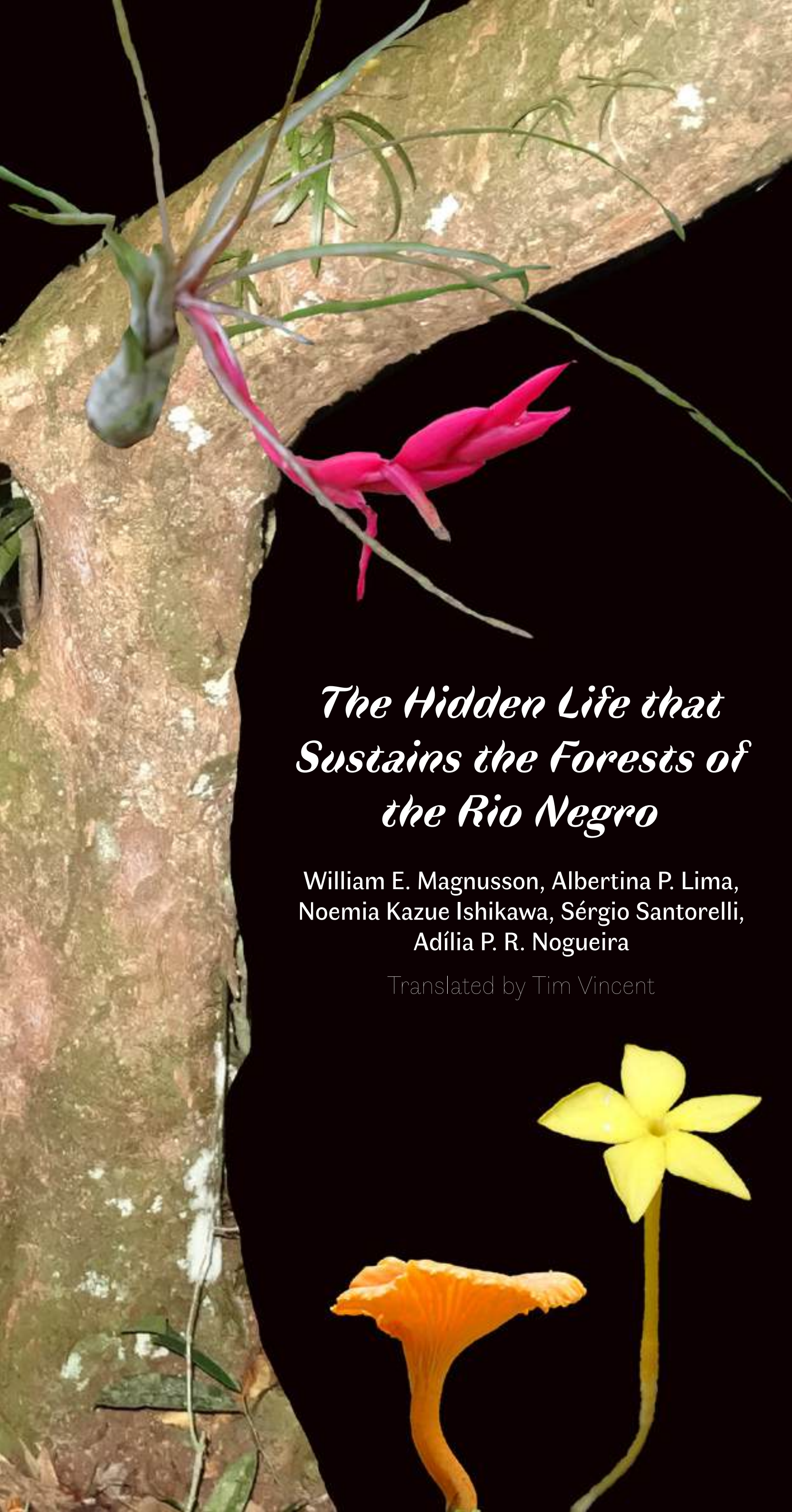

# The Hidden Life that Sustains the Forests of the Rio Negro

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Translated by Tim Vincent

The objective of this book is to introduce to students, ecotourists, and residents who live or visit the Rio Negro a little about the incredible relationships between living beings, soil, and water that sustain the forests in this region.

Dados Internacionais de Catalogação na Publicação (CIP)
(Câmara Brasileira do Livro, SP, Brasil)

The hidden life that sustains the forests of the Rio Negro [livro eletrônico] / William E. Magnusson...[et al.] ; [tradução Tim Vicent]. -- Humaitá, AM : Ed. dos Autores, 2023.
PDF

Outros autores: Albertina P. Lima, Noemia Kazue Ishikawa, Sérgio Santorelli, Adília P. R. Nogueira. Título original: A vida escondida que sustenta as flroestas do Rio Negro.
ISBN 978-65-00-79698-8

1. Amazônia - Aspectos ambientais 2. Amazônia - Fotografias 3. Biodiversidade - Amazônia 4. Ecoturismo 5. Fauna e flora 6. Florestas - Amazônia - Brasil 7. Rio Negro (Amazonas, Brasil) I. Magnusson, William E. II. Lima, Albertina P. III. Ishikawa, Noemia Kazue. IV. Santorelli, Sérgio. V. Nogueira, Adília P. R.(Amazonas, Brasil) I. Magnusson, William E. II. Lima, Albertina P. III. Ishikawa, Noemia Kazue. IV. Santorelli, Sérgio. V. Nogueira, Adília P. R.

23-171118 CDD-577.098111

Índices para catálogo sistemático:
1. Amazônia : Biodiversidade : Floresta : Conservação : Ecologia 577.098111
Aline Graziele Benitez - Bibliotecária - CRB-1/3129

# ***The hidden life*** that sustains the ***Forest of the Rio Negro:***

A large part of the Amazon rainforest grows on soils that are poor in essential nutrients for plants. How this is possible is one of the most intriguing questions, but there is no single answer. The processes that allow the forest to grow in this type of environment make the Amazon the most complex biological system known. A walk through the forests in the Rio Negro region, such as those that occur in the Rio Negro Sustainable Development Reserve (RDS-RN), is a good start to understanding some aspects of this complexity. There, a part of the forest grows in sandy soils known to be among the poorest in nutrients.

There is a variety of soils in the Rio Negro region. Most of them have a lot of sand in their composition, but some consist almost entirely of pure silica, which alone, could not sustain any plant life. The origins of these soils are still unknown, but it seems that most of them constist of sand dunes formed by winds in drier times. The tricks used by plants to colonize and stabilize the dunes will be the predominant subjects of this booklet, but first, let's consider the relationship between soils and water because this is crucial for plant life and for people living in these areas.

**Figure 1.** Many white sand soils in the Rio Negro region consist almost entirely of pure silica, as can be seen in this leafcutter ant nest.

## The soil and water

Let's start our tour near a stream, as roads and residences are usually nearby, and most visitors like to frequent bathing spots. This is neither good for the forest nor for the people, but it is the reality of the region. One of the first things the visitor notices is that the water is dark, the color of black tea. People who are used to streams in regions with clayey soil, where the water is usually clear and more transparent, might think that the stream is dirty and the water unsuitable for bathing, but this is not true.

**Figure 2.** Black-water streams have a dark reddish color due to organic acids, but the water is clean.

The dark color of these waters comes from the leaves of the forest. When the leaves of the trees are renewed, the old ones fall to the ground and begin to decompose. In this process, nutrients that are still in the leaves and other substances, such as humic acids, are released. These acids are produced by all decomposing vegetation and they combine with minerals present in the soil, resulting in loose friable soils. This is great for sustaining plant roots, and that's why decomposed organic matter is often used as fertilizer in agriculture.

**Figure 3.** The islands of the Anavilhanas Archipelago were formed by the action of the black-water of the Rio Negro on the sediments of the Rio Branco.

The capacity of humic acids to combine with minerals can be seen in the Rio Negro below its confluence with the Rio Branco. The waters of the Rio Branco are rich in suspended sediments, giving a whitish color to its waters. When this water mixes with the black-water of the Rio Negro, which is rich in humic acids, the suspended particles in the water of the Rio Branco combine to form flakes. These flakes are denser than water and settle to the bottom where they have created the islands that make up the Anavilhanas Archipelago, the second-largest fluvial archipelago in the world. The largest, Mariú, is a little further up the Rio Negro.

The Rio Negro is the largest blackwater river in the world because most forested areas that drain into the Rio Negro have sandy soils, similar to those in the RDS-RN. These soils are mainly composed of relatively coarse silica grains (silicon dioxide [$SiO_2$]), a substance that hardly reacts with plant nutrients and humic acids. Thus, these substances end up passing through the soils without being retained and accumulate in blackwater streams and rivers.

Contrary to what most people think, under good environmental conditions, blackwater is suitable for bathing. Many of the pathogenic microorganisms that cause diseases in people are adapted to the acidity of our blood, which is much less acidic than Amazonian blackwaters.

In some small streams, a white foam appears, similar in appearance to the foam in highly polluted rivers, such as stretches of the Tieté River in São Paulo. However, in black-water, this indicates that the conditions are clean. Those who have traveled to regions with alkaline water, such as the Bonito region in the Pantanal, may have noticed how difficult it is to make soap foam and how common it is to feel something sticky on the skin after bathing. This is because fats does not easily dissolve in alkaline water. In contrast, blackwater quickly cleanses the skin of fats, and the few oils from the forest leaves create foam on the water's surface.

Unfortunately, people remove the vegetation from the banks of streams and install toilets in low-lying areas. If it were only one person, the cleansing power of the forest would not be affected, but almost everyone does the same thing, each thinking that their actions will not harm the environment. The negative effect of these actions can be seen in the old bathing spots of Manaus.

**Figure 4.** White foam forms in blackwater streams, but the water is clean, and the foam does not indicate pollution.

People bought land near the streams and took advantage of the clean water coming from the forest to create bathing areas. When others bought land upstream and deforested it, the bathers became ill, and people abandoned their sites. This process continued and was repeated until most of the bathing areas became open sewers. Nowadays, Manaus residents have to drive for hours to visit bathing areas in conditions similar to those that were next to their homes just a few years ago. Unfortunately, the same degradation process is happening in many streams in other areas, such as those located in the RDS-RN.

**Figura 5.** Deforestation of the forest and construction of houses near streams threatens biodiversity and people.

Many of the animals and plants associated with the blackwaters of the Rio Negro basin depend on clean water and cannot survive without the purifying action of the forest. They do not occur anywhere else in the world, so the degradation of streams threatens many lives beyond those of bathers.

## Too much and too little water

Just as it does not retain nutrients, sand also does not hold water, and many plants cannot survive these arid conditions. It is extremely difficult to study forest trees because they are large and interconnected in

**Figure 6.** Many stream animals cannot survive after the surrounding forest has been deforested.

a complex way that we will consider later. However, studies with pea plants (*Pisum sativum*) have shown the different senses that plants can use, one of which is hearing. Pea plants are capable of making relatively complex decisions based on what they are hearing. The sound of running water usually indicates excess water, and when the soil is moist, pea plants do not respond to the sound of running water. However, in times of water scarcity, when the soil does not have enough water to sustain normal plant growth, pea plants send their roots in the direction of the sound of the water current. Many plants are also known to produce more nectar when they hear the sound of their

**Figure 7.** The stemless red palm, *Attalea* sp., captures falling leaves and directs its roots upwards to intercept nutrients.

pollinators. Plants likely respond to sounds in many other situations, but until now, no one has dared to investigate how these organisms use hearing in tropical forests. The destruction of the environments around streams will certainly affect how plants perceive their world, which will have negative effects on much larger areas than we can imagine.

## The forest and its soil

Let's go back to our initial question. How can the forest of the RDS of Rio Negro be so rich in species of plants, animals, and microorganisms if the soil is so poor in nutrients and if the nutrients from the vegetation are quickly lost to the streams and rivers? Let's start answering this question with examples of some plant behaviors, but we will also discover that they cannot do this by themselves.

We have seen that sandy soils contain few nutrients to sustain plants life and that nutrients that do become available are quickly washed away when it rains. The first strategy that plants use is to capture nutrients before they reach the mineral soil. This strategy is most easily seen in large stemless palms. We are used to seeing the crowns of palms gracefully waving at the top of assai (Euterpe sp.) and peach-palm (Bactris sp.) trunks, but within the forest, we find crowns of palms as large or even larger emerging directly from the forest floor, such as seen in the stemless red palm.

Like the crowns of the other palms, the crowns of stemless palms also need to capture light for photosynthesis and generate energy for plant growth, but stemless-palm leaves have one more use: they function as a funnel to direct falling leaves from trees to the base of the palm. Thus, they obtain the material they need, but these palms need one more trick to prevent the nutrients from escaping through the sand and being lost.

The roots of most plants grow downward towards the soil, a phenomenon called positive geotropism. This makes sense in most situations because the nutrients needed for plant growth are in the mineral soil below the plant. However, stemless palms hold the decomposing leaves above the ground and therefore need to send their roots upwards to obtain nutrients. If we dig into the material accumulated between the palm leaves, we find roots growing upwards, which is called negative geotropism. It is a strange situation where both the leaves and roots grow upwards towards the

**Figure 8.** Some plants send their roots upwards, a phenomenon known as negative geotropism.

atmosphere. This phenomenon is more easily seen in stemless palms, but we will discover that this is a strategy used by many other plant species in the forests of RDS-RN.

There is a type of forest called campinarana, which is very common in the Rio Negro region. It occurs mainly on higher ground, but campinarana areas resemble lowland areas, as they do not have many leaves on the ground and are often dominated by a palm species called burutirana. These can be confused with the lowland buritis, but in general, their stems are thinner and their leaves have long fibers at the ends. In these

**Figure 9.** Some parts of campinarana have shallow water, do not accumulate leaves on the ground, and resemble the riparian forest.

places, water tends not to penetrate very deep into the soil because of a layer of fine organic material called silt. Since nutrients cannot be carried further down, they remain available to surface roots.

The situation is different on slightly higher ground, where water does not accumulate and takes nutrients down and away from the tree roots. There, the trails used by people seem to be dug into the soil and are lined by walls of about a handspan or more in height. Upon closer inspection, we can see that the "soil" in the walls of the trail contains no sand or clay grains, but is soft and looks more like a cushion. It turns out that that

**Figure 10.** People walking on the trail create grooves in the ground, showing that the “soil” is made of roots and organic material.

it is not just palm roots, but also those of the forest trees that are growing above the mineral soil.

In the higher parts of campinaranas, the soil is created by the forest and consists almost entirely of decomposing roots and leaves. Where the soil was not suitable, the forest created its own! If we happened to find a fallen tree, we notice that almost all of its roots had grown parallel to the surface of the soil and few had penetrated the mineral part.

## Forest-cleaning fungi

It seems that trees are sending their roots upwards in frantic competition with their neighbors to obtain nutrients, but the situation is even more complicated than that. We also need to think about another element of the forest: fungi. If someone asked, "What is the largest creature in the forest?" you would be unlikely to say it is a fungus. Normally, the only part of a fungus that we see is the mushroom, which is the part we eat or avoid because it might be toxic. However, most of the fungus consists of a web of small threads called mycelia. There are so many fungi mixed in the tropical forest that it would be difficult to say where one individual ends and another begins, but in a simpler forest system in the Blue Mountains of the USA, researchers were able to map the mycelium of a fungus. It covered almost 100 hectares and is considered to be the largest organism known to date, with an estimated age of over 2,000 years. Some individual fungi in the tropical forest are likely even larger!

It's not just their sizes that are impressive; fungi are essential to the functioning of the forest. Despite what many people think, these organisms are not plants. They are biologically more similar to animals than to plants. Some fungi are predators, others are herbivores or pathogens, but it is the decomposer fungi that allow us to walk through the forest. The leaves and branches that fall from the canopy have few nutrients available to most organisms. Termites have bacteria in their intestines that can digest lignin, which is the hardest part of the wood, but the action of termites is very slow, and they would not be able to prevent a buildup of logs and branches in a layer several meters high, which would block our passage.

The only organisms capable of degrading wood quickly, leaving it soft enough for insects to chew, are some types of fungi. These fungi often have fruiting


**Figure 11.** The mushrooms we see are a small part of the fungi, which consist mainly of hidden threads.

bodies that look like a dish coming out of the trunk. From time to time, we stop to admire those that are red or have colorful designs. On some rainy days, we can see what looks like smoke coming out of the "dishes", which are microscopic spores that fungi use for reproduction and dispersal. This is the only function of mushrooms and other fungal fruiting bodies. Fungi mostly consist of the delicate mycelial threads that are inside the trunk, digesting it and clearing the way, allowing us to walk through the forest. Without fungi, the only agent capable of cleaning up the accumulation of branches would be fire, which is devastating for the forest and people.

**Figure 12.** Decomposer fungi clean the forest floor, releasing nutrients for plants and allow us clear passage.

## Fungal partners

We are used to seeing the thick roots of plants that are good for support, but plants can only obtain nutrients through their root hairs. These tiny hairs are delicate, cannot extend too far, and it would be very costly for the plant to build thick roots over an area large enough to support the root hairs, even though it can produce a lot of energy through photosynthesis in its leaves. In contrast, the mycelia of fungi can spread rapidly through the soil, but their growth is limited by the lack of energy sources. The best solution would be for plants and fungi to work together, and that's exactly what happens.

Some fungi, called mycorrhizas, live in a symbiotic association with plants. Plants provide energy to fungi in the form of sugars and other products of photosynthesis, and the fungi send their mycelia in search of the nutrients, such as phosphorus and potassium, that the plant needs. The partnership is so close that it is difficult to say whether we are talking about one organism or two. In many cases, neither the plant nor the fungus could survive without the other.

In reality, mycorrhizal fungi form much more complex and interdependent systems with plants, because the same fungus can make associations with several trees at the same time. In Europe, researchers studied rings on the ground formed by what looked like the outer bark of a tree, but in the center, the wood had died and rotted. What happened is that the trees had been cut hundreds of years before, leaving only the base, and no one could understand how the bark had remained alive without leaves. They finally realized that they had continued to be connected to other trees in the forest by mycorrhizal fungi: the other trees were supporting their companions who could no longer use photosynthesis!

The interconnections in the tropical forest are likely even more complex because there are many more species of trees and fungi, but there is a lack of researchers to study these relationships in areas with the greatest biodiversity on the planet, such as the Amazon. In many regions of the world, such as North America, Europe and Japan, some mycorrhizal fungi are highly prized, such as truffles, chanterelles, porcini, and matsutake. Mushroom collectors know exactly where to find them because they only grow in association with certain tree species.

In the RDS-RN, a species of fungus, *Cantharellus* sp., very similar to European chanterelles, is found in the

**Figure 13.** The giant macucu probably manages to grow where other trees struggle due to the benefits of its partnerships with fungi.

campinarana, usually near an Aldina heterophylla tree, known locally as campineira or macucu. These provide a delicious dish for those who enjoy fine mushrooms.

## Opportunists

In the story we have told so far, the soil seems like a benign environment, with all species living in harmony, helping each other. However, our experience with human societies indicates that there will always be opportunists wanting to benefit from the work of others without giving anything in return. The same

**Figure 14.** The *Cantharellus* sp. fungus lives in a partnership with trees where the tree provides energy and the fungus provides nutrients.

thing happens in the soil. While many fungi are mycorrhizae and help plants, others are pathogens and try to enter the plant to kill it. Therefore, plants and fungi have complex communication means to identify who is a friend and who is a foe. This communication can be through electrical pulses, as in our nervous system, but acting at a much shorter distance. Fungi and plants can also communicate through odors or chemical substances dissolved in water. These different types of signals have a function similar to the password for your bank account. If it's not correct, the bank won't let you in.

**Figure 15.** The fungi usually associated with macucu trees resemble European chanterelles and are equally tasty.

There are also opportunistic plants. In the RDS-RN, it is common to find small yellow flowers coming out of the forest floor. If we dig a few centimeters, we find roots in the soil, but curiously these plants do not have leaves and do not produce energy. They are the "charlatans" of the forest: they deceive the fungi that feed them with the energy produced by other plants and give nothing in return.

**Figure 16.** These leafless plants are sometimes called saprophytes, but they are parasites of mycorrhizae and their associated plants.

## Escaping from the soil

Little light reaches the forest floor. To find light and escape from soil opportunists, several photosynthetic organisms live on top of other plants, and these plants are called epiphytes. In reality, some of them are not exactly plants. Some are small protists, which usually only have one cell, have chlorophyll, and can therefore undertake photosynthesis, which are called algae. When a lake has many nutrients and the water turns green, this happens because of the algae. Algae do very well in water and are responsible for most of the primary production in the oceans, but their tiny size

**Figure 17.** Lichens are composed of fungi, bacteria, algae, and yeasts, and are usually thin and sustained on the trunks and leaves of plants.

and fragility leave them at a disadvantage compared to plants in the terrestrial environment.

Some algae have overcome this disadvantage by partnering with fungi, bacteria, and yeasts. Fungi provide the support structure and algae provide energy through photosynthesis, but the role of bacteria and yeasts is still unknown. These associations are called lichens, and we can see them forming patches of various colors on plant leaves and spots or rings on tree trunks. The most common are green or light blue, but some are orange or dark red. Generally, lichens are flat and function as plant leaves do, but since they do

**Figure 18.** Orchids have tiny seeds and depend on an association with fungi even to germinate.

not have branches or stems, they depend on plants to keep away from the ground where there is little light and many enemies. The RDS-RN has a very special environment where you can find lichens growing directly from the ground, but we will discuss this exception later.

Some simple plants called mosses are not much more complex than algae and often take advantage of other plants for support. However, in the forests of the Rio Negro, the largest plants that live on other plants are orchids, bromeliads, calatheas, and species from the Cyclanthaceae family. All of these have terrestrial

**Figure 19.** Bromeliads use crassulacean acid metabolism to conserve water and only open their stomata at night.

species, but they mostly grow on branches in tree canopies where there is plenty of light and few organisms capable of causing disease or damage. Living without soil is not easy for a plant. Orchids have tiny seeds that can be carried by the wind to the highest parts of trees, but because they are so small, the seeds do not have enough reserves to form seedlings. That is why they can only germinate if they are colonized by a mycorrhizal fungus.

Living in the canopy without roots in the soil also implies a lack of water. To conserve water, most of these plants use a carbon fixation pathway called Crassula-

**Figure 20.** The macucu trees in the campina are covered by orchids and other epiphytic plants, such as bromeliads and ferns.

cean acid metabolism (CAM photosynthesis). During the day, the plants close the small openings they have on their leaves called stomata, which are used for breathing and capturing carbon dioxide. Only at night can they open the stomata without losing too much water and complete the photosynthetic process. This process is not as efficient as regular photosynthesis, which is why these plants usually grow slowly.

Normally, not many of these plants are found when walking in the forest. Many fall from trees, where they survive for a short time due to lack of light or the actions of the enemies they may encounter. However, there are places where they can survive on the forest floor. The nutrient-poor soil in the Rio Negro region creates a unique environment where it is possible to find many epiphytic plants, even on the ground. There are areas called campinas, which have patches of pure sand, where there is no carpet of roots covering the ground and most of the plants are low, rarely exceeding the height of a person. It is not known why these open areas exist, but one of the most accepted suggestions is that fire in the past, whether natural or from indigenous farms, destroyed the layer of roots that supported the tall forest. The plants that can colonize this type of environment are relatively small and slow-growing, except for the macucu, which we also find in the campinarana.

If this theory is correct, the campina is a type of regrowth, meaning an area of forest that is regenerating after being cleared and burned for agricultural or livestock purposes.  A forest on clay soil would take about a hundred years to recover its original complexity after clearing and burning, but it would take several hundreds or thousands of years to recover the functionality of the forest on white sand. Regardless of its origin, the campina offers a unique opportunity to appreciate epiphytes without having to climb into the canopies of tall trees. Among the shrubs of the campina, macucu trees occur together with their mycorrhizae, showing that trees can grow in the campina.

However, since the macucu trees in the campina do not need a tall trunk to outcompete other plants, they produce canopies with horizontal branches that often do not exceed the height of a person. These branches are covered by an exuberant quantity of orchids and bromeliads that impresses everyone. It seems like an environment where you would find fairies and gnomes, and this impression is even stronger at night or

**Figura 21.** O líquen *Cladonia sp.* da campina não depende de plantas para apoio e parece uma esponja surgindo do chão.

in the early morning when the campina is covered by a white veil of mist.

In the campina, there is a lot of light at ground level around the exposed patches of white sand, which allows a type of lichen to grow there. This lichen forms tiny branches that resemble  sea coral. People step on the tufts that look like green sponges without realizing how special is the presence of these organis-ms. If you find this type of lichen in the Amazon, you know you are in a campina. Many of the epiphytes that fall to the ground in the campina do not die, unlike what happens in the forest.

**Figure 22.** Orchids, such as *Cattleya eldorado*, are a great attraction for tourists, but the forest holds a much greater treasure.

With so much light and sand poor in nutrients, the campina does not support the diverse soil organisms that cause diseases that are common in other places. It's as if the epiphytic plants don't know they're on the ground! For those who enjoy photographing or simply admiring orchids and bromeliads, the campinas of the Rio Negro are unmissable, all because of poor soil!

This was a very brief presentation about many complex concepts, but we hope it was enough to give you an idea of how special the soils and forests of the RDS-RN are, and why they arouse the interest of ecotourists. However, the complex interactions we mentioned also generate possibilities for other economic activities. There are many things that are part of traditional knowledge and have not yet been recorded, but the potential for new knowledge and technologies is much greater than that.

Traditional-knowledge-based medicine often uses forest products in their natural form, such as the sap of the pau-de-lacre plant that is used to cure fungal infections. However, these raw products often contain other toxic chemicals and their full use can only be achieved through modern techniques to isolate and purify the biologically active agents. Many people see a deforested and burned forest as an opportunity to plant cassava, and thus make flour used to make chibé, a traditional beverage made from cassava flour and water, commonly consumed in the Amazon region of Brazil as a substitute for meals when food is scarce. Other people see the deforested areas as a wasted opportunity to gain new knowledge. With education, technology, and the standing forest, children can discover things in the future with the potential to change the world. We hope this brief walk through the forest helps change your view of the Amazon: the forest is not only more complex than we imagine, it is more complex than we can imagine!

## Acknowledgments

Thanks to the CENBAM team, especially Andresa S. de Mello, Ilderlan Viana, and EmÌlio Higashikawa for their vital participation in the logistical aspects of fieldwork. Thanks to Dona Alindomar and Jánio Lopes and their entire family for their hospitality. Thanks to Mr. Armando and Dona Lúcia Toga, who always welcomed us with great affection. Thanks to Mr. Ananias da Silva Nascimento, who took us to the campinas and campinaranas for the first time. Thanks to all the residents who have always welcomed us, an indispensable partnership throughout all these years of work along the Uga-Uga Road.

## Research in this area

Since 2015, researchers and postgraduate students from the National Institute of Amazonian Research (INPA) who are part of the Biodiversity Research Program (PPBio) of the Ministry of Science, Technology, and Innovation (MCTI) together with residents who hold vast traditional knowledge of the region, have been studying the biological diversity of the western RDS. Studies in the region have been mainly funded by the Amazonas State Research Support Foundation (FAPEAM) through different projects.

## Support and funding

This book was only possible thanks to the support of the following projects and institutions: “Monitoring of Anuran and Bird Diversity for Conservation and Scientific Inclusion of Rural Communities” (Call for Proposals 002/2018, Process No 062.00187/2019, Universal Amazonas, from FAPEAM), Biodiversity and Tourism in the RDS Rio Negro (Call for Proposals No. 007/2021 - Biodiversa/FAPEAM - Grant Agreement: 322/2021), National Institute of Amazonian Research - INPA, National Institute of Science and Technology for Integrated Studies of Amazonian Biodiversity - CENBAM, Biodiversity Research Program - PPBio, and Amazonas State Research Support Foundation - FAPEAM. Sergio Santorelli Junior receives a scholarship from the Human Resources Fixation Program for the Interior of the State (Call for Proposals 009/2021 - PROFIX-RH) from FAPEAM. The graphic design and layout were done by Yurie Yaginuma.

FAPEAM
Fundação de Amparo à Pesquisa do Estado do Amazonas
INPA
INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA
CENBAM
Centro de Estudos Integrados da Biodiversidade Amazônica
PPBio
UFAM

ISBN: 978-65-00-58527-8
9 786500 585278