BX17 - Contributions from 10-year Biodiversity Research Consortium to the Sustainability of Bauxite Mine Operations

Mayra Barral[1], Ana Carla Souza[2], Valniele Cascais[3], Jonilton Paschoal[4], Rosiane Ferreira[5], Denia Bitaraes[6] and Cícero Viana[7]
1. Environment Analysts
2. Environment Analysts
4. Environment Manager
5. Administrative Assistant
6. Environment Analysts
7. Senior HSE Manager
Hydro Paragominas, Paragominas – PA, Brazil
3. Environment Analyst, Terra meio ambiente, Paragominas – PA, Brazil
Corresponding author: mayra.barral@hydro.com

Abstract

The Biodiversity Research Consortium Brazil – Norway (BRC) is a partnership between Hydro and four research institutions: Federal University of Pará (UFPA), Museu Paraense Emílio Goeldi (MPEG), the Federal Rural University of the Amazon (UFRA) and the University of Oslo (UiO). The consortium was founded in 2013 and has approved 26 research projects so far, and more than 250 people have benefited from it amongst students, technicians, and researchers. Nine projects were concluded from which two projects are being renewed, 1 project has not started yet, and the 16 projects that are underway have research planned until 2026. With the promotion of research projects many positive results are obtained in addition to the gain in scientific knowledge, such as the investment in permanent materials to improve the structure of laboratories in the educational institutions and the increase of income of students and researchers through the scholarships included in the projects. In this paper, based on the studies published within the consortium, we are going to evaluate the contributions of the research projects to the knowledge about biodiversity in the mining area and surrounds, how this knowledge has contributed to the sustainability of Hydro Paragominas operations, and the social benefits that came from the consortium over 10 years of existence.

Keywords: Biodiversity, Bauxite mining, Scientific research, Amazon, Partnership.

1. Introduction

The Brazil-Norway Biodiversity Research Consortium (BRC) conducts research on biodiversity and climate change in the Brazilian Amazon. Founded in 2013, the governance of the BRC is composed of representatives of the 5 participating institutions, the Federal University of Pará (UFPA), the Emílio Goeldi Museum of Pará (MPEG), the Federal Rural University of the Amazon (UFRA), the University of Oslo (UiO) and the Norwegian aluminum production company Norsk Hydro (Hydro), organized in two nuclei: Board and Scientific Committee, in addition to the BRC secretariat. The first agreement of the BRC was signed in 2013 and it has been running since then with 26 approved research projects so far.

In the BRC Consortium agreement, the main objective of the cooperation is to "develop applied and basic research activities and build a solid foundation of results in biodiversity and climate knowledge" among the partners. The consortium should also contribute to the "enhancement of the university-industry partnership". In addition to exchange, joint research and publications, "graduate studies (master's and doctorate) will be an important element of the consortium's activity."

The BRC was created with a primary focus on the upstream activities within the aluminum value chain and specifically on bauxite extraction by Hydro's operations in the State of Pará, promoting basic and applied research for more sustainable practices in mining operations. The impact of bauxite extraction on the environment is well documented; areas of forest need to be removed to allow access to this raw material, impacting the forest, the soil and fauna in that area. Thus, the BRC should focus not only on research for the improvement of restoration techniques, but also conduct research that may inform managers how to achieve the 'State of the Art' in the rehabilitation of mined areas combining the operational activities of bauxite mining in all its stages with scientific-based knowledge. This includes research on optimal monitoring of the biodiversity recovery, as life-forms return to restoration areas, compared to the biodiversity of the original forest.

2. Methods

The present work was carried out through bibliographic research which consists of the review of the literature related to the BRC consortium. To this end, annual reports, scientific papers, thesis, articles, internal financial reports, and the BRC site were consulted.

3. Results and discussions

On topic 3.1 we demonstrate the contributions of the research projects to the knowledge about biodiversity in the mining area and surrounds, and how this knowledge has contributed to the sustainability of Hydro Paragominas operations. On topic 3.2, we present the social benefits generated through the consortium with Hydro Paragominas' support and funding.

3.1 Contributions to science and knowledge on biodiversity

To support the acquisition of science-based knowledge in the Amazon and in the mining areas, the consortium has a total of 26 approved projects. Most of the projects are currently active and 9 are concluded (Figure 1). The BRC projects are developed in different lines of research related to biodiversity, according to the definitions of each project call.

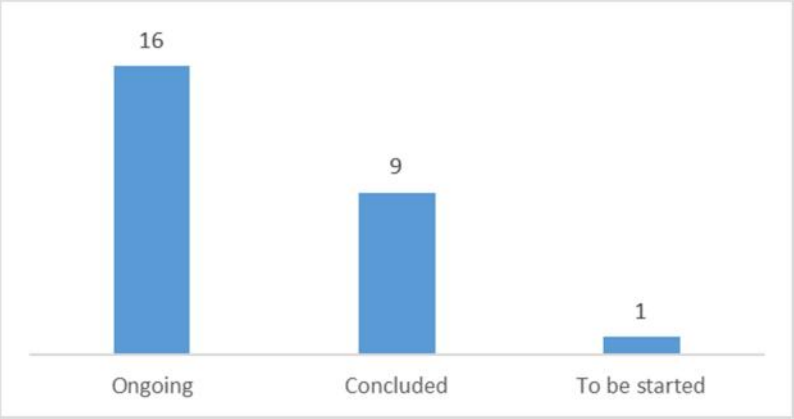

Figure 1. Status of the 26 projects approved within the consortium (reference year: 2022).

Throughout the consortium existence (from 2013 to 2023), there were 53 papers published in important scientific journals since the signing of the agreement until september/2023, and other 5 productions that have been submitted (Figure 2). Among the most prominent journals that BRC projects have published we can mention Ecological Indicators, PlosOne, Hidrobiologia and Journal of Animal Ecology, all with factor impact over 2.0.

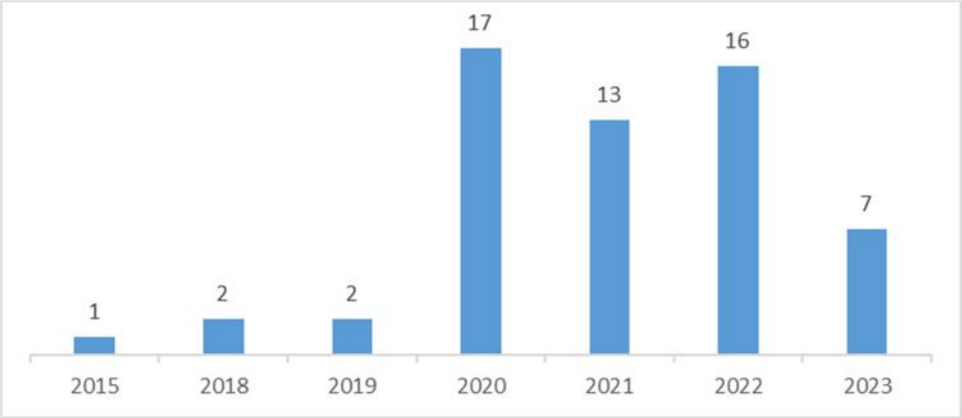

Figure 2. Scientific production within the BRC projects over the years.

The approved projects and the articles described here present results that generate direct applications to the Degraded Areas Recovery Plan (PRAD), indicators and bioindicators in activities and processes developed by Hydro Paragominas, and knowledge that can contribute to the decision-making process in the plant. For a better understanding the technical/operational results obtained from the projects studies were divided by macro themes.

Macro theme: **State of art on the Rehabilitation of mined areas**

- Description: Evaluate the relationship between soil and plants in Hydro Paragominas rehabilitation areas.
- Results obtained: Identification of the most suitable species for planting for the rehabilitation of mined areas. Future use of plant species with soil decompaction (scarification) property. Knowledge about the indicators of the restoration of ecosystems degraded by bauxite mining [1–11, 19 – 22].

Macro theme: **Mammals herbivores**

- Description: Effect of large herbivorous mammals on forest recovery in post-mining areas in Paragominas, Pará, Brazil.
- Results obtained: Knowledge of how species respond to anthropogenic threats and on different gradients of land use [12, 13].

Macro theme: **Entomology**

- Description: Determine the set of groups of insect indicators that can allow the monitoring of biodiversity and the integrity of ecosystems.
- Results obtained: Knowledge about the behavior and morphology of insects in different environments [14-17].

Macro theme: **Wood destination**

- Description: Biodiversity, propagation of plant species and recovery of areas degraded by bauxite mining in the Northeast region of Pará, Paragominas, Pará.
- Results obtained: Understanding the potential uses of species will contribute to improving the overall economic potential and sustainability of them. [25]

Macro theme: **Birds**

- Description: Bird diversity in three areas in different states of conservation in the Eastern Amazon.

- Results obtained: There are no differences in functional diversity and functional richness of birds between the methods of recover restoration: natural regeneration, planting seedlings, and nucleation [26].

Macro theme: **Herbivorous Insects**

- Description: Diversity of herbivorous insects in four areas of the mining company Hydro.
- Results obtained: Information regarding which set of variables explain the herbivory amount in aquatic macrophytes, emphasizing the importance of landscape isolation, leaf traits and defense compounds on those organisms in freshwater ecosystems [32]

Macro theme: **Terrestrial Arthropods**

- Description: Metabarcoding and metagenomics for inventory and high throughput monitoring of terrestrial arthropod biodiversity.
- Results obtained: Validation of the arthropod monitoring technique, and information on the presence of arthropods in the Hydro Paragominas rehabilitation areas in comparison to forest areas. [33-34]

Macro theme: **Aquatic Biota**

- Description: Monitoring and evaluation of the aquatic biota upstream and downstream of the bauxite pipeline and effects of land use on the diversity of aquatic macrophytes.
- Results obtained: Studies that present relevant information to the water body monitoring program, with potential application to the actions of eventual environmental investigations, regarding the evaluation of water resources at Hydro Paragominas and a better understanding of the relationship of macrophytes with the aquatic environment and the effect of different land uses in this environment [18, 23, 27–31, 35–50]

As observed, the studies produced within the consortium have enhanced the scientific knowledge in the plant and surrounds, in addition to have supported other studies in the Amazon region. In Figure 3, we show in percentage values how much of these studies contributed to Hydro Paragominas' sustainability strategies and biodiversity management.

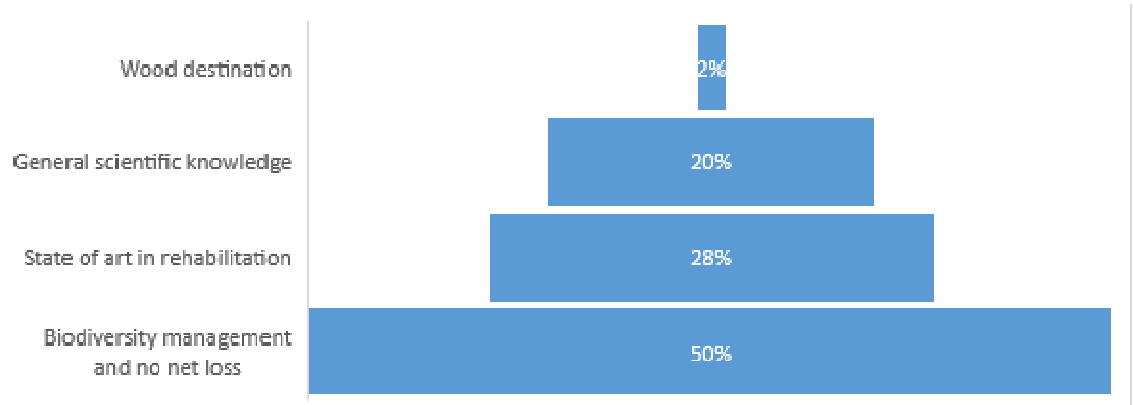

Figure 3. Contributions from BRC papers to HYDRO PARAGOMINAS's sustainability in percentage of published papers.

The studies counted in achieving the "state of art in rehabilitation" are those that directly contributed to the knowledge about the rehabilitation areas in Hydro Paragominas. Through those studies we acquired knowledge about which of the 3 rehabilitation techniques applied are more efficient for different indicators. One of the findings, for instance, was that natural regeneration is an efficient technique for litter production during the initial phase of regeneration [1]. The paper that contributed to the wood destination strategy is described as macro theme above.

"General scientific knowledge" contributions are related to those papers that were not performed within Hydro Paragominas' areas but have fomented studies within the Amazon region and other places in Brazil that have contributed to scientific production about biodiversity. For instance, we can mention two papers: the assessment of fish biodiversity using eDNA metabarcoding from water samples collected from the Amazon [24] and the First record of tail bifurcation in Tropidurus hygomi in northeast Brazil [51].

Contributions on "biodiversity management and no net loss" are studies that enhanced knowledge about biodiversity within Hydro Paragominas' areas beyond its monitoring program. For instance, many studies about the response of aquatic insects and herpetofauna to different land uses or rehabilitation gradients. The studies counted is this contribution, also increased knowledge about threatened species habits, and promoted studies that might serve as reference for defining strategic areas for the conservation of biodiversity in the plant.

3.2 Other social benefits from BRC

By participating, funding, and encouraging scientific research in the Amazon region, through the consortium we have contributed to the formation of a great number of students. Over the years, BRC projects counted with nearly 270 people among students, technicians, and researchers. The number of students involved in BRC research projects from 2015 to 2022 is divided by bachelor, master, phD and post-doc (Figure 4).

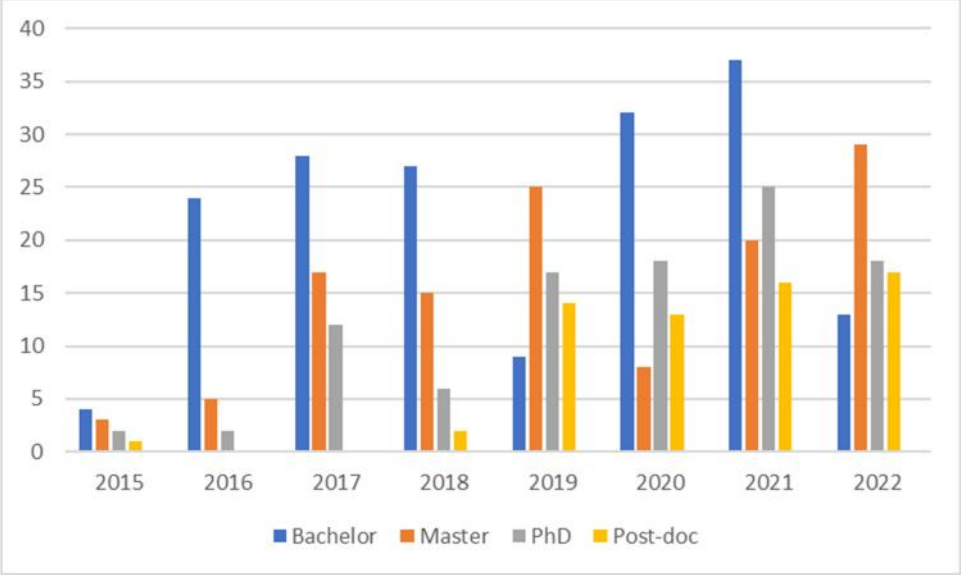

Figure 4. Number of students involved in BRC projects from 2015 to 2022 [52]

The students involved in the projects have gained experience with the integration of the technical area with the academic area, it is a unique opportunity to put theory into practice. Through the consortium Hydro has invested nearly 6 million Reals (MBRL) in scholarships throughout these years. This financial aid helps the students have a more productive academic life and encourages them to be part of the research without worrying about work.

By funding the consortium projects, Hydro has also contributed to cultural and scientific exchange of knowledge between Norway and Brazil. Almost 950 thousand Reals were invested in exchange programs, giving the students and researchers the opportunity to be part of an international experience.

Additionally, through the projects nearly 2.9 MBRL was invested in permanent material for the universities and institutions involved. Among these investments there are the construction of greenhouses, laboratory and electronic equipment acquisition, as well as remodel of buildings and other university facilities. These investments promoted better infrastructure in public institutions for research and will continue to be used on behalf of science even after the BRC projects are concluded.

Through the projects funding, Hydro Paragominas has also invested approximately 5 MBRL into the university financial institution, which supports its continuity on helping manage the investments of private companies to the academy.

4. Conclusion

During this decade BRC has matured from a formal agreement into a fully operational research consortium. The board and scientific committee are constituted and consolidated. This is achieved through frequent events and personal encounters and is clearly shown in the open discussions about the environmental status at Hydro Paragominas.

The studies developed through BRC consortium have brought applied knowledge related to the rehabilitation of mined areas, besides we have considerably increased our knowledge on biodiversity within Hydro Paragominas' areas, from big mammals to small insects.

The consortium has also positively impacted the life of the people involved in it. The 26 projects were possible because of BRC, the consortium has supported students in their process of obtaining master's, doctorate and post-doctorate degrees.

The increase in BRC's participation in all kinds of events, both national and international, indicates that we are on the right track regarding the improvement of the relevance of the BRC on the world scene. More and more people are paying attention to BRC's research and relevance, thanks to the great efforts of all the people involved in the consortium.

Through their participation in the Brazil-Norway Biodiversity Research Consortium (BRC), Norsk Hydro and Hydro Paragominas have contributed directly to the promotion of scientific research on the Amazonian biodiversity.

5. References

1. Bruno Rocha Martins et al., Litter and nutrient deposition in mining areas submitted to forest restoration methods in Paragominas, Pará, *FLORESTA,* Vol. 48, No. 1, (2018), 47-48.
2. Sabrina Riberio Santos et al., Forest Restoration Evaluation Through Indicators in Areas of Bauxite Mining, *Floresta e Meio ambiente,* 2019.
3. Bruno Rocha Martins et al., Litterfall, litter stock and water holding capacity in post-mining forest restoration ecosystems, Eastern Amazon, *Revista Brasileira de Ciências Agrárias,* Vol.13, No. 3, (2018).
4. Denis Conrado da Cruz et al., Tree communities in 3-yr-old post-mining sites under different forest restoration techniques in the Brazilian Amazon, *Forests*, Vol. 527, 2020.
5. W. B. R. Martin, Survival, growth and regeneration of forest species in mining areas in the Eastern Amazonia, *Scientia Plena,* Vol. 6, 2020.
6. Thiago Pereira Mendes et al., Recovery processes in areas affected by mining: a scienciometric review*, Ciência e Natura,* Vol. 43, 2021.

7. Julia Isabella de Matos Rodrigues et al., Stock of litter and nutrients: indicators of the restoration of ecosystems degraded by bauxite mining, *Entrepreneurship and Innovation in Forest Engineering 3,* Chapter 5, 2021.
8. Ana Cláudia Vale do Nascimento et al., Evaluation of the phytosociological structure of a forest fragment in the Municipality of Paragominas-PA, Brazil, *Research, Society and Development*, Vol.10, No.9, (2021).
9. V. P. Oliveira et al., Development and quality of seedlings of Parkia gigantocarpa Ducke (Fabaceae) as a function of controlled release fertilizer, *Scientia Plena*, Vol. 17, No. 9 (2021).
10. Cerqueira, R.M et al., Phytosociology of the Tree Stratum in Native Forests and Recovery Areas of Degraded Areas On the influence of mining, Paragominas, Pará, Brazil, *Nature and Conservation,* Jun-Ago 2021, Vol.14, No.3, (2022).
11. Rodrigo Brito et al., Diversity and community structure of Drosophila (Hexapoda, Diptera) in post-mining sites under different forest restoration techniques in the Brazilian Amazon, *Restoration Ecology,* 2023.
12. Juliana Teixeira Santos et al., Environmental factors influencing the abundance of four species of threatened mammals in degraded habitats in the eastern Brazilian Amazon, *Plos one,* February 26, 2020.
13. Ana Cristina Mendes et al., Wild canids and ecological traps, facing deforestation and climate change in the Amazon Rainforest, *Ecology and Evolution,* Vol 13, No. 6, (2023).
14. Flavio Roberto de Albuquerque Almeida et al., Voragocoris weirauchae sp. n. (Heteroptera: Schizopteridae: Schizopterinae), a further minute litter bug species from Brazil, *Zootaxa,* Vol. 4729, No. 1, (2020).
15. Rony P. S. Almeida eta al., The role of morphological traits in predicting the functional ecology of arboreal and ground ants in the Cerrado–Amazon transition, *Oecologia,* 2022.
16. Cândida A. P. Rodrigues et al., The influence of abiotic factors on the foraging activity of Cephalotes borgmeieri (Kempf, 1951), *Sociobiology,* 2023.
17. Cristian Camilo Mendoza-Penagos et al., Assessing sodium limitation as a resource for ground-dwelling ants (Hymenoptera: Formicidae) in an area of the Amazonian Terra Firme Forest, *Boletim do Museu Paraense Emílio Goeldi. CiênciasNaturais*, Vol. 15, No. 1, (2020),135-143.
18. R. C. Bastos et al., Environmental impacts from human activities affect the diversity of the Odonata (Insecta) in the Eastern Amazon, *International Journal of Odonatology,* 2021, 300-315.
19. Elson Junior Souza da Silva et al., Biometric characterization of Solanum paniculatum L. seeds and germination performance after dormancy overcoming, *Colloquium Agrariae,* Vol. 06, No. 4, (2020), 29-27.
20. Alberto Bentes Brasil Neto et al., Natural Regeneration for restoration of degraded areas after bauxite mining: a case study in the Eastern Amazon, *Ecological Engineering,* Vol. 171, 2021.
21. Elson J. S. da Silva et al., Growth and Quality of Inga heterophylla Willd Seedlings According to the Slow Release Fertilizer, *Journal of Agricultural Science,* Vol. 11, No. 5, (2019), 479-484.
22. Denmora et al., Seed viability changes during fruit ripening of Tapirira guianensis: Implications for collection, *Research, Society and Development,* Vol. 9, No. 11, 2023.
23. Fernando Geraldo Carvalho et al., Detecting Darwinian Shortfalls in the Amazonian Odonata, *Neotropical Entomology,* Vol. 51, (2022) 404-412.
24. Jake M.Jackman et al., eDNA in a bottleneck: Obstacles to fish metabarcoding studies in megadiverse freshwater systems, *Environmental DNA*, 2021, 1–13.
25. Graciene S. Mota et al., Bark of Astronium lecointei Ducke Trees from the Amazon: Chemical and Structural Characterization, *European Journal of Wood and Wood Products,* No. 5, (2021), 1087-1096.

26. Fernanda de Carvalho Barros et al., Taxonomic diversity and functional diversity of bird communities in mining areas undergoing passive and active restoration in eastern Amazon, *Ecological Engineering*, Vol. 182, 2022
27. Thaisa Michelan et al., Diversity of macrophytes in the Amazon deforestation arc: information on their distribution, life-forms and habits, *Rodriguesia,* Vol. 72, 2021.
28. Híngara Leão; Louise Cathrine Rolstad Esdar; Bárbara Dunck, The role of macrophyte architecture in driving periphytic algal communities in a lowland river in the Brazilian Amazon, *Brazilian Journal of Botany,* 2020.
29. Sildiane Martins Cantanhede et al., Distribution of metals in different environmental compartments and oxidative stress biomarkers in Bryconops caudomaculatus (Osteichthyes: Characiformes) from a bauxite mining area in the Eastern Amazon, *Environmental Research,* Vol. 216, 2023.
30. Gabriel Martins Cruz, Ana Paula Justino Faria, Leandro Juen, Patterns and metacommunity structure of aquatic insect (Trichoptera) in Amazonian streams depends on the environmental condition, *Hydrobiologia,* 2022.
31. Calebe Maia et al., Fish functional responses to local habitat variation in streams within multiple land uses areas in the Amazon, *Neotropical Ichthyology,* Vol. 20, No. 4, 2022.
32. Ana Luisa Biondi Fares et al., Which variables influence the herbivory amount on Montrichardia spp. in aquatic ecosystems, *Biologia Tropical,* Vol. 70, 2022, 263-276.
33. Viana-Junior AB et al., Collecting arboreal arthropods: a technique for sampling plant-inhabiting arthropod communities in a tropical forest understory, *Entomologia Experimentalis et Applicata, 2020, 1-10.*
34. Ana Luísa B. Fares et al., Environmental factors affect macrophyte diversity on Amazonian aquatic ecosystems inserted in an anthropogenic landscape, *Ecological Indicators,* Vol. 13, 2020.
35. Ana Luisa Biondi Fares et al, New records of the invasive macrophyte, Urochloa arrecta extend its range to eastern Brazilian Amazon altered freshwater ecosystems, *Acta Amazonica, 2020.*
36. Leandro Schlemmer Brasil et al., The Habitat Integrity Index and aquatic insect communities in tropical streams: A meta-analysis, *Ecological Indicators,* Vol. 116, 2020.
37. Cintia Oliveira Carvalho et al., Morphological and allometric variation due to percentage of cover in Eichhornia azurea (Swart) Kunth (Pontederiaceae), *Brazilian Journal of Botany,* Vol. 43, 2020, 389–395.
38. Ana Paula Justino Faria et al., Response of aquatic insects to an environmental gradient in Amazonian streams, *Environmental Monitoring and Assessment,* Vol. 193, 2021, 763.
39. Lenize Batista Calvão et al., Influence of biotic and abiotic factors on the adults of Odonata (Insecta) in Amazon streams, *Animal Biology*, 2020.
40. Rafael Costa Bastos et al., Morphological and phylogenetic factors structure the distribution of damselfly and dragonfly species (Odonata) along an environmental gradient in Amazonian streams, *Ecological Indicators,* Vol. 122, 2021.
41. Rodrigo Arison Barbosa et al., Habitat conditions in streams influence Odonata larval assemblages in the eastern Amazon, *International Journal of Odonatology,* Vol 25, 2022.
42. Carina Kaory Sasahara de Paiva et al., The anthropic gradient determines the taxonomic diversity of aquatic insects 1 in Amazonian streams, *Hydrobiologia,* 2021.
43. A. Luiza-Andrade et al., Niche breadth and habitat preference of Ephemeroptera, Plecoptera, and Trichoptera (Insecta) in streams in the Brazilian Amazon, *Hydrobiologia,* 2022.
44. Rayssa Silva Carmo et al., Does the structure of riparian vegetation affect the diversity of macrophytes in eastern amazonian streams, *Biologia,* 2022.
45. Lenize B. Calvao et al, Correlates of Odonata species composition in Amazonian streams depend on dissimilarity coefficient and oviposition strategy, *Ecological Entomology,* 2022, 1-13.

46. Lenize B. Calvão et al., Effects of the loss of forest cover on Odonate communities in eastern Amazonia, *Journal of Insect Conservation,* 2023.
47. Luciano Fogaça de Assis Montag et al., The complete mitogenome of Amazonian Hyphessobrycon heterorhabdus (Characiformes: Characidae) as a valuable resource for phylogenetic analyses of Characidae, *Fishes*, Vol. 8, 2023, 233.
48. Michelan et al., Land-use increases macrophytes beta diversity in Amazon streams by favoring amphibious life forms species, *Community Ecology,* 2023.
49. Myllena Lima et al., Land use changes disrupt streams and affect the functional feeding groups of aquatic insects in the Amazon, *Journal of Insect Conservation,* Vol. 26, 2022,137-148.
50. Dieison A. Moi et al., Human land-uses homogenize stream assemblages and reduce animal biomass production, *Journal of Animal Ecology,* 2023, 1-4.
51. Tainara L. Silva et al., First record of tail bifurcation in Tropidurus hygomi in northeast Brazil. *Herpetologia brasileira*, 2023.
52. Rafael Assis and Fridtjof Mehlum, The biodiversity research consortium Brazil-Norway (BRC) annual report 2022, Oslo, 30th January, 2023.
53. Gracialda Ferreira, The biodiversity research consortium Brazil-Norway (BRC) annual report 2014, Oslo, 25 April, 2015.
54. Torkjell Leira, The biodiversity research consortium Brazil-Norway (BRC) annual report 2015, Oslo, 13 March, 2016.
55. Fridtjof Mehlum, Torkjell Leira, André Carvalho, The biodiversity research consortium Brazil-Norway (BRC) annual report 2016, Oslo and Belém, 25 February, 2017.
56. Fridtjof Mehlum, Torkjell Leira, André Carvalho, The biodiversity research consortium Brazil-Norway (BRC) annual report 2017, Oslo and Belém, 15 February, 2018.
57. Fridtjof Mehlum and André Carvalho, The biodiversity research consortium Brazil-Norway (BRC) annual report 2018, Oslo and Belém, 30th January,2019.
58. Rafael Assis and Fridtjof Oslo, The biodiversity research consortium Brazil-Norway (BRC) annual report 2019, 30th January,2020.
59. Rafael Assis and Fridtjof Mehlum, The biodiversity research consortium Brazil-Norway (BRC) annual report 2020, Oslo, 27th January, 2021
60. Rafael Assis and Fridtjof Mehlum, The biodiversity research consortium Brazil-Norway (BRC) annual report 2021, Oslo, 11th January, 2021.
61. Consortium, *BRC site,* https:/ www.brcbn.com (Accessed on 14 July 2023).