16/2018 -Large Herbivorous Mammals	2018	Agreement Celebration	03
BRC 17/2018 -DNA and Metabarcoding	2018	Agreement Celebration	08
BRC 18/2018 – Carnivorous Coexistence	2018	Agreement Celebration	03
BRC 19/2018 - One Health	2018	Agreement Celebration	09
BRC 20/2018 - Effects of mining on hydrological resources (chemical, physical and biological).	2018	Agreement Celebration	05
BRC 21/2018 - Pipeline Aquatic Biota	2018	Agreement Celebration	14
BRC 22/2018 - Bird telemetry monitoring	2018	Agreement Celebration	09
BRC 23/2018 - Biomonitoring of Aquatic System	2018	Agreement Celebration	06
BRC 24/2018 - Physical, chemical and biological tools to evaluate the water resources	2018	Agreement Celebration	13
BRC 25/2018 - Riparian vegetation, aquatic macrophytes and plankton	2018	Agreement Celebration	06
BRC 26/2018 - Terrestrial arthropod biodiversity	2018	Agreement Celebration	15

6. Results

As previously presented, the BRC Biodiversity Research Consortium has mobilized at least 259 people in its 26 projects developed, in development or in the beginning phase of agreements celebration to begin activities in coming years.

However, this topic will present the results obtained mainly from the most relevant researches or with the researches already completed, which are:

1. BRC 05/2015 - Camera Traps
2. BRC 06/2015 - Chemicals Compounds by Timbers Storage
3. BRC 08/2015 - Birds Diversity
4. BRC 10/2015 - Aquatic Biota

6.1. Cameras Traps Project

This study was conducted between Hydro Paragominas, Federal University of Pará (UFPA) and University of Oslo (UiO) and aims to analyze how terrestrial mammals in the area of Hydro Paragominas are using the local landscape, with emphasis on animals with conservation interest. In addition, the study verifies the importance of different habitats and what are the determining environmental and physical factors that are modeling the occurrence of these animals.

The project coordinators are Professors Ana Cristina Mendes de Oliveira and Leonardo Senna (UFPA); and Professor Oystein Wiig (Natural History Museum (NHM) - University of Oslo). In addition to the coordinators, there are three students at the master's level, who are using this research as study subjects for the conclusion of their master's thesis.

6.1.1. Results Obtained

Of the three years of monitoring of terrestrial mammals, more than 180,000 photos have been identified or are in the identification step. Some 26 species of mammals have already been identified form these photos, of which 9 are species under some degree of threat, according to the list of the IUCN (International Union for Conservation of Nature), as noted in Table 2. [2]

Table 2. List of conservation interest species registered on Hydro Paragominas area in Camera Trap study. Source: BRC.

Popular Name	Scientific Name	Status
Giant Armadillo	*Priodontes maximus* (Kerr, 1792)	Vulnerable
Giant Anteater	*Myrmecophaga tridactyla* (Linnaeus, 1758)	Vulnerable
Margay	*Leopardus wiedii* (Schinz, 1821)	Near Threatened
Jaguar	*Panthera onca* (Linnaeus, 1758)	Vulnerable
Tapir	*Tapirus terrestris* (Linnaeus, 1758)	Vulnerable
Red Brocket	*Mazama americana* (Erxleben, 1777)	Data Deficient
White-lipped Peccary	*Tayassu pecari* (Link, 1795)	Vulnerable
Bush Dog	*Speothos venaticus* (Lund, 1842)	Near Threatened
Ka'apor Capuchin	*Cebus kaapori* (Queiroz, 1992)	Critically Endangered

Figure 4. A. Students collecting pictures from trap cameras. B. Jaguar (*Panthera onca*), C. Giant Anteater (*Myrmecophaga tridactyla*) and D. Puma (*Puma concolor*) recorded in Hydro Paragominas areas. Source: BRC.

6.2. Evaluation of Chemical Compounds from Timbers Stored

This study carried out between the Federal Rural University of Amazonia (UFRA) and Hydro Paragominas, aims to evaluate if timber stored in areas recovered by nucleation and storage yards can cause soil contamination, either by leaching of chemical components of the wood, bark and the natural degradation of the material through its anatomical structures, especially the parenchyma cells or contributing to local resilience through the availability of nutrients in the area. [3]

The project coordinator is Professor Gracialda Ferreira, and will result in completion of two master's dissertations, a doctoral thesis and a postdoctoral dissertation.

6.2.1. Results Obtained

During the analysis of the data obtained, it was possible to observe that the nutrient values are always higher in zone of influence of the wood and increase positively with the time of its deposition. It is suggested that the presence of wood and its decomposition over time, makes a continuous contribution of organic matter to the soil and so serves as a contribution to soil quality, rather than a potential contaminant, as expected by the main objective of the study. [4]

Figure 5 A and B. Timber piles evaluated in the storage yards and UFRA staff carrying out the collections. Source: BRC.

6.3. Birds Diversity

The study celebrated between Federal University of Pará (UFPA) and Hydro Paragominas, aims to record how birds are using the landscape formed by a mosaic of recovering areas and forests.

The project coordinator is Professor Dr. Marcos Pérsio. A master's degree has already been concluded with results obtained by the study, and the work will also serve as the object of study for the conclusion of a graduation during the execution of agreement.

6.3.1. Results Obtained

For the sampling of birds, 185 points were installed for the census. Of the 185 points, 24 were made in the Nucleation technique; 70 points in the Traditional Plantation; 51 points in Natural Regeneration; and 40 points from the Forest.

During the samplings, a diversity richness of 240 species was recorded, divided into 18 orders and 41 families. The most diverse treatment was forest, with 146 species; the recovery areas (degraded areas recovery program - PRAD) presented 90 species.

The birds' diversity in the PRAD area was arranged according to Figure 6, and the technique that presented highest number of bird species was Natural Regeneration (53), followed by Traditional Planting (49), and with 37 species, the Nucleation technique. [5]

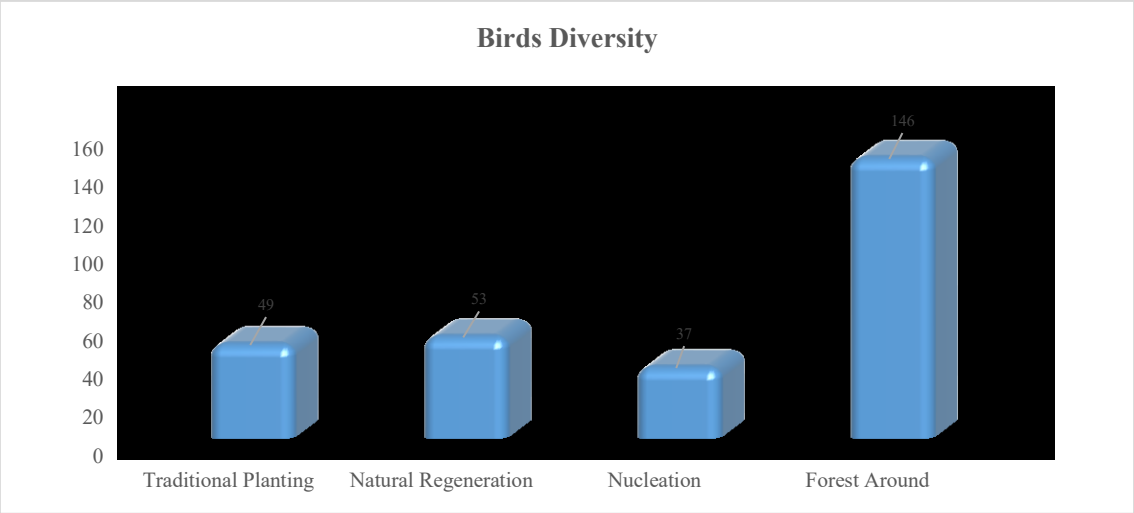

Figure 6. The Birds Diversity recorded during the project implementation at Hydro Paragominas. Source: BRC.

Figure 7. Bird species recorded during the project activities. A: *Guaruba guarouba* and B: *Pitangus sulphuratus*. Source: BRC.

6.4. Aquatic Biota

An agreement between UFPA and Hydro Paragominas aims to evaluate how reforestation measures are affecting the integrity of aquatic ecosystems and related fauna and flora, using different methods of analysis: Ecological, Biomarkers, Taxonomic Inventory and Genetic Code.

The Ecological studies are led by Professors Leandro Juen and Luciano F. A. Montag (UFPA). The biomarkers studies are coordinated by Professor Lílian Lund Amado (UFPA) and Dr. Cléverson Rannieri Meira dos Santos (MPEG), and the studies based on Taxonomic Inventory and Genetic Code are coordinated by Professor Alberto Akama (MPEG) and Dr. Jonathan Ready (UFPA).

6.4.1. Results Obtained

The sub-project "Ecological Study" has the purpose to evaluate changes in environmental variables, to verify if the observed differences are related to land use (areas of high conservation value and areas of different reforestation categories) by studying aquatic insects, fish and

macrophytes. This exercise is in addition to assessing the aquatic biodiversity of the region through taxonomic richness, species composition and environmental integrity indexes. [6]

The results presented in Table 2 were observed during the study's execution.

Table 2. Main results of the activities carried out in the Aquatic Biota Study project. Source: BRC.

Biota Aquática Survey	
Rivers Sampled	18
Fish Species	70
Algae Species	49
Aquatics Insects	782 individuals
Odonatas	39 species

Figure 8 A and B. Collection activities in Aquatic Biota project at Hydro Paragominas. Source: BRC.

6.5. New Discoveries

Since beginning the studies, 3 new species of decay-wood funghi have been registered (BRC 09/2015 - Wood-Decay Funghi), under the supervision of Professor PhD. Karl-Henrik, University of Oslo, and with technical execution by Post-Doctorates Kadri-Runnel and Doctor Adriene Soares (Federal University of Pernambuco). There was also a description of a new species of lichen during collections in the area of Hydro Paragominas. Currently the works are in the publication stage of the species.

During the collections made by Professor Dr. Fernando Carvalho (Museu Paraense Emílio Goeldi), a new species of wasp was registered and confirmed. This tiny specimen belongs to the genus *Probaryconus*. As this was the first new species of the BRC Consortium, the animal served as inspiration for the BRC logo (Figure 09A).

Under the supervision of Professor PhD José Antônio Fernandes (Federal University of Pará a new genus (possibly a new subfamily) of *Heteroptera* (true bugs), is in the description phase. If confirmed, it is the first subfamily in 20 years, according to Brazilian experts. [7]

7. Results and Discussions

With the results of the four studies discussed here, it was observed that valuable information about the ecological dynamics of the region was obtained, such as:

The habits of terrestrial mammals under the influence of mining activities, mainly species of conservation interest;

The study of decaying wood suggests that the presence of decaying wood in the areas of Nucleation and storage patios, present a quantity of nutrients favorable to soil recovery, with increase of organic matter, favoring the development of the local recovery;

The diversity of local birds, as well as the preference for forest recovery techniques, as well as species of conservation interest;

The ecological dynamics of water bodies in surrounding mining areas, as well as an understanding of how these groups can serve as indicators for the processes of mining and environmental recovery.

During the samplings of several groups surveyed, six new species for science have already been registered, with potential to expand these new discoveries with new projects that will begin in the coming years.

With the help of these partial results, it is possible that Hydro Paragominas adopts new and improved environmental control measures before, during and after its activities, which will serve to inform strategic decisions for the conservation of local biodiversity.

In addition to the ecological results, it is worth commenting on the value of the social and academic gains, which are evidenced through the promotion of studies for the local Amazon, as well as the academic improvement of the students involved.

8. Conclusions

While this article reports on the partial results of only four research projects being delivered in the area of Hydro Paragominas, other studies continue to be carried out. In the future it is expected that more results will be presented that will add value and technical knowledge to the pre-mining activities (biodiversity inventories and management specific groups as examples); during mining (top soil management); and post-mining (in the environmental recovery activity), with the proposal of indicators, techniques and actions that favor and increase environmental restoration, underpinned by scientific and academic knowledge, informing the technical operations of mining, in search of the State of Art in Environmental Restoration in bauxite mining areas.

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