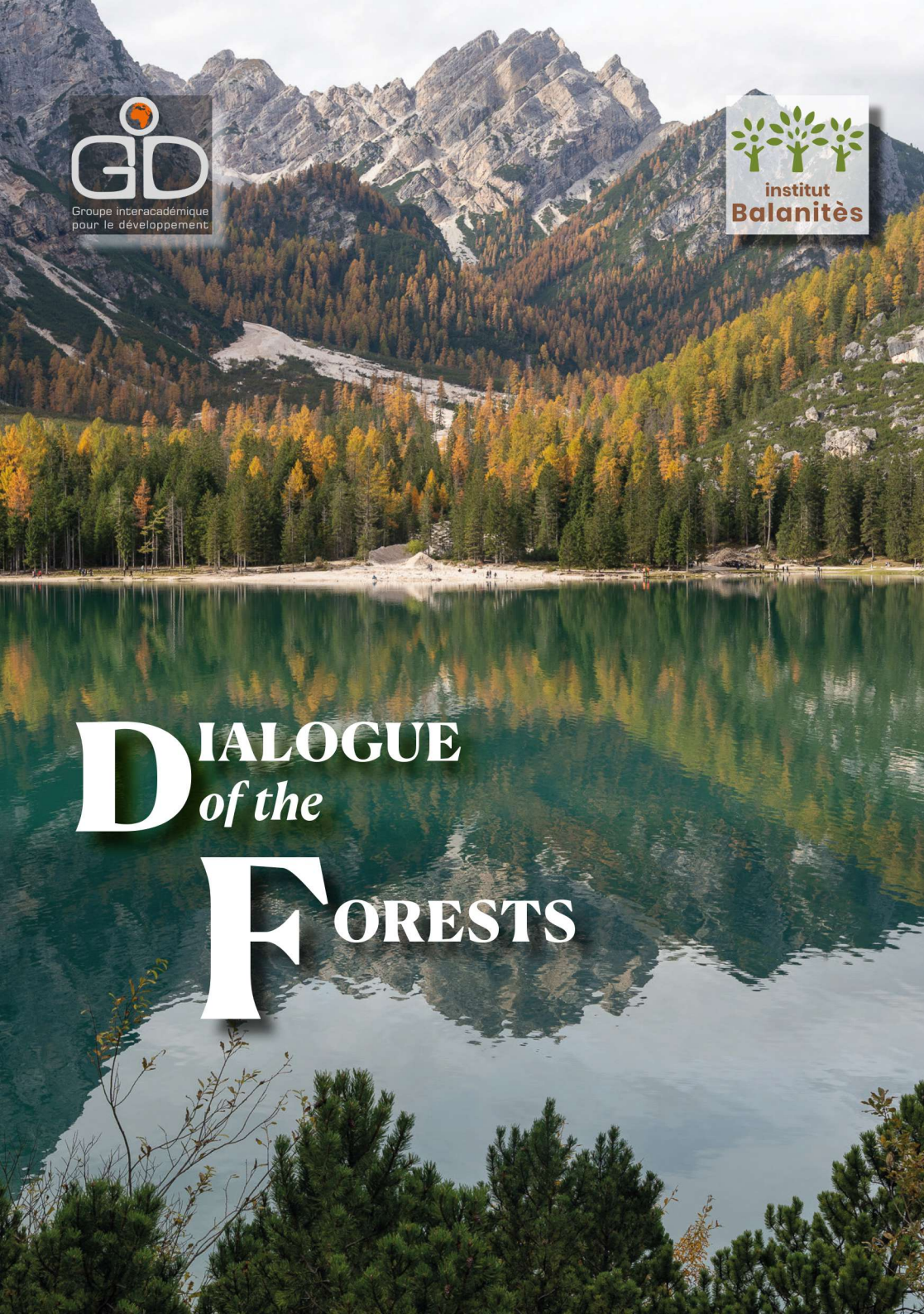

GID
Groupe interacadémique pour le développement
institut Balanitès
DIALOGUE of the FORESTS

In partnership with

Dialogue of the Forests

Gilles Boëtsch

President of the Balanitès Institute

COP30, to be held in Belém (Brazil) from November 10 to 21, 2025, is an international conference organized by the United Nations dedicated to climate change and its impacts on socio-ecosystems. This "Conference of the Parties" will bring together the signatory countries of the United Nations Framework Convention on Climate Change (UNFCCC). Scientists, as well as environmental organizations, policymakers, and industry stakeholders, are key partners who must commit to reducing the planet's average temperature and preserving biodiversity. Deforestation is a crucial issue in the current context, as it significantly contributes to biodiversity loss and greenhouse gas emissions.

Scientists play an essential role in combating climate change by providing reports and studies on the dynamics of the process and modeling future projections. They identify both established knowledge and research gaps across various sectors. Thanks to their understanding of the underlying mechanisms, they propose technological solutions to reduce greenhouse gas effects, optimize energy efficiency, and develop renewable energy sources, including sustainable agroforestry practices.

The destruction of forests is responsible for a significant portion of greenhouse gas (CO_2) emissions, as trees store carbon, which is released into the atmosphere when forests are cleared—contributing to global warming. Forests host a high proportion of global biodiversity, and deforestation threatens ecosystems and both plant and animal species.

What is a forest?

The term "forest" is a familiar one: it refers to a relatively large ecosystem composed of a population of trees, shrubs, bushes, herbaceous plants, fungi, mosses, ferns, microbes, and bacteria, as well as all the animal species associated with and interacting within this environment. The

FAO defines a forest according to the following criteria: a minimum area of 5,000 m² (0.5 ha), tree cover of more than 10%, and mature tree height of at least 5 meters. Human activities often interfere with forest ecosystems. It is worth noting the vast diversity of forests: temperate, boreal, Mediterranean, dry or humid tropical. Their specific characteristics are primarily determined by abiotic factors (climate, altitude, soil type, hydrology...). They may be considered natural (ecologically balanced without intensive human management) or artificial (created or restored by human action). Forests serve numerous functions: water cycle regulation, CO_2 storage, biodiversity shelter, and resources (wood for construction, heating, cooking, tools...; medicinal, edible, and cosmetic plants).

Deforestation currently accounts for one-fifth of global greenhouse gas emissions. By the end of the 20th century, half of the world's tropical forests had already disappeared compared to a century earlier. Since 2000, the annual rate of tropical deforestation has hovered around 10 million ha/year (fewer than 23% of tropical forests remain today). The primary causes are fires (50%), exacerbated by climate change. Seventeen of the twenty countries that host the largest natural forest areas have increased deforestation since the Glasgow Declaration (2021), which had set a goal to halt global deforestation by 2030. Forest destruction is responsible for a large share of greenhouse gas emissions due to the release of carbon stored in trees. Global warming weakens and slows forest development. The IPCC forecasts an average global temperature increase of +2.5°C by 2020, but this could reach +4°C in forests, leading to droughts, heatwaves, fires, plant mortality, and massive release of CO_2stored in woody biomass and soil.

What is a tree?

Botanists define a tree as a perennial vascular plant characterized by the following: a woody trunk, vertical growth (trees can reach several meters in height), branches forming from the trunk to create an aerial structure (canopy), organs specialized in photosynthesis (leaves, needles, or scales), and anchored roots that stabilize the tree in the soil and draw water and nutrients (some species can reach depths of up to 10 meters in search of water, phosphorus, nitrogen, and potassium). Roots often function in symbiosis with fungi and bacteria. Trees produce oxygen through photosynthesis and provide various resources used by other ecosystem elements and by humans (fruits, leaves, roots, bark, branches, trunks).

A culture?

A forest cannot be reduced solely to its ecological function or its role as a raw material provider for many human activities. It is also a symbolic, spiritual, and artistic space widely utilized by human societies. Forests reflect humanity, serving as cultural artifacts shaped by communities through legends, rituals, artistic creations, and both ancient and modern social practices (hiking, ecological activism).

Mythologies often associated with spiritual beliefs have made many forests sacred: Celtic druid oak groves, Kleczanów forest (Poland), the sacred forest of Osun-Osogbo of the Yoruba people (Nigeria)... Forests serve as vehicles for knowledge transmission across generations through tales involving forests (fairies, monsters, witches, giants, goblins...), such as the Grimm Brothers' *Hansel and Gretel*, or the "Adze" witches of Togo, similar to Tanzania's "Popobawa," who emerge from the forests at night to drink human blood, or "Bill," the hairy giant of Cameroon who also lives in the forest. The forest is both the home of real or imaginary sylvan beings and a place of regeneration for plants, animals, and humans alike. Forests are spaces of freedom and danger. They also inspire artistic creation—literature, painting, cinema; they form a universal artistic archetype linking humanity to nature, the wild, and the sacred. They may appear ever-changing, frightening or soothing, presenting infinite forms and colors depending on location and era.

Dialogue of the Forests

Forests are distributed across the planet according to bioclimatic criteria. This results in a wide variety of forest types, landscapes, and biodiversity. The IUCN has identified more than 60,000 tree species on Earth, with 55,000 found in tropical zones[1]. Tropical forests play a crucial role in regulating the global climate, conserving biodiversity, and maintaining a wide range of ecosystem services.

The three largest tropical forest regions are the Amazon, the Congo Basin in Africa, and Southeast Asia. Approximately 50% of tropical forests are located in the Americas, 30% in Africa, and 20% in Asia.

The Amazon is the largest tropical forest on Earth, a complex ecosystem vital to the global environmental balance, stretching across nine South American countries—about 60% of which lies within Brazil. Despite its size and environmental importance, the Amazon faces growing threats.

1. CHAVE Jérôme, SHUGART Herman, SAATCHI Sassan, WHITE Peter, *Le Grand Atlas des arbres et forêts*, Paris, Éditions Glénat, 2022.

As detailed in its dedicated chapter, illegal deforestation, land grabbing, predatory mining, and the unchecked expansion of the agricultural frontier are endangering not only the integrity of its ecosystems but also its inhabitants and the future of many ecosystems both inside and outside Brazil. Forest degradation directly affects greenhouse gas emissions, rainfall patterns, and biodiversity loss—not just in Brazil, but globally.

The Congo Basin, the second-largest tropical rainforest, is represented here by the Gabonese rainforest. It accounts for one-tenth of the vast regional forest and is structured by the Ogooué Basin, which irrigates over 80% of the country, with a remarkable diversity of environments—mangroves, swamp forests, and upland forests. This forested area is a crucial global ecological asset in the fight against climate change and biodiversity loss. Gabon's forests play a key role as carbon sinks, absorbing significantly more CO_2 than they emit (140 million tons absorbed versus 40 million emitted). To compensate for dwindling economic resources due to declining oil reserves, Gabon is banking on carbon sequestration revenue rather than resorting to deforestation for oil palm plantations.

Although located in the humid tropical zone, the Nanthaburi forest in Thailand is a monsoonal deciduous ecosystem with a distinct wet season and a marked dry season. Biodiversity is high (60–80 woody species per hectare, including teak, mahogany, bamboo...), but this forest—community-managed by local populations (61,000 ha)—faces risks of privatization through carbon credit projects (REDD+), due to its CO_2 storage potential of 150–200 tons per hectare, threatening existing local practices.

The dry deciduous forests of Madagascar are found in the island's western region. These forest ecosystems host rich biodiversity with many endemic plant and animal species. These areas have undergone massive deforestation due to agriculture (about 100,000 ha/year from 2010–2014) and remain highly vulnerable. However, in 2023, the Andrefana dry forests were inscribed on the UNESCO World Heritage List, recognized for their unique geological phenomena and evolutionary processes dating back millions of years. Their future will depend on the level and effectiveness of protection implemented, sustainable solutions for local communities, and increased international funding.

Launched in 2007, the Pan-African Great Green Wall initiative faces numerous climatological and geopolitical challenges. The goals of

this vast forest belt stretching across the Sahel are threefold: to halt desertification, sequester CO_2 (global target: 250 t/year), and improve food security in the Sahel region (250 million people). This is a wooded savannah with a two-month rainy (monsoon) season. In Senegal, the Great Green Wall is home to many plant and animal species, including numerous replanted woody species (*Acacia senegal*, *Acacia seyal*, *Balanites aegyptiaca*, *Ziziphus mauritiana*).

The Mediterranean forest of the Massif des Maures, like many others, is facing significant challenges. As France's oldest forested massif, it boasts exceptional biodiversity for a temperate region. It contains cork oaks and 35 rare plant species. Increasing urbanization, coupled with climate change (recurrent droughts), contributes to habitat loss and soil erosion, reducing biodiversity and ecosystem resilience.

The Białowieża primary forest also serves as an open-air laboratory for studying natural forest ecosystems. Straddling Poland and Belarus, it is the last remaining lowland primary forest in Europe. One-fifth of its Polish portion is strictly protected. It is home to 500-year-old oak trees reaching 40 meters high, along with spruces, linden, and giant ash trees. Its animal biodiversity is rich, including bison, wolves, lynx, otters, and beavers. As with many natural forests, its preservation is a constant challenge in the face of economic and political pressures (logging, tourism).

This "Dialogue of the Forests" is based on the work of researchers who view the forest as more than just a collection of trees. In response to today's and tomorrow's environmental challenges, researchers must help us better understand the climatic and socio-ecological mechanisms that will allow forests to take a leading role in the fight against global warming: carbon sinks, carbon storage, albedo effect, maintenance of primary forests, restoration of degraded ecosystems, adaptation of forest species, and integration of climate justice.

Cartography


Primeval Forest
Renata Krzyściak-Kosińska
Bożena Kornatowska
& Cédric Béraud
page 51
Seasonal Tropical Forest
Serge Morand
Phurin Makaew
& Surasak Kiatphattharaporn
page 93
Dry Forest
Joelisoa Ratsirarson
& Mikoja M. Rambinintsoa
page 65
Tropical Rainforest
Étienne Massard Kabinda Makaga
& Juste-L. Boussienguet
page 79

Tropical Forest
Amazon Forest

Leila de Morais
Elimar Pinheiro do Nascimento

The Amazon, the largest tropical forest on the planet, is a complex ecosystem that plays a major role in maintaining global environmental balance. Stretching across nine South American countries—about 60% of its area lies within Brazil—the Amazon plays a crucial role in regulating the global climate, conserving biodiversity, and sustaining a wide range of ecosystem services.

Recognition of the Amazon's importance extends beyond national borders and draws the attention of governments, international organizations, civil society, and the productive sector. It is home to countless species—many still unknown to science—and shelters traditional communities and Indigenous peoples who have developed deep environmental knowledge over centuries. Its conservation and sustainable use require innovative solutions that reconcile economic growth, social justice, and the protection of natural resources. In short, an economy that generates and distributes wealth, ensures quality of life for its inhabitants, and keeps the forest standing.

Despite its size and environmental importance, the Amazon is facing growing challenges. Illegal deforestation, land grabbing, predatory mining, and the uncontrolled expansion of the agricultural frontier threaten not only the integrity of its ecosystems but also its population and the future of numerous ecosystems

both within and beyond Brazil. Forest degradation has a direct impact on greenhouse gas emissions, changes in rainfall patterns, and the loss of biodiversity, affecting not just Brazil but a significant portion of the planet.

In addition to providing various ecological services, the Amazon holds immense socioeconomic potential, with fruits such as camu camu, buriti, bacaba, and the well-known açaí; hardwoods and various seeds like the Brazil nut; and oils such as andiroba, copaíba, and pracaxi. These natural resources support industries producing ice cream, jams, jellies, and sweets from fruits; cosmetics, pharmaceutical, and therapeutic products from oils and seeds. Not to mention its rich fish diversity—with 2,500 known species—which can be used to produce flour, leather, and "glue" for manufacturing gelling and clarifying agents in the food and beverage industries, gelatin capsules for pharmaceuticals, moisturizers in face creams and masks, and other industrial products. And most importantly: a socioeconomy that delivers increasingly in-demand food products without destroying nature—preserving the forest in the process.

In this context, the United Nations Climate Change Conference (COP30), to be held in Brazil in 2025, is a critical moment for setting global environmental commitments and policies. The Amazon not only symbolizes the challenges of environmental degradation but also represents an opportunity to build an innovative economic model based on the bioeconomy, sustainable natural resource management, and the application of traditional knowledge.

Within this transformative landscape, it is important to highlight the federal government's ecological transformation program, which proposes restructuring financial mechanisms to support sustainable development. This initiative aims to integrate environmental preservation with economic growth by promoting incentives that value the Amazon's products and ecosystem services. By bringing together public and private sector efforts, the program seeks to usher in a new era of environmental policies that preserve this natural heritage while ensuring development opportunities for local populations.

The transition to a development model that harmonizes environmental preservation with economic prosperity is a complex challenge requiring coordinated efforts and the implementation of innovative solutions. The Amazon—with its unique biodiversity and potential to generate income through the bioeconomy, including sustainable extractivism,

biotechnology, and community-based tourism – serves as a living laboratory for the development of practices that can be replicated in other regions of the world.

This text provides an overview of this magnificent forest, discussing its biodiversity, ecosystem services, and the challenges and opportunities related to its preservation. The Amazon is one of Earth's greatest natural treasures, and its protection is a collective responsibility that must unite governments, businesses, local communities, and the international community in pursuit of a sustainable future.

FACT SHEET

The Amazon rainforest covers 6.7 million km² and spans nine South American countries. Its coordinates range from 5°N to 15°S in latitude and 45°W to 75°W in longitude. In Brazil, the Amazon covers 5 million km²—amounting to 59% of the national territory—houses approximately 29 million people, and stores around 120 billion tonnes of carbon.

Ranging in altitude from 0 to 2,995 meters (Pico da Neblina), the Amazon is traversed by the majestic Amazon River – the largest river in the world in terms of water volume – as well as thousands of tributaries, such as the Negro, Madeira, Xingu, Solimões, and Tapajós rivers. The climate is hot and humid, with temperatures ranging from 22°C to 32°C and annual rainfall between 1,500 and 3,000 mm. Average humidity exceeds 80%.

Thirty million people live in the Amazon region, including more than 400 Indigenous peoples—such as the Yanomami, Kayapó, and Munduruku—as well as isolated groups who live autonomously deep within the forest. It is a true cultural mosaic, where over 300 Indigenous languages are spoken, many of which are endangered.

The Amazon's biodiversity is among the richest on the planet: over 390 billion individual trees belonging to around 16,000 species, many of which are threatened—such as Amazonian cedar, Dalbergia species (known as rosewood), and the Brazil nut tree, famous for producing Brazil nuts. Its fauna includes more than 100,000 invertebrate species, 2,500 fish species, 1,300 bird species, 400 mammal species, and 400 amphibian species. About 1,200 of these are endangered, including the jaguar (a symbol of ecosystem integrity), the pink river dolphin, and the Amazonian manatee.

The Amazon offers a wide range of non-timber products—fruits, resins, medicinal plants, and fish—that generate income for local communities and pave the way for a sustainable bioeconomy. More than 150 native species have economic value and can be used sustainably to produce medicines, foods, flavorings, condiments, dyes, fibers, oils, and ornaments. According to Carlos Noble, "the standing economic potential of the Amazon forest exceeds that of agriculture" and could, in the future, generate a more powerful and inclusive economy based on the biome's biological wealth. It is estimated that sustainable extractive activities could replace the income of about 13.5 million people in the region, while encouraging innovative sectors such as pharmaceuticals and cosmetics.

The exotic fruits of the Brazilian Amazon play a fundamental role in the lives of local populations, both culturally and economically. Besides enriching the diets of Amazonian communities, they also form the basis for various sustainable economic activities. Their use goes beyond fresh consumption: they are processed into a variety of products—frozen pulp, ice cream, candies, beverages, and cosmetics—broadening commercial outlets and adding value to local production chains. This diversification allows them to reach national and international markets, generate revenue, and promote regional economic development while preserving the forest.

Ecotourism and community-based tourism in the Amazon attract visitors from around the world, drawn by its lush landscapes, rich cultural diversity, and the coexistence with Indigenous communities that preserve millennia-old traditions. These activities not only create jobs and income but also increase environmental awareness, reinforcing the importance of forest conservation for the global climate balance.

Other activities are equally important for promoting sustainable economic development in the Amazon: agroforestry (integrating agricultural crops with native forest species, restoring degraded areas, and diversifying community incomes); handicrafts (strengthening the local economy and preserving traditional artisanal techniques through the use of natural materials); and biotechnology (adding value to local biodiversity and integrating communities into high-value production chains).

The Brazilian Amazon is home to an impressive variety of native and exotic tree and plant species whose medicinal properties have been used by traditional communities for centuries to treat diseases such as diabetes, hypertension, and infections. One example is **cat's claw (*Uncaria tomentosa*)**, known for its anti-inflammatory and immunomodulatory properties. Research shows that it contains alkaloids that help fight viral infections and reduce inflammatory processes. Guaraná (*Paullinia cupana*) is another species, whose leaves are recognized for their stimulating and antioxidant qualities, enhancing cognitive functions and increasing physical energy.

The Malay apple (*Syzygium malaccense*) is a tree that produces red fruits. In addition to its ornamental value, the fruit is eaten fresh or used to make jellies and juices. **Soursop (*Annona muricata*)**, native to tropical regions of the Americas, has bark, leaves, roots, fruit, and seeds with anti-inflammatory properties, used to treat digestive disorders.

Copaíba (*Copaifera langsdorffii*), known for its resinous oil extracted from the trunk, has anti-inflammatory, analgesic, and healing properties and is used to treat skin diseases, arthritis, respiratory problems, as well as pulmonary and urinary infections.

Açaí (*Euterpe oleracea*), an indigenous palm rich in anthocyanins (a powerful antioxidant), is a staple food for riverside communities. Its pulp is traditionally consumed with manioc flour and fish. Andiroba (*Carapa guianensis*), a tree valued for the medicinal and cosmetic oil extracted from its seeds, is essential to traditional medicine and the natural cosmetics industry, with antiseptic, anti-inflammatory, healing, and insect-repellent properties.

The Amazon rainforest is the largest river basin in the world. It holds 14% of the planet's freshwater and about 80% of Brazil's surface water. The biome consists mostly of upland areas but also includes várzea floodplain forests, igapó flooded forests—where **the giant water lily *Victoria amazonica*** can be found—and coastal mangroves, whose brackish waters provide an ideal habitat for crustaceans.

It harbors around 10% of all known tree species on Earth. The trees function as massive carbon reservoirs, absorbing large amounts of CO_2 and storing it for decades. This capacity is due to their immense size and the fact that these forests contain "thick-trunked trees," which form a vast carbon stock in the soil. This carbon sequestration process is crucial to maintaining the planet's climate.

Through evapotranspiration, the trees release water vapor, which condenses to form what are known as **"flying rivers"**—atmospheric flows of water vapor that transport moisture to distant regions. This phenomenon influences rainfall patterns across various parts of South America and ensures the water supply necessary for agriculture and the health of ecosystems. According to António Nobre, a single large tree can release up to 1,000 liters of water into the atmosphere each day, significantly contributing to the formation of these aerial rivers.

Another vital function is soil retention, which prevents erosion and land degradation, preserves fertility, and protects communities from landslides and flooding. These natural services act as a true barrier against environmental disasters, the replacement of which through engineering projects would cost billions of dollars.

The region faces major challenges, such as accelerating deforestation, which threatens the integrity of its ecosystems and the livelihoods of local communities. Between 2019 and 2022, the Brazilian Amazon suffered significant forest cover losses, totaling approximately 46,329 km².

Between January and December 2024, **deforestation in the Legal Amazon** reached 3,739 km²—a 7% reduction compared to the same period in 2023, when it had reached 4,030 km². Nevertheless, forest degradation increased by 497%, putting the quality of the remaining forests at serious risk.

Despite the reduction in deforestation, the cumulative impact remains considerable and threatens the essential ecosystem services provided by the forest. Deforestation—whether for logging or cattle ranching—and widespread forest burning are currently the main threats to the Amazon and have led to the extinction of several animal and plant species.

Deforestation in the Amazon is not only an environmental issue; it has deep political and social implications. Illegal logging, agricultural expansion, and large-scale infrastructure projects often trigger land and social conflicts, the displacement of traditional communities, and the loss of cultural heritage. This worsens inequality and hinders sustainable development. Such activities—often enabled by inadequate public policies—exacerbate social disparities and jeopardize regional sustainability.

Forest degradation also directly affects the health and well-being of local populations. The loss of biodiversity threatens food security, access to water resources, and the traditional ways of life of Indigenous and riverine communities. Additionally, smoke from fires is linked to respiratory issues and other illnesses, placing strain on local healthcare systems. This reinforces the importance of protected natural areas and Indigenous territories in conserving biodiversity, as only 5.8% of the 88 million hectares of lost forest occurred within these areas, while 94.2% occurred outside them.

The Amazon represents a priceless heritage that transcends national borders. Its preservation is essential not only for maintaining biodiversity and mitigating climate change, but also for ensuring social justice and respect for traditional cultures. It is therefore our collective responsibility to ensure that public policies

are both effective and inclusive, in order to promote a sustainable future for the Amazon and its people.

Deforestation in the Amazon © Marizilda Cruppe/Greenpeace.

Amazonian biodiversity also ensures vital ecological functions. The forest is a living laboratory that maintains processes such as pollination —which supports the production of many plants and is carried out by bees, bats, and other animals—and the nutrient cycle sustained by its vast network of roots and leaves. The tropical rainforest has some of the most fertile soil in the world, thanks to its efficient nutrient recycling. It also contributes to natural pest control. Its diversity serves as a genetic laboratory as well. In addition to offering countless possibilities for biotechnological research, the rainforest contains a wide variety of substances with therapeutic potential estimated to be seven times greater than what is found in pharmacies worldwide.

Without the forest's integrity, unfavorable climatic phenomena and water shortages could become more frequent, negatively impacting agriculture, energy production, water supply in various regions, and — above all—the survival of its rare species, resulting in biodiversity loss and reduced ecosystem functionality.

The precarious health conditions of riverside and Indigenous communities are exacerbated by unsustainable practices such as deforestation and the overexploitation of natural resources. Ecosystem degradation endangers local biodiversity and affects air and water quality—both of which are crucial to human well-being. Furthermore, the introduction of invasive species harms local ecosystems by disrupting essential ecological dynamics.

Deforestation, among other things, alters the habitats of the *Aedes aegypti* mosquito, thereby increasing the incidence of disease. **Forest fires**—often started to clear land for agriculture or pastures—release air pollutants, including particles and toxic gases, that degrade air quality, raise respiratory illness rates, and destroy essential habitats for various Indigenous species. Smoke from these fires can reach communities far from the center of the blaze, carried by trade winds toward the Andes. Once it hits this mountain barrier, the smoke moves southward across the continent, reaching western Brazil, Peru, Bolivia, and Argentina. In 2022, a large volume of smoke from Amazonian fires covered the city of São Paulo.

Flames in the Amazon rainforest
on 15 August 2020 © Carl de Souza/AFP.

The degradation caused by fires brings about radical changes in ecosystems, encouraging the extinction of native species and facilitating the invasion of exotic organisms that compete with local species for essential resources. This undermines key ecosystem services such as access to potable water and climate regulation.

The indiscriminate use of pesticides and chemical fertilizers in intensive agriculture not only compromises water quality but has also been linked to outbreaks of infectious diseases in socially vulnerable communities.

Another important factor is the impact of habitat loss on zoonoses. As ecosystems become more fragmented, interactions between humans and wild animals intensify, increasing the risk of pathogen transmission. The link between environmental degradation and outbreaks of diseases such as yellow fever and dengue clearly illustrates this dynamic. These circumstances endanger the health of local populations and place an additional burden on public health systems.

Illegal mining has caused serious environmental and social damage, with direct repercussions on the health of local populations. Mercury-based gold extraction contaminates rivers and soils, affecting the neurological and cardiovascular health of riverine and Indigenous communities who rely on these natural resources for survival. More than half (51.77%) of the 3,791 sub-basins in the Tapajós region exceed the legal mercury limits set by Brazilian environmental law. Illegal mining has also contributed significantly to deforestation.

Illegal mining site in the Madre de Dios region of Peru
© Ministerio del Ambiente/Flickr.

The Amazon also faces the extraction of metals such as iron and bauxite by large foreign mining companies. The environmental degradation caused by mining compromises vital ecosystem services such as water purification and creates conditions conducive to the spread of pathogens. Mining is also associated with serious human rights violations, particularly affecting Indigenous and riverine populations.

The environment, territory, and culture form the three pillars upon which Amazonian life is built. Over generations, this tripod has ensured not only the health and safety of its inhabitants but also their survival and well-being for centuries.

Regard d'Amazonie © Wilfried Maurin/Flickr.

Amazonian peoples maintain a deep and symbiotic relationship with the forest. For them, the forest is more than a physical space: it is a spiritual being that supports their culture, identity, and way of life.

Yanomami boys in canoe © Carsten ten Brink/Flickr.

This connection is evident in the sustainable use of natural resources, such as hunting, fishing, the harvesting of biodiversity fruits, and the use of fauna elements like manatee fat and the poison of the kambo frog—practices that reinforce the integration between people and their environment.

Rivers, streams, and lagoons are always explained through myths and stories, vague enough to account both for their origins and their intended paths. These waterways are the highways and lifelines of the forest, used for navigation and communication. Daily life revolves around them, influencing everything from the location of communities to cultural customs and practices. Rivers are vital arteries, where people fish, eat, and weave stories—central elements in their myths and traditions that structure and organize their daily life and worldview.

Fishing, an essential activity for food and the local economy, is governed by traditional rules that ensure the replenishment of fish stocks and the health of aquatic ecosystems.


© Claude Tazibt
Claude Tazibt
PHOTO

Mediterranean Forest
The Maures Forest

Magali Maire
Charles Dereix

Composite assemblages of species with varied biogeographical origins, Mediterranean forests are the legacy of a long history that began in the Cretaceous period, 100 million years ago. Shaped by multiple tectonic and climatic events, the glacial and interglacial phases of the Pleistocene had a decisive influence on their particularly remarkable biodiversity, accounting for both their high genetic diversity and elevated level of endemism. Thus, three major forest types share the landscape according to bioclimatic zoning: Sclerophyllous forests of the Mediterranean and meso-Mediterranean zones, dominated by evergreen oaks; Deciduous forests of the supra-Mediterranean zone; And conifer-dominated forests (pines, firs, and cedars) of the montane-Mediterranean zone. These Mediterranean forests are found mainly around the Mediterranean Basin in southern Europe, but also in the far south of Africa and Australia, as well as sporadically along the Pacific coast of the United States and Chile. The Mediterranean Basin is one of the richest areas in biodiversity on the planet. This incredible biodiversity is found in all ecosystems: marshes, steppes, grasslands, rivers, temporary streams, the Mediterranean Sea itself of course, but also in forests and wooded areas.

With more than 25 million hectares of forests and approximately 50 million hectares of other wooded lands, the Mediterranean region

represents 2% of the world's forest area, 10% of the total surface area of Mediterranean countries, and is home to 7% of the global population.

In addition to being an integral part of the Mediterranean identity and landscape, these forests provide a considerable number of goods and services: from biomass production to soil stabilization and erosion reduction, from improving surface water capture to replenishing underground reservoirs, and through to educational, cultural, and recreational services. These ecosystems also contribute to food security, rural development, and thereby to poverty reduction and, more broadly, to human well-being.

In the face of climate change, Mediterranean forests are on the front lines. Characterized by a climate with hot, dry summers and mild, wet winters, climate change is leading to a rise in annual temperatures, with a particularly sharp increase in summer temperatures. For example, in the French Mediterranean region, the average annual temperature has shown a faster warming trend over the past hundred years than the global average. If the current trend continues, we can expect at least a 5°C increase in summer and a 2°C increase in winter over the 21st century. If this relatively optimistic scenario is confirmed (according to IPCC scenarios), the +2°C average threshold could be reached as early as 2040, not in 2100—the limit agreed upon in the Paris Climate Accord.

Regarding rainfall, predictions are more uncertain and less consensual than for temperatures. However, a reduction in precipitation is already observed, mainly in winter and summer. In a region with constant rainfall, it is likely that the water stress on plants will increase mechanically with temperature due to higher evaporation and transpiration. Furthermore, extreme rainfall events, leading to significant losses through runoff, are likely to become more frequent and separated by increasingly long dry periods. The summer situation is particularly severe during periods of intense thermal stress. The winter situation is also problematic, as soil water reserves may be insufficient during the period of maximum vegetation growth in spring.

Currently, it is observed that dieback of many species has significantly increased over the past thirty years. These changes affect the water and carbon cycles and the dynamics of plants across the entire Mediterranean region, especially when they are located at the edge of their distribution range. In these specific areas, garrigues and maquis, composed of species highly adapted to extreme droughts and shallow soils, are deteriorating in some places over dozens of hectares.

Significant changes in the composition of flora and, in general, losses in biodiversity have been demonstrated. The life and reproduction cycles of plants are disrupted, and soil quality and fertility are degrading.

In this context, the risk of forest fires is one of the major risks in the Mediterranean region: prolonged drought periods, increased frequency and intensity, regular production of large quantities of dead, highly flammable and combustible biomass, accumulation of biomass in poorly maintained natural environments, and the creation of spatial continuity of this fuel on a large scale, as well as the multiplication of interfaces between urban areas and natural environments, are the main contributing factors.

Thus, the combination of repeated droughts and increasingly frequent and violent fires threatens the survival of Mediterranean forests and presents a major global challenge. Let us rise to this challenge! For indeed, Mediterranean forests can and must contribute significantly to the global agenda, particularly in achieving several key objectives of the three Rio Conventions of the UN, the 2030 Sustainable Development Agenda, and the United Nations Forests Strategic Plan (2017-2030)!

FACT SHEET

Located in the South-East of France, in the Provence-Alpes-Côte d'Azur region, between Hyères and Fréjus, the Maures massif stretches across 21 municipalities, 50 km long and 30 km wide, and is part of a broader area consisting of plains and coastline, covering more than 100,000 hectares.

The altitude ranges from 50 to 780 meters, under a thermo-Mediterranean and Euro-Mediterranean subhumid climate.

Its wooded areas are three-quarters made up of private properties and a quarter of public forests (State and local authorities) managed by the National Forestry Office. It is a highly diverse area due to the heterogeneity of topographical conditions (marked climatic contrasts) and the long-standing anthropogenic impact (deforestation for cultivation, pastures, oak forest management, and fires).

Cork oak: 38,000 ha; chestnut groves, often in fruit orchards: 3,500 ha; downy oak groves often in mixed stands associated with holm oak and cork oak. The pine forests, which have been greatly reduced in area, are found mainly on the periphery of the massif and on the slopes, and are made up of pinion, Aleppo and maritime pines.

The choice of the Maures Forest is based on several arguments: first, it represents an exceptional forest area, whether from a biological, landscape, historical, or cultural perspective. Rich in highly diverse biotopes offering rocky landscapes, riparian zones, coppices, maquis, meadows, and magnificent forest formations, the Maures massif is home to exceptional flora and fauna, earning it multiple protection designations: among them, a Natura 2,000 zone of 31,240 hectares, a 500 hectare National Nature Park, a 2,850 hectare National Nature Reserve, and a 2,000 hectare Integral Biological Reserve. This area unfolds across an accentuated terrain, crossed by numerous streams and rivers, and forms a crystalline zone that contrasts with the rest of the limestone Provence.

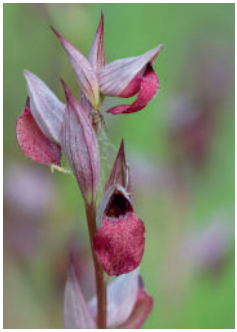
Furthermore, while many forests and wooded areas could have been highlighted in this booklet as emblematic of the Mediterranean—globally recognized as a biodiversity hotspot—the Maures Forest represents a particularly interesting illustration of territorial dynamics: it is indeed a prime example of the dynamic driven by local forest development strategies, bringing together all local actors, public and private owners, managers, and users in a participatory approach. The multifunctional and participatory management of the Maures massif is considered one of the most effective methodologies to address its significant challenges. By agreeing on a diagnosis and a shared vision that necessarily evolves due to the uncertainties and risks induced by major global changes in the Mediterranean region, the stakeholders of the area align and move forward in a coordinated manner to support their forest in its necessary adaptations, to develop its local economy, contribute to the resilience of these ecosystems, and preserve its social and cultural heritage.

Finally, the Maures Forest massif illustrates the dynamic seen since the 20th century in the northern Mediterranean, namely the abandonment of agricultural and pastoral lands, leading to a significant increase in forested areas despite the resurgence of fires, which are part of its history. In this sense, the Maures Forest reflects one of the fundamental characteristics of Mediterranean forests through the importance of the anthropo-zoological impact that shapes it so strongly, and in a way that contrasts sharply with the southern Mediterranean basin, where overgrazing represents such pressure that it can lead to the degradation, or even the complete disappearance, of wooded formations.

Among the remarkable floral species, we note the flax-leaved broom (*Genista linifolia*) and the Toulon adenocarp (*Adenocarpus telonensis*) along the relatively xerophilic ridges of thermophilic cork oak groves.

The chestnut groves are also very rich in herbaceous species such as the Pleasant vetch (*Vicia laeta*), the Plantain-leaved doronicum (*Doronicum plantagineum*), the Perfoliate Alexanders (*Smyrnium perfoliatum*), and **the Wood tulip (*Tulipa sylvestris*)**.

The priority habitat of Mediterranean temporary ponds and streams present in the massif represents major ecological interest, hosting species such as the Durieu's quillwort (*Isoetes durieui*), the Summer spiranth (*Spiranthes aestivalis*), the Revelière's buttercup (*Ranunculus revelierei*), the Portuguese adder's tongue (*Ophioglossum lusitanicum*), and the Filiform cicendia (*Cicendia filiformis*).



Other habitats of community interest are particularly remarkable. Mesophilous meadows with Serapias host a range of heritage species: the Neglected Serapias (*Serapias neglecta*), **the Hyères Serapias (*Serapias olbia*)**, the Greek linaria (*Kickxia commutata*), the Small Moly garlic (*Allium chamaemoly*), and the Colonna's Romulea (*Romulea columnae*). The very rare and threatened *Nerium oleander* (Oleander) and *Vitex agnus-castus* (Chaste tree or Wild pepper) can be found in the oleander-lined wadis.

In the humid undergrowth of alder and **lime trees** in the cool valleys, we find the Royal fern (*Osmunda regalis*), associated with remarkable ferns such as the Soft-bristle fern (*Polystichum setiferum*), the Common spleenwort (*Phyllitis scolopendrium*), and the very rare Spiked beech fern (*Blechnum spicant*). Finally, the coastal rocks host the halophyte Jupiter's beard (*Anthyllis barba-jovis*), which is highly threatened.

Like many forests around the world, the ecosystem services provided by the Maures Forest are countless. While the valorization of its timber products and other goods derived from woody resources is being revitalized through territorial dynamics, examples include the exploitation of early thinning of pine forests for bioenergy, the use of cork oak groves for cork production, and the harvest of chestnuts. The Maures Forest also offers many other ecosystem services, the benefits of which directly benefit local populations.

In environmental terms, its remarkable biodiversity includes very rare and even endemic floral and faunal species. Moreover, this remarkable landscape of 100,000 hectares, with its contrasting topography of ridgelines and slopes that fade into a vast plain, makes it a true sanctuary for hiking, tourism, and leisure activities in general. Taking advantage of these diversified spaces and its unique floral resources, sylvo-pastoralism and beekeeping are also long-standing activities that continue, as does hunting.

Furthermore, while the carbon sink effect per unit of area in the Mediterranean domain is below the French average due to slower growth dynamics (effects of heat, drought, and fires), it is far from negligible. In terms of climate regulation, carbon storage is one of the key services provided by forest ecosystems, with an estimated 44% of the carbon contained in soils, 42% in aboveground and underground biomass, 8% in dead wood, and 8% in litter[1].

The Maures massif also provides crucial regulatory services, particularly in terms of soil protection and runoff mitigation. While these ecosystem services are significant, raising awareness among local populations is often more complex: it was after a fire that ravaged 8,400 hectares of forest in August 1990, in the watershed in the western part of the massif, that the drinking water distributor of a coastal town commissioned a study on the consequences that the disappearance of the wooded slopes around the water retention lake could have.

1. Pan *et al.*, 2011.

In light of the results, the community decided to contribute financially every year to the prevention of fires in the watershed. Ultimately, the combination of all these goods and services provided by the Maures massif contributes to human well-being, whether through the valorization of its timber and non-timber products, the magnificence of its landscapes, the clean air it generates, the carbon storage it enables, or the soil stabilization it reinforces.

© Claude Tazibt.

The Maures massif (including the plain and coastline) is home to 28% of the businesses in the Var department. Despite its rural character, businesses in the agricultural and forestry sectors are in the minority.

However, the economic potential of the Maures Forest is real, although the impact related to the valorization of forest products is relatively low to date due to several factors.

Firstly, there are cyclical factors. Until 1970, cork production from 40,000 hectares of cork oak groves employed over 2,000 people in 150 factories, exploiting more than 12,000 tons of cork annually. But after the abandonment of cork oak grove maintenance due to the closure of cork factories (relocated to Portugal and Spain), a dramatic decline in cork oak occurred over the course of a century. The latest major fires, coupled with droughts in the context of climate change, have accelerated its decline, particularly on the south-facing slopes.

Furthermore, one of the main obstacles to forest management dynamics—and ultimately to economic dynamics—lies in the difficulty of mobilizing multiple small private forest owners, who represent 79% of the total forest area: in this regard, the Maures Forest is highly representative of French forests, which are three-quarters privately owned. The state-owned areas (belonging to the government) and municipal areas (belonging to local authorities) within the Maures massif fall under the French forest regime, which is managed by the National Forests Office (ONF). While the ONF guarantees the multifunctional management of state forests and woodlands, the local maritime pine is currently only usable for bioenergy or wood processing due to its small diameter at the time of exploitation. This valorization is expanding, notably with several bioenergy projects.

It is particularly thanks to the revitalization efforts led by federating structures such as the Free Syndicate for Forest Management of the Var Cork Oak Groves that the management of private forests is becoming possible again. This private law association, which brings together 321 private landowners managing 16,700 hectares of land, enables the exploitation of 150 tons per year while ensuring quality work during cork harvests **(cork harvesting operation)**.

Similarly, the objectives of the Forest Charter for the Territory (a unifying tool for municipalities) aim to revitalize the cork industry through public-private partnerships, generating a renewable economy and local jobs.

Cork oaks after removal © Gayard C./ONF.

In terms of valorization, the local maritime pine is currently only usable for bioenergy or processing, due to its small diameter at the time of exploitation. This valorization is expanding, particularly with several bioenergy projects.

The chestnut tree, on the other hand, could yield the finest logs for construction timber and sawing. For the remainder, the outlet remains firewood. However, the territorial dynamics led by forest municipalities through the implementation of management plans face more challenges in private forests due to their fragmentation and the inherent difficulty of mobilizing numerous and often very small landowners. The Syndicate of Chestnut Producers of Var is pushing for the identification of areas with chestnut potential (former orchards), of which 150 hectares are currently being exploited for chestnut production.

Finally, pastoralism, a historic activity still very present in the massif (sheep or goats), helps maintain fuel breaks, thus combating forest fires: 50 professional pastoralists regularly traverse the massif, either permanently or during winter transhumance, half of whom sell part of their production directly.

Fire and health problems are the two biggest threats to the Maures Forest. The cork oak forest and the pine forest are particularly vulnerable to health attacks, phenomena exacerbated by repeated summer droughts, the aging of stands, and the frequent occurrence of fires.

The maritime pine, weakened by an infestation of a scale insect called *Matsucoccus feytaudi*, which thrives in the Mediterranean climate, becomes even more vulnerable to secondary pests such as the *Ips sexdentatus* bark beetle and *Orthotomicus erosus*, leading to high mortality rates.

The cork oak has shown a particularly worrying health condition in recent years: **the oak longhorn beetle (*Cerambyx cerdo*)** and the oak jewel beetle (*Coroebus bifasciatus*), both wood-boring insects, along with the cork worm (*Coroebus undatus*) and the red-headed ant (*Cremastogaster scutellaris*), cause branch dieback and trunk alterations. Fungal diseases like *Hypoxylon mediterraneum* and *Diplodia mutila* can also be particularly virulent.

The chestnut tree, on the other hand, suffers from significant dieback and mortality in younger trees, leading to both qualitative and quantitative production losses, caused by a fungus (*Endothia parasitica*) commonly known as chestnut blight.

Forest fires represent the second major threat to the Maures massif, which has been dramatically marked by large fires, notably in 1919, 1934, 1989, and 1990, the major fires of 2003, and more recently, a megafire in 2021: 10 days of burning, nearly 8,000 hectares of vegetation burned, and 40% of the Hermann's tortoise population affected—one of the most threatened reptiles in Europe and globally.

Due to the low stakes in terms of forest production, land enclaves, and the insufficient resources allocated to forest fire protection, this massif is weakened by summer heat and reduced humidity, but also,

very often, due to severe human negligence. For while the Mediterranean forest burns, it is not only because it is highly combustible, but also because it is deliberately set on fire, either carelessly or intentionally! In this context, prevention is one of the key factors in combating this scourge.

Moreover, the resilience capacity of the Maures Forest, most of whose species are adapted to fire (like those of Mediterranean forests more broadly), could have its limits. For example, the thick bark that protects the cork oak from the lethal impact of temperatures during a fire may no longer serve its purpose due to the likely increase in fire frequency. Similarly, the time between two fires may become too short for pines to reach maturity and release their seeds to ensure their regeneration. This is why experts are warning about the limits of this natural resilience of Mediterranean flora, the collateral effects of which are numerous: increased runoff of rainwater, flood risks, and water quality, which is especially essential for animals.

Scientists warn: we should not expect species to adapt to a new fire regime in just a few decades! Ecosystems will not be able to withstand this without irreversible long-term effects. Because adaptation requires several thousand years...

Links with the Local Population

The current connection between the Maures Massif and the local population is closely tied to its history. Until the 1940s, the forest was heavily utilized by local farmers who grew olive trees, chestnuts, and sourced firewood. The collection of medicinal plants and other edible plants, such as wild asparagus or heather, was common. Cork oak cultivation and the cork industry were also thriving.

Although this connection with the forest still persists, the rise of viticulture and seaside tourism has pushed local populations toward activities in the plains. However, the work previously done by local communities is gradually being recognized as a source of protection for the massif (clearing brush to reduce fire risk, establishing terraces to mitigate flooding) and its biodiversity.

"Placing humans and their good practices at the center of environmental and species conservation is a crucial challenge" is one of the key recommendations of the Natura 2,000 Objective Document.

Mediterranean forests are a precious heritage; three key areas of progress are prioritized to ensure they sustainably provide their goods and benefits:

- Valorization of forests through sustainable management, which utilizes all aspects of their multifunctionality: wood and non-wood product production, biodiversity protection, water, soil, and air conservation, landscape beauty, public reception, nature activities, sylvo-pastoralism, and many others. This should also include the cultural dimension of these natural spaces, which resonate deeply within our hearts. However, this sustainable management is still insufficiently widespread and must be resolutely developed, often requiring the consolidation of forest owners.

- Protection against fire through a prevention strategy built through dialogue among all stakeholders and reflected in the Departmental Forest Fire Protection Plan. Beyond field actions, this Plan should include a section organizing the sharing of a risk culture so that everyone is aware of the fire threat and adopts appropriate behavior.

- The "territorial project", as this is the level where all actors can come together to share an assessment and co-construct a local, sustainable, and prosperous development project focused on the forest, wood, and environmental services. It is also at this level that a frank and sincere dialogue between foresters and civil society can be established to build this "social pact" that will allow for a calm and collective vision for the future of forests.

Thanks to the ONF Midi-Méditerranée for providing documents and to the Syndicat Mixte du Massif des Maures for exchanges and contributions.

Wooded Savanna
The Great Green Wall

Doyle McKey
Aly Diallo

What is a forest? There are hundreds of definitions. Some are administrative or legal (for example, an area may be legally designated as a "forest" if it once had tree cover). Other definitions are based on land use (for example, an area whose primary use is timber harvesting). Still other definitions are based on the extent of tree cover, such as tree density or the proportion of land area covered by tree canopy, with different threshold values depending on the definition.

Although the vegetation of the northern Sahel could be qualified as a "forest" under some of these definitions, for the ecologist the application of this term to the vegetation of the northern Sahel obscures important functional differences between tree-dominated ecosystems and open ecosystems, where trees coexist with extensive herbaceous vegetation, notably grasses.

For the ecologist, Sahelian vegetation is a wooded savanna. Trees, more or less dense, are scattered across a landscape otherwise covered in grass lawns and herbaceous plants. The functioning of this ecosystem is governed by interactions that determine the dynamics of woody and herbaceous plants.

In savannas around the world, potential tree cover increases with precipitation. When tree growth is unhindered and there is sufficient rainfall, trees can outcompete herbaceous plants. However, this potential is often not realized, as herbivorous

mammals, fires, and droughts negatively impact trees and favor grasses. Fires are important in humid savannas, where biomass accumulation during the rainy season provides abundant fuel that feeds fires during the dry season. In the semi-arid savannas of the northern Sahel, fires are less frequent and less intense due to sparser herbaceous vegetation, and herbivorous mammals are the main factor (in addition to the arid and seasonal climate) limiting tree growth.

The dominance of thorny trees such as *Vachellia* species and *Balanites aegyptiaca* testifies to the selective pressure exerted over millennia by herbivores—formerly wild mammals, now almost exclusively domesticated ruminants—on the trees of these ecosystems. Moreover, trees lacking these mechanical defenses possess other, chemical ones. For example, all tissues of *Adenium obesum*, the desert rose or "false baobab", contain cardenolides, the ingestion of which can lead to cardiac arrest. Another abundant small tree, *Boscia senegalensis*, contains glucosinolates, toxic metabolites whose bitter taste deters herbivores. Local inhabitants take advantage of these properties. For instance, the leaves of *B. senegalensis* are used to protect millet and peanut seeds from rats and insects.

It is true that the features of wooded savannas are quite different from those of most ecosystems included in this booklet. Non-tree vegetation plays crucial roles in their functioning. Grasses and other herbaceous plants likely account for a greater proportion of primary production in savannas than trees. They support a large share of the animals in herbivore and detritivore trophic networks. And according to some studies, their contribution to soil carbon storage in wooded savannas is even greater than that of trees.

So, why include these wooded savannas here? Without overlooking the importance of herbaceous vegetation, it is essential to highlight the unique roles played by trees in Sahelian savannas. First, in these arid environments characterized by a very long and harsh dry season, the herbaceous cover, composed mostly of annual species, disappears during the long dry season. Trees, thanks to their deep root systems, are the only plants with access to water for 9 to 10 months each year. Some species, like *Balanites aegyptiaca*, are evergreen. Their foliage is one of the only forage sources available to livestock during this period. Trees are also the only plants that flower during the dry season. The resources provided by the flowers—nectar and pollen—are crucial for many insects that act not only as pollinators but also contribute to the regulation

of other arthropod populations (as predators and parasitoids) and to nutrient cycles (as detritivores). The insects supported by trees are, in turn, crucial resources during the dry season for insectivorous birds. As for birds, many species depend on trees for nesting sites and even for the materials used to build their nests. The following sections of this chapter include additional examples of ecological functions and ecosystem services (nature's contributions to people) provided by trees in Sahelian wooded savannas.

The Great Green Wall (GGW) zone stretches from Senegal to Djibouti, over 7,800 km, passing through 11 countries, covering—in its initial conception of a long corridor 15 km wide—117,000 km². In Senegal, the GMV covers an area of 8,175 km², located in the Ferlo region (latitude 15°N, longitude 15°W).

In the Ferlo, altitude varies little: around 25 to 50 m. Annual rainfall is around 300 mm, limited to a short (2-3 months) rainy season. The maximum temperature reaches 46°C in May (rainy season). During the dry season, the harmattan, a cool north wind, brings night-time temperatures down to 15°C. Ferlo soils are either clay (Ferlo latéritique) or sand (Ferlo sableux).

The woody flora of the Ferlo includes around 82 species of trees and shrubs. The biodiversity of insects is little known but considerable: for example, more than 350 species of insects have been collected visiting the flowers of one species of tree, *Balanites aegyptiaca*. Among vertebrates, amphibians are poorly represented in this arid environment (seven species). Eleven species of reptiles have been documented and 217 species of birds, including a large number of Palaearctic migrants, some of which are threatened. The Ferlo is home to four species of rodents and nine species of larger mammals. At least two million people live in the Sahelian zone of Senegal. The main ethnic groups are the Peuls, Wolof, Moors, Serer, Laobe and Toucouleurs.

FACT SHEET

Including Sahelian savannas in this booklet also allows for the discussion of important, timely general questions about ecological restoration strategies. Numerous initiatives around the world advocate increasing tree cover as a means to restore ecosystem integrity and mitigate climate change through carbon storage in forest ecosystems. This is one of the actions of the Great Green Wall initiative in the Sahelian savannas. At the same time, more and more voices are warning about the potential dangers of this approach for open ecosystems, which host specific biodiversity different from that of forests. Planting trees and encouraging increased tree cover can be beneficial actions for ecosystems and biodiversity under certain conditions, but harmful under others. Likewise, the "natural" colonization by woody plants can benefit biodiversity at some sites but be detrimental at others. Open environments that have hosted endemic biodiversity for millions of years rely on disturbances for their maintenance. In today's world, as fires are increasingly suppressed and wild herbivores become rarer, these two forces preventing woody encroachment in savannas are weakened. This phenomenon of "bush encroachment"—the colonization of open habitats by woody plants—threatens the biodiversity of ancient savannas that depend on open environments.

Where to plant trees, which ones, and how many? Might it be better not to increase woody cover in certain sites? These questions are complex, and the answers will vary depending on the evolutionary and human history of different sites. As for the Sahelian savannas, it appears that tree density sharply declined during the droughts of the 1970s–1990s, and that increasing tree cover will have positive impacts. But these questions encourage reflection on the best restoration strategies for a wide range of environments where the climate allows for the existence of either closed "forests" or savannas, depending on how people perceive and manage the environment.

Balanites aegyptiaca (Zygophyllaceae), also known as desert date, withstands drought thanks to a dual root system and photosynthetic branches that remain active year-round. It plays a crucial role in human and animal nutrition, providing edible fruits, oil, and fodder, and is used in traditional medicine and the making of various utilitarian objects. Its repeated flowering throughout the year makes it an essential resource for pollinating insects.

Adansonia digitata (Malvaceae) is the African baobab, a species widespread in the arid savannas of sub-Saharan Africa. Its imposing size (18 to 25 meters tall and up to 12 meters in trunk diameter) and its unique bottle-shaped form make it easily recognizable. Its deciduous leaves, pendulous white flowers, and large woody fruits containing a floury pulp also contribute to its singularity. This species plays a crucial role in Sahelian ecosystems and for local populations, offering a multitude of food, medicinal, agropastoral, domestic, and even psycho-magical and cosmetic uses.

The hardiness of ***Euphorbia balsamifera*** (Euphorbiaceae) makes it ideal for creating live hedges in dry African regions. Its rapid growth, dense branching, and toxic latex, which deters browsing, contribute to the formation of an effective barrier against animals and erosion. Its propagation by cuttings facilitates its spread and integration into agroforestry systems. Additionally, it provides further ecosystem services, including contributions to dairy production in cows.

Trees in the Sahel make an essential contribution to a number of ecosystem services. In terms of regulating services, trees store carbon, reducing greenhouse gas emissions and thus mitigating climate change. Trees also play an important role in the hydrological cycle. However, the importance of trees in these services, compared with that of herbaceous plants, is the subject of debate. According to a recent study, in savannas, herbaceous plants account for more than half of primary production, and also for more than half of the carbon stored in the soil. A large proportion of the carbon stored in trees is in the above-ground parts, where the biomass is more vulnerable to fire, drought and consumption. A large proportion of the carbon fixed by herbaceous plants is stored in the soil.

As far as the hydrological cycle is concerned, trees, with their deep roots and large leaf area, increase transpiration: the water thus circulated in the atmosphere can increase precipitation; but, carried away by the wind, it can fall far from the place from which it came. The removal of water by tree roots can have a negative impact on the soil water that feeds downstream ponds and streams. The impact of trees on these regulating services can therefore vary. Management should seek, for each ecosystem, the "optimal" proportions of trees and herbaceous plants.

Trees play a key role in maintaining pollinating insects. While the flowering of herbaceous plants is restricted to the short rainy season, many tree species are in bloom at any time of the year. The floral resources provided by trees are essential to the survival of many insect species, which not only provide pollination but also a wide range of other functions, such as the decomposition and recycling of nutrients—provided by detritivores—and the regulation of prey or host populations—provided by predatory or parasitoid insects. Insects fed by flowers in turn feed insectivorous birds. A large part of the biodiversity of the Sahelian savannas therefore depends directly or indirectly on the floral resources provided by the trees. What's more, the morphological features of Sahelian tree flowers give free access to a wide variety of visitors.

In the very simple flowers of *Balanites aegyptiaca*, for example, nectaries, pollen and stigma are exposed, posing no barrier to access to floral resources and reproductive organs: *Balanites aegyptiaca* is visited by over 350 species.

As for forecasting services, trees account for the lion's share. In the vast expanse of Senegal's Ferlo region, where the sun shines relentlessly and rain is scarce, life clings tenaciously on. In this region, trees and shrubs, true heroes of resilience, are present and biologically active in all seasons, offering a multitude of predictive services to local populations.

Balanites aegyptiaca (*soump*), with its sweet and bitter fruit, feeds people and animals. Its oil, precious and rare, flavours dishes and cures ailments such as digestive disorders and skin problems.

Adansonia digitata, the majestic giant, offers fruit for which a delicious juice is made; its leaves and bark are used in food, medicine and handicrafts.

***Sclerocarya birrea* (Anacardiaceae), also known as the African plum tree, produces juicy, edible fruit** rich in vitamin C, sugars, calcium, magnesium, potassium and polyphenols, contributing to the food and nutritional security of local populations, especially during lean periods. An oil with a wide range of nutritional and therapeutic properties is extracted from the seeds, and the wood is used in handicrafts.

Boscia senegalensis (Capparaceae) is widely distributed in the Sahel region. Very hardy, **it gives good fruit yields** even after years of drought. Its fruit, rich in protein and carbohydrates, is a vital food source during the lean season, after processing to eliminate bitterness.

Pterocarpus lucens (Fabaceae, subfamily Faboidae) provides high-quality fodder for livestock, particularly in times of shortage. Populations of this ecologically important species have declined due to over-exploitation of its leaves and fruits for fodder.

Ziziphus mauritiana (Rhamnaceae) is a valuable ally in the food security of rural populations thanks to its fruit, which is rich in vitamins C and A, phosphorus, carotene and calcium, and has a wide range of uses, from food (fresh and dried fruit, juice, jam, pancakes) to traditional medicine (treatment of haemorrhage, ulcers, diarrhoea, etc.) and even fodder for livestock.

Senegalia senegal (*Acacia senegal*), **the source of the precious gum arabic**, provides income for local people.

Vachellia seyal (*Acacia seyal*), with its many uses, contributes to food, construction and traditional medicine. Finally, the Combretaceae, a diverse family, provides firewood, fodder and medicinal plants, playing a crucial role in the daily lives of the Ferlo's inhabitants.

These species, guardians of a fragile ecosystem, are much more than mere plants: they are the pillars of life in the Ferlo, weaving an indestructible link between man and nature. Their story is a lesson in resilience, adaptation and generosity, a vibrant testament to the richness and fragility of life in the Sahel.

Woody species in the Sahel play crucial roles in the local economy. Their multiple uses—ranging from food to construction, medicine, and income generation—make them essential resources.

The socio-economic importance of these species is notably illustrated by the harvesting of their fruits. For example, the fruits of *Balanites aegyptiaca*, *Adansonia digitata*, and *Ziziphus mauritiana* are actively collected and sold, thus contributing to household incomes, particularly for women, who make up the vast majority of collectors (98%). In contrast, the fruits of *Sclerocarya birrea*, which hold considerable commercial value in other parts of Africa, are not marketed in the region. The fruits of *Boscia senegalensis*, although potentially useful, are also not commercialized.

Beyond the fruits, other parts of these trees are also valued. In fact, the exploitation of trees for various non-timber forest products (NTFPs)—such as edible oils (*Balanites aegyptiaca*), leaves (*Adansonia digitata*: edible leaves; *Boscia senegalensis*: insecticidal leaves), roots (*Boscia senegalensis*: used for gynecological treatments), and bark (*Balanites aegyptiaca*: used by healers for leprosy and headaches; bark-based poisons used to catch fish)—is an important source of income for rural populations. In addition to income generation, trees contribute to "hidden harvests": harvesting "free" wild species helps reduce household expenses. For example, studies highlight the contribution of *Balanites aegyptiaca*, *Boscia senegalensis*, and *Ziziphus mauritiana* to the resilience of populations facing food insecurity in the Sahel. Transforming these species into flour, cakes, biscuits, oil, and other food products for personal consumption helps diversify food sources.

Several species also play a crucial role in livestock feeding, especially during the dry season when grassy pastures become scarce. This directly influences transhumance practices, as the availability of woody forage determines where herds can move. Species like *Pterocarpus lucens*, *Balanites aegyptiaca*, *Boscia senegalensis*, *Ziziphus mauritiana*, and *Senegalia senegal* are frequently cited as important forage sources. The abundance and nutritional quality of these species, along with water availability, influence the routes and duration of transhumance, as well as school attendance times for children. The exploitation of woody forage, whether through pruning or cutting, can also impact tree regeneration and future

forage availability, which in turn affects the long-term sustainability of transhumance.

Many tree species are used as energy wood, not only for household cooking but also for charcoal production. In addition to wood, dried cow dung is widely used as fuel in Sahelian households, especially during times of wood scarcity. This practice, although traditional, addresses urgent energy needs, particularly in rural areas where access to modern energy sources remains limited. *Balanites aegyptiaca*, *Vachellia seyal*, *Pterocarpus lucens*, and *Ziziphus mauritiana* are used as construction timber and in crafts, for making tool handles, artisanal objects, or traditional fencing.

Some species also hold economic value due to their medicinal properties. Numerous reports mention the use of these plants in traditional medicine. For example, *Balanites aegyptiaca*, *Ziziphus mauritiana*, *Adansonia digitata*, *Sclerocarya birrea*, and *Boscia senegalensis* are frequently used by traditional healers. This traditional use of plants for healthcare represents an economic advantage for local populations, reducing their dependence on expensive pharmaceuticals.

Finally, it is important to stress that the exploitation of these woody resources must be sustainable to ensure their continued availability. Several studies warn of the risks of overexploitation linked to human pressure and climate change. Biodiversity and ecosystem functioning must be taken into account in reforestation projects such as the Great Green Wall in order to ensure the sustainability of the resources and the economic benefits they provide. Moreover, diversifying the species used is essential for ecosystem resilience to pests and environmental stress, thus ensuring the sustainability of the economic activities that depend on them.

Sahelian ecosystems play a crucial role for both biodiversity and local populations. However, they face numerous pressures—both natural and human—that compromise their health and resilience. Some species, though naturally present, can become invasive and threaten ecosystem balance. This is the case for certain Combretaceae, mentioned as a dominant family in several studies. Although these trees provide resources to populations, their expansion can come at the expense of other woody species with multiple uses. This floristic imbalance can weaken the ecosystem and make it more vulnerable to further disturbances. Other species, such as *Balanites aegyptiaca*, *Calotropis procera*, and *Boscia senegalensis*, are noted for their resistance to harsh conditions and human activity. Their dominance may also indicate an imbalance reflecting environmental degradation.

Human activities exert significant and multifaceted pressure on Ferlo's ecosystems. The main threats include:

- Bushfires: Recurrent and devastating, especially at the beginning of the dry season, they destroy vegetation, deplete soils, and contribute to desertification.
- Overgrazing: The high density of livestock typical of pastoralism in the region leads to pasture degradation, regression of plant species, and soil erosion. Intensive browsing puts particular pressure on trees, weakening the trophic networks that depend on them.
- Overexploitation of resources: Excessive woodcutting for fuel and unsustainable harvesting of other natural resources (gum arabic, fruits, etc.) contribute to the disappearance of certain species and the degradation of ecosystems. Mining (including quarrying for concrete production) is also identified as a major threat to forest cover in some areas.
- Climate change: Drought, exacerbated by climate change, weakens ecosystems and makes them more vulnerable to other pressures.

The health of Ferlo's Sahelian ecosystems is fragile. The combination of natural and anthropogenic threats calls for sustainable and integrated resource management. Restoration and conservation efforts are essential but must account for the complexity of interactions among species and environmental factors. The participation of local populations and collaboration among different stakeholders (scientists, managers, private sector) are crucial to ensure the long-term survival of these fragile ecosystems.

Sahelian species, whether woody or herbaceous, are deeply connected to the lives of the people of Ferlo, in Senegal. These populations—primarily Fulani, but also Wolof, Moors, Serer, and Laobe—depend on these species for their survival and economic activities.

Extensive livestock farming, the main economic activity in Ferlo, relies on natural pastures. During the rainy season, livestock feed on the herbaceous layer, while in the dry season, the woody layer becomes essential for fodder. Species such as *Pterocarpus lucens* are particularly important for fodder. The degradation of these resources, due to drought and human pressure, directly impacts local communities.

Beyond fodder, woody species provide many Non-Timber Forest Products (NTFPs) that are essential to the populations. These NTFPs also contribute to the local economy, generating income for communities, especially for women, who are the majority in the harvesting sector.

The relationships between populations and Sahelian trees are complex and dynamic. Unsustainable resource use can lead to ecosystem degradation and the disappearance of important species such as *Sclerocarya birrea*, *Adansonia digitata*, and *Senegalia senegal*. It is therefore crucial to understand these interactions and implement sustainable management strategies to preserve biodiversity and ensure food and economic security for the people of Ferlo.

Looking ahead, several scenarios are possible. A pessimistic scenario would involve continued biodiversity degradation, with the disappearance of emblematic species and the destabilization of ecosystems. Climate change could accelerate this process, making life even more difficult for local populations.

A more optimistic scenario would rely on adapting biodiversity management strategies. This would include diversifying the species planted within the Great Green Wall project, encouraging natural regeneration, taking into account the biotic interactions that underpin ecosystem functioning, and involving local populations more deeply in resource management. Scientific research, particularly on plant life histories, the vulnerable phases in their life cycles, and the structure of woody and herbaceous communities, could provide key insights for the sustainable management of Sahelian ecosystems.

Lastly, an intermediate scenario might combine ongoing degradation with local successes, showing significant disparities between regions and species. The future of Sahelian species will therefore depend on the ability of local and international stakeholders to implement effective conservation and restoration strategies.

Primeval Forest
Białowieża Forest

Dr. Renata Krzyściak-Kosińska
Dr. Bożena Kornatowska
Dr. Cédric Béraud

Introduction

The Białowieża Forest is located on the border between Poland and Belarus in the lowlands of Central Europe. It lies within a temperate transitional climate zone. This region is characterised by a high number of days with very cold weather, where the average daily air temperature falls below -15°C, as well as a notable frequency of moderately cold frost days. Over the last decade, the mean annual multi-year air temperature in the area has risen to 8.1°C, compared to 6.8°C between 1950 and 2003. Precipitation is crucial for maintaining the environmental condition of the Białowieża Forest. The average annual precipitation over the last decade was 725 mm.

As its name suggests, the Białowieża Forest is predominantly covered by forest communities, which account for approximately 96% of the area. Shrub plant communities and non-forest communities mainly develop in river valleys and in man-used mid-forest clearings. The Forest encompasses all forest community types found in this geographical region. The forest vegetation is dominated by oak-hornbeam forests, then there is a significant proportion of ash and alder carrs occurring along rivers and their oxbow lakes as well as pine and birch swamp forest occurring in extrusion basins and on swampy river terraces. Other forest types include dry thermophilus oak-hornbeam forest, pine-spruce coniferous forest and a mosaic of pine coniferous forest. Larger and smaller patches of alder carrs, oak-spruce wet mixed coniferous forest, fresh mixed coniferous forest, pine-oak mixed coniferous forest are distributed throughout the entire area.

The tree stands of the Białowieża Forest differ from those of Western European forests mainly in the absence of beech, while from those of

Eastern European forests in the abundance of oak and hornbeam. The species that links the Białowieża forests with those of north-eastern Europe, however, is the Norway spruce – present in almost all forest types and significantly affecting the structure and dynamics of forest communities. In recent decades, outbreaks of the bark beetle (*Ips typographus*) in the Białowieża Forest have significantly contributed to a decrease in the share of spruce in the stands of the Forest.

Białowieża Forest is an exquisite example of unique ecological processes. For the past 10,000 years, since the last glaciation, its ecosystems have been primarily shaped by climatic conditions and biological processes. As the result, the stands of the Białowieża Forest exhibit a multi-layered and age-differentiated structure.

The biotic factors affecting the ecosystem include, among others, the toppling of trees followed by the emergence of new vegetation, the rooting of wild boar, the direct impact of herbivores such as red deer, roe deer, elk and European bison (*zubr*) on the vegetation, and the relationship between herbivores and predators. All these factors support the emergence of new ecological niches, particularly important for cryptogams and invertebrates.

The Białowieża Forest is an area of most significant and important natural habitats for *in-situ* biodiversity conservation. A characteristic feature of the Forest is its remarkable biodiversity and a significant number of species typical of forests and relicts of primeval forests.

The Białowieża Forest is inhabited by numerous animal species, including 61 species of mammals, more than 250 species of birds, 13 amphibians, seven reptiles and almost 12,000 species of invertebrates. The symbol of the Białowieża Forest is the European bison, whose population is the most numerous of the freely roaming populations in Europe. The area is known primarily for the presence of large mammals such as the bison, elk, red deer and wolf, but rodents are the most numerous group (18 species). Slightly less numerous are bats (14 species), mammalian predators (12 species) and insectivores (eight species). The fewest representatives are lagomorphs (two species).

Many of these species are typically forest animals, *e.g.* lynx, forest marten, yellow-necked mouse, dormouse. Others occur in both forest and open areas, *e.g.* weasel, bank vole, and common shrew. There is also a significant group of open-land species, living mainly on the banks of water bodies and swampy river valleys. These include otter, beaver, northern water vole, Eurasian ermine, water shrews and voles. In the immediate vicinity of humans live, among others, the house marten, house mouse, brown rat and some bat species. So far, 254 bird species have been recorded in the Forest, of which more than 170 are nesting birds here. Compared to other European forest areas, the Białowieża Forest's avifauna is characterised by unparalleled species richness. It is particularly abundant in birds of prey (15 species), owls (eight species), woodpeckers (10 species) and leaf warblers (23 species). The reptiles of the area

are represented by seven species, among which the rarest is the European pond turtle. The most common species are the grass snake and the viviparous lizard. There are 13 species of amphibians. They represent different families with different habitat requirements, ecology and behaviour. There are 32 species of fish and lampreys representing 11 families. More than 9,000 insect species have so far been recorded in the Forest, but it is estimated that their number reaches up to 20,000.

Old stands provide habitat for saproxylic species, especially those requiring old and large trees. It is estimated that there are almost 500 species of lichens in the Forest. The Białowieża Forest is considered one of the most important refuges of macrofungi not only in Poland and Belarus, but also in the entire hemiboreal region. By 2018 at least 1,988 species of macrofungi had been found here. This high diversity is due to two main factors: the large area of forest habitats of primeval character and the continuity of ecological processes. Of the 33 species considered particularly threatened with extinction in Europe, at least five occur in the Forest. In particular, the fungi associated with dead wood are worth attention as being in danger of extinction throughout the entire northern hemisphere. A total of 384 endangered fungi species have been found in the Polish part of the Forest.

FACT SHEET

Białowieża Forest is situated in the North-East of Poland (central point: 52.7326 N 23.8988 E), in Podlasie Province, southeast of the city of Bialystok, in Hajnówka District as well as the South-West of Belarus, Brest Region and Grodno Region. Poland extends across the North European Plain from the Sudetes and Carpathian Mountains in the south to the Baltic Sea in the north. It's highest point is Rysy in the Carpathain Mountains with 2,500 m a.s.l and the lowest is -1.8 m b.s.l. The average elevation is 173 m. Belarus is predominantly a lowland country with the highest point of 346 m a.s.l. The mean altitude of the Białowieża Forest: 160–180 m above the sea level; minimum altitude: 134 m above mean sea level; maximum altitude: 202 m AMSL.

Average annual temperature is 7°C, coldest January (-4.5°C), warmest July (18.3°C). Mean annual precipitation (for last five decades): 650 mm.The total area of the Białowieża Forest: approx. 150,000 ha: 60,000 ha is in Poland, 90,000 ha in Belarus.

Main rivers: Narew, Hwoźna, Narewka, Leśna. Biodiversity facts: Vascular plants: 1,060 species. Fungi: 2,000 species. Mammals: 61 species. Birds: 250 species. Reptiles: Seven species. Amphibians: 13 species. Invertebrates: over 12,000 species. The biggest free-living population of the European bison in the world. Big predators: wolf, lynx, brown bear (visiting). Local population in Poland—Hajnówka District is 40,200. There are three main ethnic groups: Polish, Belarussian and Ukrainian.

Uniqueness of the Forest

The Białowieża Forest is one of the last existing and best-preserved natural forest complexes of primeval character in lowland Europe. Its greatest value lies in its diversity of habitats and species, as well as the natural processes that have been occurring uninterruptedly for thousands of years. Because the Forest served as a royal hunting ground from the 15th century and certain areas were placed under strict protection at the beginning of the 20th century, it has retained its unique character.

The forest is one of the few areas in the world where trophic relationships between plants, herbivores and predators can be observed in a form undisturbed by human activity, in parallel with the overlap of ecological niches of related species. Many phenomena documented in scientific literature were first observed in the Białowieża Forest, *e.g.* the Dehnel phenomenon, the relationship between rodent abundance and fruiting of forest trees, the effect of predators on ungulate populations.

The park's reach avifauna is characterised by high species diversity, low densities of individual species and high predation pressure. These are characteristics of primeval forests, regardless of the climatic zone, and can be used as indicators of the maturity of the forest and the absence of human disturbance.

Another unique feature of the Forest is the amount of dead wood which provides adequate opportunities for the development of a diverse community of decomposers.

The Forest's low degree of fragmentation, combined with a high proportion of natural forests with multilayered and age-diverse stands, fosters the presence of relict species. The numerous trees of monumental dimensions, the low proportion of invasive species, the specific geographical and biogeographical location together with the diversity and richness of wildlife and the occurrence of the European bison (*zubr*) create a unique ecosystem. It is formed by a mosaic of forest and non-forest habitats interconnected by a network of rivers. The valleys of the rivers integrate the whole area, providing natural migration corridors for animals, but also for seeds and spores transported by the waters of these rivers.

The Białowieża Forest is the last lowland area in Europe where our continent's largest land mammal survived in the wild until the early 20th century.

Today, thanks to a long-standing restoration program conducted in the forest, the area is inhabited by the largest free-roaming **European bison (*zubr*)** herd in the world, consisting of over 800 specimens (only in the Polish part of the Forest). There are other ungulate species such as elk, red deer, roe deer and wild boar. Among the predators, wolves and lynxes are the most important.

River valleys are used by mammals such as beaver and otter, but also by representatives of other groups. They serve as migration routes for water birds.

A characteristic feature of the Forest is its high biodiversity and a significant number of species typical of forests and relicts of primeval forests. There is a long list of bird species of particular scientific interest. Leading the list are those species whose occurrence is determined by the presence of dying and dead trees in the forest. These are mainly the white-backed woodpecker, the three-toed woodpecker, pygmy owl and flycatchers.

In terms of fungi, the Białowieża Forest is the most valuable forest area in the northern hemisphere. In boreal and boreo-nemoral forests, polyporoid fungi are the most important reducers of dead trees. The number of species of polyporoid fungi of the Forest is 210. Among the most interesting ones you might list *Amylocystis lapponica*, *Pycnoporus alboluteus*, *Dentipratulum bialoviesense*, *Aurantiporus priscus*, *Aporpium macroporum*. Some of them has been described as new to science from the Białowieża Forest.

European bison (*Bison bonasus* [*zubr*]), Białowieża primary forest, Poland
© Marek Kosinski.

Ecosystem Services

Ecosystem services (MEA 2005, TEEB 2010) evaluated in the Białowieża Forest include provisioning, regulating, cultural, and supporting services. The Forest provides irreplaceable natural services that support biodiversity, carbon sequestration, water balance, erosion control, desertification reduction, and ensure mitigation of the effects of natural hazards. Provisioning ecosystem services is significant at local and regional levels (*e.g.* tourism). Benefits related to ecological processes (*e.g.* maintaining biodiversity, mitigating climate change) have a great importance at a global level.

Goods provided by the Forest include **mushrooms** and berries. These are mostly collected by the local community for their own needs. Some surplus is sold to food processing companies or local restaurants. Several medium-sized companies use forest goods to produce herbal teas, juices, and processed forest fruits as a component of natural medicine. Natural honey with healing and antibacterial properties is obtained from the apiaries located in the Białowieża Forest. The pharmaceutical industry greatly benefits from the genetic diversity of species protected in the Forest ensuring great potential for future discoveries of new medicines.

Harvesting timber in the Białowieża Forest is generally considered unsustainable and primarily benefits a narrow group of people. Timber has been mostly sold outside the region, nevertheless, there is taken into consideration the provision of firewood to meet local needs. As far as the game is concerned, caution is recommended as reducing animal numbers by hunting can result in behavioural and ecological changes in the stability of species populations.

Forest cover and riparian vegetation regulate the water cycle and surface water run-off. Carbon sequestration as well as regulation of a microclimate is an important benefit generated by the Forest.

Possibilities for research, education, art, and recreation are some of Europe's biggest. Preserved natural forest landscape is a very important benefit attracting thousands of visitors. Sustainable tourism has a long local tradition and is based on the conservation of forest habitats, the presence of European bison, and the existence of the Białowieża National Park. These benefits are founded on the uniqueness of the Białowieża Forest's natural landscapes, biodiversity, as well as an almost undisturbed course of natural processes.

According to the IPBES approach (Nature's Contributions to People-NCP), forest ecosystems provide numerous natural services, which are classified into three general categories, i.e.: regulating (*e.g.* regulation of climate, hazards, and water cycle, soil formation), material (food, energy, materials for clothing, shelter) and nonmaterial (nature's effects on subjective or psychological aspects). Recent surveys on local community preferences reveal that the residents of the municipalities situated in the vicinity of the Forest highly value nonmaterial nature contributions, such as knowledge acquisition, learning, inspiration by nature for art and technological design, and enjoyment based on contact with nature, as well as the basis for religious, spiritual, and social cohesion.

Mushrooms, Białowieża primary forest, Poland
© Jessica Buczek.

Economic Impacts

The Białowieża Forest has always played a significant role in both the local and regional economy, transferring money and materials locally and outside the area. The forest also holds importance for local services, crafts, and small-scale industries.

Studies on the economic impacts of the Białowieża Forest show that this protected area generates multiple and direct economic benefits. The assessment and management of ecosystem services in the Forest is quite challenging because local human needs (especially those related to provisioning ecosystem services) must be considered along with the maintenance of naturalness and biodiversity which demands generally low-intensity land use.

The National Park and three Forest Districts located in the Białowieża Forest offer approximately 250 jobs. More than one hundred licensed guides are employed by local tourist offices, and many more jobs are expected to be created as tourism develops and sustainable natural resource use advances. Provisioning services are also economically important, with the annual value of harvested mushrooms and extracted honey estimated at €180,000 and €100,000, respectively.

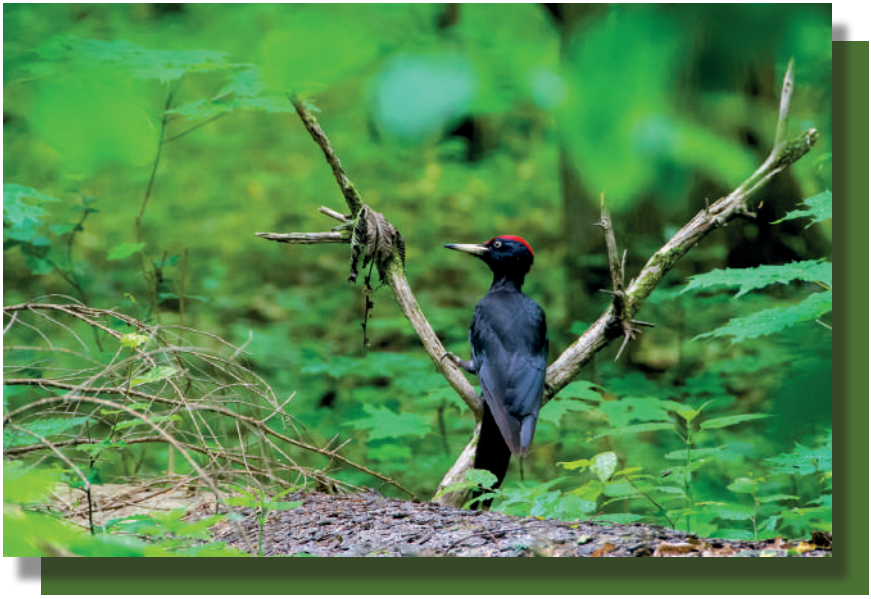
The unmanaged nature of the Białowieża Forest is the main reason for the millions of people to visit the region. One of the most frequently visited objects is the bison park where also other animals occurring in the Forest can be observed. **The Forest is one of the most popular places to watch birds in Europe** and is visited by thousands of birdwatchers every year. Nature-watching contributes substantial income to the local economy. Tourism is a key economic driver, generating €100,000 annually from entrance fees, €100,000 from hunting licenses, and €150,000 from horse-riding activities. Sustainable tourism development presents a viable alternative to timber extraction, which had historically been practiced in the Forest.

Approximate estimates indicate that timber extraction amounted to €6 million annually (this has been stopped in 2018). This contrasts with the results of the study on visitors to the Forest that indicate the value of €4 billion of all the recreational, amenity, and existence type values. It seems that the loss of benefits associated with the exploitation of the Białowieża Forest's tree stands is of minor importance when compared to other benefits provided by the Forest.

The region has a huge tourist potential, related to the unique natural values of the Białowieża Forest on a European and global scale, as an object of international nature conservation and the only natural habitat of the European lowland bison. It is complemented by original cultural values, a recognized international tourist brand, and a well-developed tourist infrastructure.

Despite this, the region's tourism potential remains underexploited, offering opportunities for significant growth in tourist traffic and increased revenue. These benefits can extend to local institutions, businesses, and local communities involved in tourism.

Apart from tangible benefits from provisional services, such as mushrooms berries, and wood, or cultural services, the tourism industry may provide incentives for local conservation. Yet, diverse stakeholder groups may give emphasis to not the same ecosystem service types and attach different values to particular ones—depending, for instance, on their proximity to the specific ecosystem, the scale of provided ecosystem services, or else socio-cultural and economic characteristics of stakeholders involved.



Black woodpecker, *Dryocopus martius*, Białowieża primary forest, Poland

The main threats to the natural environment of the Białowieża Forest are climate change and the spread of alien species, which is anthropogenic in nature and is also related to climate change. Climate change results in the modification of climate elements such as:

1) Rising global temperatures, which affect the forest through changes in the species phenology and geographical ranges, as well as an increase of the likelihood of the mass occurrence of pathogenic organisms.

2) Droughts and changes in snow cover, which may pose a threat by lowering of groundwater tables, drying up of small water reservoirs and watercourses, decrease in the availability of drinking water sources for animals, threat to the reproductive success of species associated with aquatic ecosystems (*e.g.* dragonflies, amphibians), water deficits during the growing season, increase in the vulnerability of ecosystems to abiotic, biotic and anthropogenic factors that may cause disruption of natural adaptation processes.

3) Extreme weather events related to heavy rainfall and strong winds, which may affect ecological processes and biodiversity. The projected increase in the frequency and area of windthrows and windbreaks may further disrupt the forest life cycle.

A direct result of climate change is an increasing fire risk. The mean annual multi-year air temperature in the Białowieża Forest in the last decade has increased to 8.1°C, compared to 6.8°C between 1950 and 2003. Moreover, the number of rain-free days, particularly during the growing season, has increased—a worrying trend that heightens fire risk. While human activities amplify this risk, Poland's forest administration has implemented an efficient fire prevention system, featuring an extensive network of observation towers and advanced technologies. This ensures rapid response times, allowing fires to be extinguished promptly and effectively.

The introduction and spread of alien species are primarily driven by human activities, such as international trade, transportation, and tourism, and are further accelerated by climate change. Globally and within Europe, the rate of alien species introductions is increasing, and invasive species are considered one of the greatest threats to the biodiversity of the Białowieża Forest. Their impacts include:

- Displacing native plant and animal species, preventing the reproduction and dispersal of native species.
- Causing the extinction of native species, either directly or through hybridization with alien species.
- Altering the physical, chemical and biological properties of soil.
- Disrupting nutrient cycling and hydrological processes within the ecosystem.
- Disturbing food webs, including impact on herbivores, organisms living in the near-surface soil (edaphic) and pollinators.
- Increasing pressure on native species due to increasing populations of alien and invasive animal species such as American mink and raccoon dog, and occurrence of new species (raccoon, golden jackal), reducing the health of the bison population and other native animals due to the spread of alien parasites and pathogens.

Direct threats, resulting from human management, which affect the ecological processes and biodiversity of the Białowieża Forest include, above all, fragmentation and isolation of habitats and populations. It may be linked to changes in hydrological conditions and declining water resources; roads, as well as the construction and maintenance of the barrier along the Polish-Belarusian border.

Timber harvesting and removal of dead trees can also be one of the causes of habitat and population fragmentation and isolation. Timber harvesting affects biodiversity and opens up sites for invasion by light-demanding, expansive and non-native species. It must be stressed, however, that the Białowieża Forest is almost entirely excluded from traditional forest practices. Timber exploitation is not permitted and in case of any natural disasters, natural regeneration of the forest stands is promoted.

Timber harvesting, Białowieża primary forest, Poland

Links with the Local Population

The Białowieża Forest region is sparsely populated. There are just few villages within the forest complex, the largest being Białowieża, with less than 2,000 inhabitants. At the western edge of the Forest there is a small town, Hajnówka, with the population of less than 20,000 people. For centuries, Białowieża Forest served as a royal hunting ground, and settlement was largely prohibited, with only a few exceptions. As a result, the forest remains relatively intact, with few settlements and limited road infrastructure.

In Poland, forests are mainly the state property, and the access is free. This rule does not apply to the national parks and nature reserves where people are allowed in certain areas and marked tourist paths usually. Most of the Białowieża Forest, however, is open to visitors. Therefore, local community is strongly attached to the forest and its nature. Mushroom picking is the national hobby, if not sport, of Poles and the Forest serves as an ideal area for mushroom picking, especially in Autumn when honey mushroom is abundant (honey mushroom soup is the local specialty). Another national sport is berry picking. With large areas of coniferous forests and its characteristic vegetation the area is well known for blue berries, cow berries as well as cranberries.

The Forest shapes the identity of local community.

PUSZCZA BIAŁOWIESKA. Hist.moment sprowadzenia do Puszczy pierwszych żubrów po wojnie 19/IX 1929.

In Europe, apart from the Białowieża Forest in the East, the great primeval lowland forests have disappeared and given way to secondary forests where forest culture is based mainly on timber and firewood exploitation, tourism, leisure, etc. For that reason, the NGO Association Francis Hallé pour la forêt primaire is working since 2019 to create the conditions for the rebirth of a primeval forest in Western Europe (France, Belgium, Germany, Luxembourg), through a "free evolution" process developed over an area of relevant ecosystem dimension.

Thinking about and creating the conditions for the revival of such a forest could provide new answers to (1) the closely interconnected emergencies of unprecedented biodiversity loss and climate change, and (2) the profound necessity of redefining the relationship between humans and other living beings in Western societies. In the context of Western Europe, this represents a unique research-action program, a tangible exercise in foresight and in territorial and civic co-construction of a space conducive to sustainable development. The forest will be considered beyond its biophysical environment, considering the socio-economic context of the regions involved. In this sense, this document initiates a European collaboration for strong protection and large-scale restoration of ancient forest spaces in response to the current emergencies.

Dry Forest
Forest of Madagascar

Joelisoa Ratsirarson
Mikoja M. Rambinintsoa

Introduction

Madagascar, an island renowned for its unique and remarkable biodiversity, is home to numerous ecosystems, each with its own characteristics. According to climatic conditions (Cornet, 1974) and vegetation formations (Ministry of the Environment, 1996), four ecoregions make up the Great Island, composed of four types of forests: the humid forests of the East, the dry forests of the West, the spiny forests of the South, and the mangroves along the West coast (Vieilledent *et al.*, 2016). The majority of Madagascar's biodiversity is found in forests, with 90% of the local fauna depending on them (Harper *et al.*, 2007). However, threats and pressures on these forests persist due to poor management in the face of the population's growing needs, lack of law enforcement, corruption, and land tenure issues (Waeber *et al.*, 2015). From a research perspective, numerous studies have been conducted on tropical forests, most of which have focused on humid forests, resulting in fundamental and essential knowledge for their management and conservation.

In comparison, little attention has been paid to dry forests, which face ongoing and unpredictable climatic and economic challenges (Carpenter & Gunderson, 2001; Walker *et al.*, 2002), despite their ecological, economic, and social importance.

Madagascar's dry forests play a significant ecological and socio-economic role. They are located in the western part of the island,

following a North-South and East-West rainfall gradient (Cornet, 1974), with decreasing precipitation and a shorter rainy season toward the western and southern regions of Madagascar. The so-called dry forests of Madagascar include the deciduous dry forests, found mainly in the northwest, and the spiny forests or thickets of the south and southwest. These dry forests are home to remarkable animal and plant species that are unique and well-adapted to the semi-arid climate, such as the endemic jumping rat *Hypogeomys antimena*. Madagascar's dry forests also provide ecosystem services to the local population, directly linked to their subsistence activities and daily life, especially for fuelwood, grazing areas, agricultural land expansion, and the regulation of biogeochemical cycles of the biosphere—particularly the water and carbon cycles. The latter is essential for supporting a wide range of other ecosystem services (Kooch *et al.*, 2022), especially in dry forests, which are among the most vulnerable ecosystems. In fact, population growth increases human needs, and when combined with harsh climatic conditions—as well as instability in management and conservation policies—these factors intensify the pressures and threats on Madagascar's dry forests. As a result, these ecosystems have become the most threatened on the island, with deforestation rates significantly higher than those in the humid forests of the East (MEFT *et al.*, 2009; Brinkmann *et al.*, 2014; Zinner *et al.*, 2014).

Initiatives have been undertaken to conserve the remaining ecosystems, such as the establishment of protected areas, which now cover 10.4% of the island's surface (Mondanaro *et al.*, 2024), along with restoration efforts aimed at preserving biodiversity and the services these ecosystems provide—especially for the local communities living nearby. To contribute to the conservation and preservation of the unique richness of Madagascar's dry forests, the Bezà Mahafaly Special Reserve was created more than thirty years ago, based on a consensual approach with the local community. Collaborations with the local population have been established to involve them in biodiversity conservation through regular volunteer patrols and annual reforestation activities. These efforts aim to strengthen conservation through an inclusive and participatory approach. This protected area falls under Category IV, which focuses on protecting specific species or habitats (Woodley, 2018). It is home to various exceptional species found in the dry forest and xerophytic forest, dominated by highly drought-adapted species (Sussman & Ratsirarson, 2007). Beyond its importance for biodiversity conservation, the Reserve provides goods and services to the local communities living in surrounding villages, particularly for their

subsistence activities such as agriculture, livestock farming, handicrafts, and the extraction of rock salt.

Unfortunately, this dependence on the forest and the goods and services it provides contributes to the pressures and threats it faces—especially in the absence of sufficient knowledge of the environment to develop adapted and effective conservation strategies for the island's dry forests.

In this context, this document aims to highlight the importance of Madagascar's dry forests, and more specifically the Bezà Mahafaly Special Reserve, by presenting the uniqueness of this type of forest, the remarkable species it harbors, the various ecosystem services it provides, and their economic impacts. For longer-term objectives, an analysis of the forest's health status is presented, followed by a section on its connections with the local population, before outlining prospects.

Located between 23°38'60'' and 23°41'20'' South latitude and 44°32'20'' and 44°34'20'' East longitude, the Bezà Mahafaly Special Reserve is situated in Fokontany Mahazoarivo, within the commune of Ankazombalala (formerly Beavoha), in the district of Betioky Atsimo, Atsimo Andrefana region, Madagascar. The protected area covers a total surface of 4,200 hectares and is inhabited by the Mahafaly, Antandroy, and Tanala ethnic groups.

With an elevation ranging between 100 and 200 m, the eastern part of the Reserve lies along the banks of the Sakamena River, a tributary of the Onilahy River, located approximately 8 to 10 km north of the Reserve. The climate of the southwest is marked by two distinct seasons: a short rainy season characterized by high ambient temperatures ranging between 34°C and 48°C, and a long dry season during which the coldest months, July and August, experience average temperatures between 23°C and 30°C, sometimes dropping to as low as 3°C at night. The average annual temperature is 25°C, while the average annual precipitation in the region ranges from 600 to 750 mm, mostly occurring between November and March.

Fauna: 13% mammals (21 species and 15 families), 63% birds (102 species and 43 families), 24% reptiles and amphibians (39 species and 11 families). 105 species and 15 families of insects in three orders (Hymenoptera, Coleoptera and Lepidoptera). Flora: 396 species listed, including 250 endemic to the island and two local endemics. Endangered species: three bird species, three lemur species, one bat species, one carnivore species, two reptile species.

FACT SHEET

The western part of Madagascar is composed of dry forests that are richly diverse and located in the semi-arid region, an ecoregion ranked among the 200 most important ecological regions in the world, with the highest level of plant endemism in Madagascar. These forests are made up of a spectacular array of endemic and threatened biodiversity, including baobabs (*Adansonia* spp.), succulent plants (*Aloe* spp.), spiny plants (*Alluaudia* spp.) from the endemic family Didiereaceae, unique bird species such as *Newtonia* spp. and *Coua* spp., lemur species including *Propithecus* spp., *Lemur catta*, and *Microcebus* spp., as well as tortoises from the *Astrochelys genus*. The presence of numerous key conservation sites within Madagascar's dry forests—such as the national parks of Ankarafantsika, Bemaraha, Tsimanampetsotsa, Zombitse Vohibasia, Menabe Antimena, and the Bezà Mahafaly Special Reserve, all centers of endemism and even micro-endemism—demonstrates the importance of conserving this unique biodiversity.

The Bezà Mahafaly Special Reserve, for example, is home to a significant portion of the biodiversity found in the island's dry forests. It is composed of deciduous dry forests, gallery forests, and transitional forests. On an international level, it is recognized as a key biodiversity area and an important bird conservation area. The Reserve hosts an exceptional variety of plant and animal life, characterized by numerous widespread woody species typical of riparian forests in the dry bioclimatic region, as well as a high density of both diurnal and nocturnal lemurs. These lemurs, along with other animal groups such as birds **(*Coua* spp.)** and reptiles (*Astrochelys radiata*, *Oplurus fierinensis*), are subjects of long-term monitoring.

Dry forests encompass several types of vegetation and are predominantly composed of plants adapted to both climatic and edaphic aridity. These conditions lead to specific plant adaptations such as leaf deciduousness, the development of swollen vine bases (*Adenia* spp., *Cyphostemma* spp.), sclerophylly, microphylly, pachycauly (*Pachypodium* spp., *Adansonia* spp.), succulence (*Euphorbia* spp., *Aloe* spp., *Kalanchoe* spp.), and pubescence (*Grewia* spp., *Commiphora* spp.).

Dry forests include emblematic trees of the island, such as **baobabs (*Adansonia* spp.)**, highly sought-after species for fine woodworking like rosewoods (*Dalbergia* spp.), as well as rare and protected species such as *Tahina spectabilis* and *Aloe voatsanda*.

In the Bezà Mahafaly Special Reserve, the dry forest is dominated by species adapted to the long dry season, such as ***Alluaudia procera* (Didiereaceae)**, *Cedrelopsis grevei*, and members of the families Burseraceae, Ptaeroxylaceae, Tiliaceae, Euphorbiaceae, Combretaceae, Physenaceae, and Sphaerosepalaceae. The last two families are endemic, and each is represented by a single species. There is also a predominance of smaller tree species, such as *Grewia* spp. and *Rhigozum madagascariensis*.

Covering 45% of the island's surface, the dry forest landscapes of Madagascar provide vital ecosystem services for the various ethnic groups living along the western coastal strip.

They provide a safety net against poverty and act as a buffer against drought and desertification by regulating biogeochemical cycles, particularly water resources, as well as the carbon and nitrogen cycles. They contribute to watershed protection and soil stabilization. For example, at Bezà Mahafaly, the presence of the forest helps limit the alarming and progressive erosion of the banks of the Sakamena River. These forests also represent an important natural asset for both mitigation of and adaptation to the effects of climate change. In fact, despite their lower carbon sequestration capacity compared to humid forests, dry forests, as tropical forests, store large amounts of carbon thanks to their dense biomass, with carbon being stored in trunks and stems, leaves, and soil.

Dry forests contribute directly to ensuring food security, as well as providing timber and non-timber forest products for the communities that depend on them. Many households, particularly in the southwest, rely on small ruminant livestock that graze in the dry forest thickets, as well as on charcoal production. In fact, as is the case for most towns in the western part of Madagascar, the raw materials for charcoal production come from dry forests. **Charcoal and firewood are the primary sources of energy for the local population in the southwest**, both for their daily needs and for subsistence activities such as the production of rock salt in the areas surrounding Bezà Mahafaly.

Other goods provided by dry forests include construction timber, such as species of *Grewia* spp., *Syregada chauvetiae*, and *Commiphora rombe*, as well as non-timber forest products used for their medicinal properties, like *Cedrelopsis grevei* and *Tamarindus indica*. During lean seasons, people also rely on the fruits of *Salvadora angustifolia*, tubers from *Dioscorea* and *Dilochos*, and even insects as food sources. Additionally, dry forests provide materials for handicrafts, such as the leaves of *Hyphaene shatan*.

At the local level, dry forests play an important role in various forms of religion and ritual ceremonies, such as communication with ancestors, protection rites, and the sourcing of ingredients for charms and talismans. They contain impressive landscapes and remarkable biodiversity that attract both tourists and researchers.

The Bezà Mahafaly Reserve holds significant potential, especially for scientific tourism, thanks to its abundant natural wealth and enriching trails. In addition to its ecological value, it also possesses cultural significance due to the presence of various tombs, including that of the former king of the region.

Madagascar's dry forests contribute in various ways to the local, regional, and national economy.

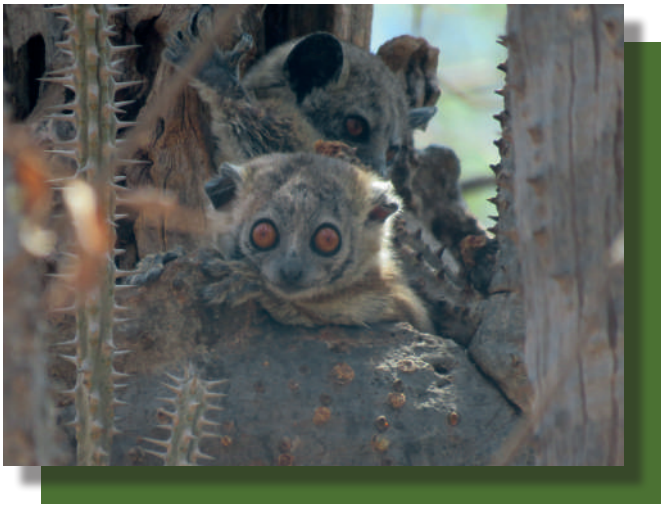
At the local level, forest resources serve as a safety net during lean periods, particularly in response to climatic or economic shocks. They provide additional income for rural populations through agricultural activities and charcoal production, among others. In fact, most households in the southwest of Madagascar, such as in Soalara, depend on resources obtained from charcoal production and goat and cattle herding, with livestock grazing in dry forests, xerophilous thickets, and certain secondary formations like tree-savanna grasslands. In this region, livestock farming plays both a social and economic role at the local level. Depending on the herders' ethnic group, it represents a significant form of capital, especially during lean seasons. For communities living in buffer zones of protected areas, a share of the income generated by the protected areas is allocated to them.

At the regional level, the sale of products derived from woody resources, such as timber and charcoal—mainly from dry and spiny forests—holds a significant place in the regional economy of the western and southwestern parts of the island. This is especially true as **charcoal production has become the most widely adopted income-generating alternative for the population**, being both profitable and requiring no initial investment.

A significant quantity of timber species from dry forests is used for construction work in both villages and towns (not including firewood and wood for charcoal). Moreover, studies on the flow of woody products have revealed the economic aspects involved in this sector—from production to transportation, sale, and eventual use.

At the national level, the commercial value of plant species (*Dalbergia* spp., *Euphorbia primulifolia*, *Aloe deltoideodonta*) and animal species (*Brookesia brygooi*, *Furcifer antimena*, *Agapornis cana*) found in dry forests contributes to the national economy through trade regulated by the CITES convention. Furthermore, although dry forests have a lower carbon stock compared to humid forests, their vast extent across the island offers a significant potential for carbon trading.

The ecosystem services provided by dry forests also support agriculture and livestock farming, which are key economic activities in the rural areas of western Madagascar. Thanks to the unique landscapes of the western and southern ecoregions of the island—home to endemic species such as ***Lepilemur petteri*** and *Propithecus verreauxi* lemurs from Bezà Mahafaly—dry forests contribute to both the local and national economy.



Madagascar's dry forests cover 4.3 million hectares, including 1.7 million hectares of spiny forests. The dense deciduous dry forest, typically found in the north, features a closed, multi-layered canopy with an evergreen or deciduous shrub undergrowth and a generally discontinuous grassy layer. Xerophilous thickets consist of very dense plant formations made up of shrub species of various sizes, interwoven with one another. Grassy and shrubby savannas are open herbaceous formations dominated by grasses, with up to 20% tree cover. All these vegetation types originally existed in a natural state, but unfortunately, pressures of both natural and human origin have led to changes, resulting in degraded, disturbed, and/or fragmented forms.

Climate change and its effects impact not only temperature and precipitation levels but also increase the intensity and frequency of extreme events such as droughts, fires, and cyclones, which negatively affect forest structure, composition, and biomass. Indirectly, **the passage of cyclones** or other natural disasters also promotes human pressure by creating openings in the forest.

The growing human population, leading to a constant increase in the demand for arable land, is likely the greatest factor putting pressure on Madagascar's dry forests. Slash-and-burn agriculture remains a traditional and predominant practice in the western and southern regions, as in all forested areas of Madagascar, and is the primary cause of recent deforestation in these areas, mainly for maize cultivation.

Repeated clearing of forest soils leads to the formation of degraded savannas and to soil depletion. In addition, charcoal production remains a constant threat, alongside other human-induced pressures such as extractive and mining industries, livestock trampling—which further limits natural regeneration—and local hunting practices used to supplement protein sources, such as the hunting of tenrecs and birds.

Due to these pressures, dry forests have the highest deforestation rate in Madagascar. Currently, the western dry forest covers 31,800 km² and has been reduced by nearly 40% since the 1970s. Thickets now cover 15,491 km² and have also declined by around 30% since the 1970s. Degraded spiny forests stretch across 9,255 km², and savannas cover 1,762 km², of which one third has been lost since 1970.

In the Bezà Mahafaly Special Reserve, forest pressures include clearing, illegal logging, roaming livestock, the collection of non-timber forest products, bushfires, and invasive plant species. Bushfires and poaching are especially observed during the lean season, confirming the local communities' dependence on the Bezà Mahafaly forest.

Cultivated field destroyed by Hurricane Freddy in 2023.

Links with the Local Population

Madagascar's dry forests play an important role for the local population. They provide both timber (woody forest products) and non-timber forest products, such as medicinal plants and materials for handicrafts. In turn, the local population contributes to forest management through community-based agreements recognized at all levels (*Dina*), along with *fady* (or taboos), which serve as one of the key conservation mechanisms, especially in areas that are not formally managed.

Local associations also contribute to the development of a management plan, including the zoning of forests for use and the methods of exploitation.

At Bezà Mahafaly, local communities recognize the *Dinan'ny Ala Tahiry*, an agreement that governs forest use among the communities, the management entities (MNP and ESSA), and the decentralized local authorities. This agreement outlines the sanctions for offenses committed against forest resources, which are essential for the local population living around the Reserve.

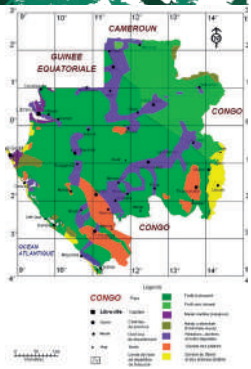
Madagascar's dry forests are home to numerous remarkable and valuable species, characteristic of semi-arid zones, with a very high level of endemism. They provide essential ecosystem services, particularly for the local populations living nearby. These forests support the local economy, especially during lean seasons, the regional economy through the supply of timber and charcoal, and the national economy due to their strong tourism potential.

However, they are undergoing alarming losses due to ongoing pressures, especially from charcoal production and slash-and-burn agriculture. Nevertheless, the scarcity and/or insecurity of access to these resources must be considered in relation to the need to pass on this natural capital to future generations.

In this perspective, gaps need to be addressed, and opportunities seized, such as the regulation of the charcoal sector. Effective implementation of measures must be accompanied by sustainable forest exploitation and the promotion of reforestation, especially in a context where natural regeneration is very difficult. In such cases, active reforestation is recommended, using techniques adapted to climatic conditions to improve survival rates.

Strengthening management and conservation mechanisms through local agreements such as *dina* and *fady* would also help preserve these vulnerable ecosystems in the western and southwestern parts of the island.

Tropical Rainforest
The Ogooué Basin



Étienne Massard K. Makaga
Juste-L. Boussienguet

Introduction

Located along the Equator, Gabon is a Central African country bordered to the west by the Atlantic Ocean, to the north by Equatorial Guinea and Cameroon, and to the east and south by the Republic of Congo.

Often associated with the Congo Basin—the second largest block of tropical rainforest after the Amazon—due to the vast continuous forest cover that stretches across Central Africa, Gabon's rainforests represent 10% of this regional forest mass and are structured around an autonomous hydrographic network: the Ogooué Basin, which spans over 80% of the territory, encompassing a remarkable diversity of environments—mangroves, swamp forests, and dryland forests.

Gabon's immense greenery stands in sharp contrast to its low population density—around eight inhabitants per km²—which has resulted in exceptional forest coverage, unmatched by most mainland countries. This dense and continuous forest cover is not merely a national asset: it is a vital global ecological heritage in the fight against climate change and biodiversity loss. Gabonese forests play a major role as carbon sinks, absorbing significantly more carbon dioxide than they emit. In a world where reducing greenhouse gases is no longer optional but a pressing global concern, Gabon's model offers a concrete response to current and

future climate challenges. Beyond their climate role, these forests serve as a sanctuary for some of the richest and best-preserved biodiversity in Africa, home to thousands of plant and animal species—some endemic, others emblematic such as the gorilla and forest elephant. This biodiversity is not only a biological treasure to protect, but also a source of wonder and a natural laboratory for scientific research.

The relationship between local populations and Gabon's dense tropical forest goes far beyond mere resource exploitation. The forest is not just a habitat or workspace—it is a natural pharmacy, a rich marketplace, and a living library of ancestral knowledge. This deep interdependence between people and nature underscores the need for sustainable management that respects both the needs of local populations and global ecological imperatives.

Over the past three decades, Gabon has demonstrated consistent and innovative political leadership in forest management and environmental conservation, through the implementation of rigorous, proactive, and forward-looking forest governance policies at both regional and national levels.

- At the regional level, even before the REDD+ mechanism was launched at the Bali COP in 2007, Central African countries agreed in February 2000 to establish the COMIFAC (Central African Forests Commission), aimed at promoting a common and robust approach to sustainable forest management tailored to the region's economic, ecological, and social realities. This unique regional framework, built upon pioneering legislation, has laid the foundation for coordinated forest preservation, driven by the countries themselves. It partly explains the remarkable integrity of Central Africa's forests today.
- At the national level, beyond strict enforcement of laws against illegal logging and poaching, the historic creation of a network of 13 national parks in 2002—covering 11% of the country—has helped maintain an exceptionally low deforestation rate compared to other Central African countries.

Nevertheless, despite these outstanding efforts, threats to the future of Central Africa's forests remain very real. Climate change, illegal resource exploitation, the expansion of mining activities, and growing human-wildlife conflicts—especially involving elephants—are all weakening ecological balances. Added to this is a troubling trend: the financialization of nature. Since the adoption of the REDD+ mechanism, which fosters the illusion that forests can be reduced to mere "green

assets", financing pledges from developed countries have multiplied—yet often fail to materialize. This narrative, focused on "carbon values" and more recently on "biodiversity value", tends to obscure the primary function of forests: as living spaces for communities who have inhabited and safeguarded them for generations.

In response to these challenges, Gabon is actively exploring pathways toward an innovative and sustainable forest economy. These include responsible forest management with greater emphasis on certification and timber traceability, the development of a wood-processing industry through the ban on log exports, and the enhancement of ecosystem services. Gabon's "forest laboratory" seeks to demonstrate how economic sovereignty, sustainable development, and ecological preservation can be successfully reconciled.

FACT SHEET

Forests in Gabon cover 88.5% of the country's 266,667 km² territory, representing 9% of Africa's forests despite the country accounting for less than 1% of the continent's land area. A dense and complex hydrographic network feeds two major rivers, making Gabon a country of water as well. The first of these, the Ogooué—Africa's third largest river by discharge—along with its two main tributaries, the Ivindo and the Ngounié, drains 72% of the territory. The Nyanga basin covers an additional 8.5%.

The climate is equatorial with maritime influence, characterized by annual rainfall between 1,500 and 2,500 mm, and an average annual temperature of 25°C. A 150 km wide coastal basin borders mountainous terrain, with maximum altitudes around 1,020 m both north and south of the Ogooué: the Cristal Mountains in the northwest, the Mayombe Range in the southwest, and the Chaillu Massif in the center. The northeastern plateaus are interrupted by the Minkébé Mountains (938 m), and the east-central region by the Bélinga Range (1,020 m). In the southeast lie the Batéké Plateaus, peaking at 850 m.

Gabon's population is estimated at 2.2 million inhabitants, with over 80% living in urban centres. Rural population density is very low—around 2 to 3 inhabitants per km²—and in many forest areas it is virtually non-existent.

Gabon's forest is a biodiversity hotspot, home to nearly 10,000 plant species, about 20% of which are endemic. It is also a sanctuary for over 600 bird species, nearly 200 species of mammals, and more than 70 reptile species. Among its emblematic fauna are the western lowland gorilla and the world's largest population of forest elephants (estimated at 95,000 individuals).

A generous natural environment combined with virtuous practices makes Gabon's forest one of the last earthly paradises: a majestic forest dominated by towering old-growth trees, where the only discernible breaks are rivers with tumultuous waters and rapids.

Sustainably Managed Forest Areas

Gabon's forest ecosystems constitute an exceptional natural heritage that, despite the growing presence of human activities, can still be considered largely intact. While forestry operations—including reserves and concessions—cover 17 million hectares, the deforestation rate remains extremely low (less than 0.04% per year), thanks to rigorous forest management policies that are increasingly being implemented by operators. From 2010 to 2022, forest production nearly doubled to reach 4.1 million hectares, while FSC certification became mandatory: 40% of FSC-certified forest areas in Central Africa are in Gabon.

Virtually "Untouched" Forest Zones

More than 30% of Gabon's forest heritage—approximately eight million hectares—mostly located east of the Okoumé boundary, along a line stretching from Oyem to Franceville, remain minimally or entirely unaffected by human activities. This area of primary forest, sparsely populated and barely touched by road or rail networks, represents one of the last remaining reserves of tropical rainforest in the world.

Fully Protected Forest Areas

Alongside human activities mindful of forest preservation, Gabon committed early to conservation through the establishment of protected areas across the country. These zones preserve various types of forest ecosystems with high biodiversity value, keeping them intact and offering Gabon significant potential for ecotourism. Though still in its early stages, this activity promises to be a future asset, due to its appeal rooted in "virgin" nature—still in its "primitive" state—and the diversity of sites (unique landscapes, exceptional flora and fauna, waterways, etc.).

In 2006, Gabon's flora included 4,797 angiosperm taxa, distributed across 4,532 species, 1,237 genera, and 157 families. These figures do not reflect the country's actual flora, as new taxa are added each year. Researchers (Sosef *et al.*, 2006) estimate that 7,500 species would be a more accurate number.

Among these, three species stand out as icons of Gabonese identity and serve as true ecological and cultural ambassadors of the country on an international scale, much like the African Grey Parrot (*Psittacus erithacus*).

Okoumé (*Aucoumea klaineana*): As a national symbol representing the richness and biodiversity of Gabon, this tree is emblematic of the Gabonese forest. It plays a central role in the forest canopy and contributes significantly to carbon storage. The "modern" exploitation of this species, harvested mainly for plywood production, dates to 1883 when Pierre Savorgnan de Brazza discovered Gabon and brought the first samples to Europe.

Iboga (*Tabernanthe iboga*): This understory plant contributes to biodiversity and ecological balance in the forest. Its primary active compound, ibogaine, makes it a valuable resource for spiritual tourism (*Bwiti* tradition) and for the therapeutic alkaloid trade.

Moabi (*Baillonella toxisperma*): This large, emblematic tree of Gabon's dense forest is vital to local fauna (elephants, gorillas, primates, etc.) thanks to its highly nutritious fruits. Its wood holds significant commercial value, prized in fine woodworking. Local populations extract vegetable oil—Moabi butter—from its seeds, used for culinary, medicinal, and cosmetic purposes.

Gabon's tropical rainforest is first and foremost a treasure for the Gabonese people: it sustains their daily lives and nourishes their traditions.

Covering nearly nine-tenths of the national territory, this forest provides essential services to local communities: a significant portion of their food (fruits, game), construction materials (wood), traditional medicine (bark), and sacred spaces for cultural and spiritual practices. Hunting provides vital protein, especially for rural populations. Initiatives such as the "sustainable" hunters' citizen network in Kessipoughou combine public health and conservation, raising awareness about zoonoses (rabies, Ebola, etc.) and promoting more responsible practices. Within this framework of forest use, humans themselves are considered part of the natural heritage, and to preserve its sustainability, local territories are managed to ensure the regeneration of their living environments. These services represent a living economy—feeding families, preserving ancestral knowledge, and strengthening social bonds. Gabonese ethnologist André Raponda-Walker, in describing the traditional *Mwiri* cult, referred to it as "a kind of league for nature protection and the upkeep of public spaces, coupled with a secret police tasked with identifying and punishing those who abuse forest resources to the point of scarcity, and establishing natural reserves where forest products would henceforth be off-limits under penalty of sanction."

On a global scale, Gabon's forests—particularly those of the Ogooué Basin—and the forests of the Congo Basin act as one of the Earth's climate pillars. They are major carbon sinks, playing a crucial role in mitigating climate change by storing more than 25% of the world's forest carbon.

Furthermore, Gabon's forests help regulate the water cycle: they absorb rainfall, slow down floods, ensure steady water supply to rivers, and release vapor that promotes regional precipitation. This hydrological role is vital for the balance of watersheds and water quality, impacting agriculture, fishing, and hydroelectric power far beyond Gabon's borders.

The exceptional biodiversity of this ecosystem is equally crucial. It holds a significant share of global biological diversity, including endemic species such as great apes, forest elephants, and pangolins. This biological wealth supports essential services like pollination, food supply chains, soil regeneration, and serves as an irreplaceable genetic reservoir.

Aerial view of Ivindo National Park © Kath Jafferey.

The forest has always played a central role in Gabon's economy. It was the country's main wealth until the oil boom of the 1970s. Today, the timber sector accounts for only 4% of GDP but remains the country's largest private employer, with over 12,500 officially declared direct jobs in 2022—a nearly 50% increase since 2010. This number could reach 20,000 people or more when including indirect jobs (transportation, informal processing, etc.).

Non-timber forest products also hold significant economic importance due to their widespread use by local populations. Although their value chains remain largely informal—despite numerous attempts to structure the sector—and are often absent from official statistics and policies, data collected by non-governmental organizations confirm the increasing economic value of non-timber forest products. An estimated 27 tons of medicinal plant-based products worth $1.5 million are sold annually in major Gabonese markets. This study highlighted the commercial importance of medicinal plants for healthcare and rituals.

Like the timber sector, tourism also contributes around 4% to the GDP, though it generates three to four times fewer jobs. While currently underdeveloped, it has strong potential—particularly ecotourism within national parks and other protected areas. These protected zones offer numerous assets: stunning landscapes, iconic wildlife species, exceptionally rich flora, and picturesque and historical sites. These attributes have led the Gabonese government to set an ambitious target: within a decade, increase the tourism sector's contribution to 10% of GDP, aiming for over 600,000 tourists annually, supported by infrastructure development (roads and lodging capacity) and governance adapted to these challenges.

New sources of revenue also seem to be emerging through the "financialization of the forest." Often cited as a model of sustainable forest management in Africa, Gabon was the first country on the continent to receive international payment for emission reductions from its forests under the Central African Forest Initiative (CAFI). An agreement with Norway set a floor price of $5 to $10 per ton of CO_2, and Gabon has already received an initial payment of $17 million for its deforestation reduction results during 2016–2017. Furthermore, private groups are now positioning themselves to acquire and use carbon credits through the purchase of forestry companies.

Given its vast expanse and dense forest cover, the Ogooué Basin Forest is, overall, in good health, despite industrial logging operations that began in the 1880s and have continued to expand. Initially confined to the coastal basin waterways—due to log transport constraints—logging has since spread throughout the entire country. Allocated forest areas increased from nearly 2 million hectares in 1960 to 10 million hectares in 1999, and reached 17 million hectares in 2022, representing 70–75% of the forest massif. Over 13 million hectares are under managed forest concessions, and 2.5 million hectares are FSC-certified. Logging remains highly selective, with only 1.5 to 3 trees felled per hectare on average.

Until the 1980s–1990s, the main species harvested were Okoumé and Ozigo (*Dacryodes buettneri*). Today, loggers extract a broader range—nearly a hundred species—while maintaining a relatively constant number of trees harvested per hectare. The low deforestation rate observed in Gabon reflects a cautious and sustainable forest management approach. This has allowed Gabonese forests to continue sheltering exceptional plant and animal biodiversity, from the tiniest orchids to the emblematic forest elephant.

Successive governments have maintained this ambitious environmental policy, reflected in the creation of national parks in 2002 and restrictive measures on log exports introduced in 2009.

However, despite these efforts, Gabon's forests remain vulnerable to upcoming economic, social, and cultural changes—including the potential erosion of traditional, environmentally respectful practices. These risks can only be addressed through appropriate public policies.

Added to these anthropogenic pressures is the looming threat of climate change. Even well-preserved, Gabon's forests are susceptible to extreme weather events, which can disrupt forest regeneration and hydrological cycles. These forests evolved under relatively stable climate conditions, and even moderate but rapid temperature increases may destabilize their ecological and physiological balance. Since the forest heavily depends on abundant and regular rainfall to maintain its dense canopy, prolonged

anomalies could reduce water availability, weaken ecosystems, and increase fire vulnerability.

As for humidity, Gabon's forests recycle a significant amount of water vapor through tree transpiration. A drop in atmospheric moisture would reduce this water recycling, increasing the likelihood of severe droughts, tree dieback, and forest fires.

All these emerging pressures—human activity combined with a changing climate—could hasten the crossing of irreversible ecological thresholds.

In traditional Gabonese societies, environmental practices are deeply rooted in a constant concern for nature. This environmental vigilance, woven into daily life, allows people to live in perfect harmony with this bountiful forest. For the communities inhabiting these vast forested areas, the forest has become both a mysterious and supportive ally. It is not only the nurturing mother that provides fertile land for cultivation; it also restores soil fertility essential for input-free agriculture and offers the fruits of gathering, hunting, and fishing that ensure human sustenance.

It is also the forest that heals, provides the tools necessary for productive activities, and supplies the materials needed to build shelters.

Nature—this fascinating forest, source of all life—has become the subject of a knowledge passed down through generations, constantly renewed and deepened. It is a partner to be cautious of at times, but above all, one with whom to always ally.

To sustainably secure the future of the forests of the Ogooué Basin, it is essential to strengthen the many achievements of policies that have enabled Gabon to enhance its regional and global leadership—leadership capable of building collective acceptance around what may sometimes seem complex. Revitalizing COMIFAC, which successfully structured effective regional public policies for the sustainable management of our forests, is a top priority to better support the coordinated management of this interdependent and indivisible forest block.

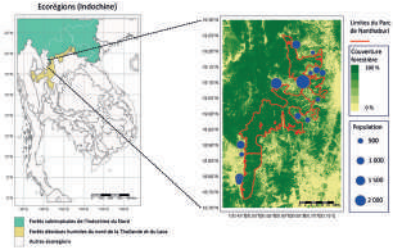
Diversifying our forest economy will help protect the forest if we significantly increase revenues from other opportunities it offers—especially responsible ecotourism in and around national parks, value chains for non-timber forest products, and sustainable agroforestry.

However, several challenges still need to be addressed. It is necessary to step up the fight against illegal logging, with a more robust and credible traceability system, and to more effectively combat poaching.

Successfully managing human-elephant conflict is essential so that the local populations affected by these tragedies do not turn away from conservation and forest protection efforts.

Finally, it is important to guard against the new risk of "the reckless financialization" of forests. If the expected benefits from the valorisation of biodiversity and forest carbon fail to materialize, the resulting disillusionment could discourage local community engagement in forest conservation—thus undermining the state's efforts in this area.

Seasonal Tropical Forest
Nanthaburi National Park



Dr Serge Morand
M. Phurin Makaew
M. Surasak Kiatphattharaporn

Introduction

Tropical and subtropical deciduous wet forests, or tropical seasonal forests, constitute a biome of the intertropical zones characterized by a tree-dominated vegetation formation with deciduous leaves, evolving in a monsoon climate. This climate is marked by high annual rainfall during the hot summer wet season and a cooler dry winter season. These seasonal wet deciduous forests, monsoon or semi-persistent, are rich in tree species diversity, with a particularly high rate of endemic species. The trees of the upper layer lose their leaves, while the trees of the lower layers are predominantly evergreen and more or less sclerophyllous. The tropical and subtropical deciduous wet forests of Asia, Africa, and the Americas make up a vast ecosystem that houses about 70% of known plant species. This hyper diversity is explained by the Janzen-Connell hypothesis, which postulates that specific natural enemies, such as seed predators, herbivores, and pathogens, help maintain the diversity of plant communities. Thus, between 80 and 200 tree species per hectare are counted in the forests of this biome.

The Nanthaburi National Park, located in the Nan Province in northern Thailand, spans across two ecoregions of Southeast Asia: The Northern Indochina subtropical forests ecoregion and the Northern Thailand–Laos moist deciduous forests ecoregion.

The subtropical forests of Northern Indochina occupy the highlands of the northern Indochinese peninsula. This ecoregion, covering an area of 677,350 km², includes northeastern Vietnam, the northern part of the Annamite Mountain range, northern Laos, the extreme north of Thailand, southeastern Yunnan, and the Shan State in eastern Myanmar. These forests combine subtropical plants common to the Himalayas and southern China, as well as species from tropical lowland forests. Mature forests form a canopy that can reach 30 meters in height. Rich in bird and mammal species, this ecoregion is particularly vulnerable, with only 7% of its area protected. The subtropical forests of Northern Indochina form a transition zone between the subtropical and temperate forests of China and the tropical forests of Indochina.

The ecoregion of the moist deciduous forests of northern Thailand and Laos spans 29,526 km² and is located between the upper course of the Nan River in northern Thailand and the Mekong River in northern Laos. This ecoregion has the highest proportion of forest cover in Thailand, with many forests dominated by teak (*Tectona grandis*), Mai daeng (*Xylia xylocarpa*), and Burmese Padouk (*Pterocarpus macrocarpus*). The river valleys have been subject to human activities related to agriculture, large dams, and commercial plantations (teak, rubber trees, bamboo). Despite this significant environmental degradation, the ecoregion still has one of the highest rates of forest cover in Southeast Asia. This ecoregion marks a transition zone between the mountain tropical forests, the subtropical forests of the north, and the dry forests of central Indochina.

In 1995, the Department of Forests of Nan Province proposed the establishment of Nanthaburi National Park to protect the Nam Yao (Pha Nam Yao) and Nam Sod (Pha Nam Sod) national forests, their flora, and fauna. Nanthaburi Park was created in 2000. It is the unique representative of the two ecoregions: the subtropical forests of Northern Indochina and the moist deciduous forests of northern Thailand and Laos. The park covers an area of 420 km² and consists of a forest complex ranging from an altitude of 330 m to 1,674 m, with Mount Doi Wao. The temperatures and rainfall patterns follow a seasonal rhythm, marked by the monsoon (hot and humid season, cool dry season, hot dry season). The park includes tree species typical of dry evergreen forests such as *Dipterocarpus turbinatus*, *Hopea ferrea*, *Hopea odorata*, *Toona ciliata*, *Mangifera pentandra*, *Dalbergia assamica*, and *Nephelium hypoleucum*; mixed hardwood forest trees like *Tectona grandis*, *Pterocarpus*

macrocarpus, *Afzelia xylocarpa*, *Gmelina arborea*, *Terminalia bellerica*, and *Anogeissus acuminata*; deciduous dipterocarp trees such as *Shorea obtusa*, *Shorea siamensis*, *Dipterocarpus obtusifolius*, and *Dipterocarpus tuberculatus*; and evergreen hill forest trees like *Schima wallichii*, *Betula alnoides*, *Podocarpus neriifolius*, and *Aquilaria crassna*. This area hosts a rich fauna with insect, amphibian, fish, mammal, and bird species. Karst forests are also present, hosting a specific fauna of arthropods, rodents, and bats unique to these habitats.

Villages live on the outskirts of Nanthaburi Park, and some even inside it. These communities own community forests, some of which are relics of past deforestation or recently reforested areas.

FACT SHEET

Located between 18°41'42'' and 19°16'40'' North latitude and 100°25'04'' and 100°45'36'' East longitude, Nanthaburi National Park (Thailand, Nan Province) covers an area of 420 km². Approximately 10,000 people live in the 15 villages situated within 2 km of the park's boundary. Various ethnolinguistic groups coexist on the outskirts of the park, with Thai and H'mong speakers. The Mlabri (or Mrabri, also called Phi Tong Luang) are a mountain ethnic group at risk of linguistic and cultural extinction. They were once nomadic hunter-gatherer groups. Formerly present in the forests of Nanthaburi Park, only a few dozen Mlabri remain today along the Laos border to the east of Nan Province.

The park, with an elevation ranging from 330 to 1,674 meters, is supplied by numerous tributaries (Huai Muang, Huai Khun, and Huai Si Phan) and the Nan River, which runs along the eastern side of the park. The average temperatures range from 15°C (cold dry season) to 36°C (hot dry season), and rainfall averages 10 mm/month during the dry season, increasing to 350 mm/month during the wet season.

The forests of Northern Thailand are home to at least 900 species of trees out of a total of 2,558 tree species recorded in Thailand. The park potentially hosts 130 mammal species and 300 bird species.

Thailand is said to have lost 43% of its forests between 1973 and 2009, according to a WWF report. These significant deforestation events led both national and local authorities to implement forest conservation measures. The goals of these policies are to combat soil erosion, landslides, and flooding through the protection of forests and reforestation of watersheds. These policies also encouraged local communities to conserve their forests, while involving them in reforestation and forest fire prevention efforts.

Buddhist monks also played a role in raising awareness among local populations about deforestation issues. **Trees have been designated as "monk trees"**: draped in orange robes, the color of Buddhist monks, they become sacred and therefore untouchable.

The forest of Nanthaburi National Park has received little in the way of in-depth scientific work compared to Thailand's major national parks. However, due to its unique position at the interface of two ecoregions, along with its significant floral and faunal richness, this protected area deserves more attention to ensure the conservation of this forest ecosystem and the sustainable use of its resources for the benefit of the surrounding communities.

The recent creation of the park in 2000 makes it an important observatory for the relationship between humans and nature.

A number of community forests border or are integrated within the park boundaries. These community forests serve multiple roles, providing goods and services for the communities, but also contributing to conservation through their buffer effects with the park's forests and by maintaining ecological continuities.

Our work on the links between biodiversity and community health, started in 2008, is integrated into a socio-ecological observatory of health and biodiversity in Saen Thong (one of the park's adjacent sub-districts). The new research we are conducting, in collaboration with the Nanthaburi Park, the Forestry Department, health dispensaries, and local communities, aims to demonstrate how reforestation, and particularly community reforestation, contributes to biodiversity and the health of humans, animals, plants, and the ecosystem in general.

Teak (*Tectona grandis*) is a tropical hardwood tree species from the Lamiaceae family. Teak is native to South Asia (Laos, Myanmar, Thailand, Malaysia) and Southeast Asia (Bangladesh, India, Sri Lanka). Molecular studies show the existence of two genetic origin centers for teak: one in India and the other in Myanmar and Laos.

Mai daeng (*Xylia xylocarpa*) is a tree from the Fabaceae family. Its seeds are edible. In Thailand, its leaves are used to treat elephant wounds. This species, naturally adapted to the conditions of Thailand, is used in reforestation efforts in certain bare or degraded areas.

The Padauk of Myanmar (*Pterocarpus macrocarpus*) is a tree from the Fabaceae family, native to the seasonal tropical forests of Southeast Asia. The wood is durable and resistant to termites; it is used for furniture and construction wood. Although it is not a true rosewood, it is sometimes sold as such.

The resin tree (Yaang Naa) (*Dipterocarpus alatus*) is a tree from the Dipterocarpaceae family, found in tropical forests, whether evergreen or mixed. This tree is considered vulnerable due to its valuable wood used for various purposes. Its resin, or wood oil, is used for varnishes, paints, lighting, sealing boats, and bamboo products. The resin has also been used in traditional medicine. Mixed with beeswax, it is used in dressing ulcerated wounds. Traditional medicine also benefits from the bark of young trees, which is used for rheumatism, liver diseases, and to stimulate the appetite of cattle.

Also worth mentioning is the diversity of fig species, whose fruits are consumed by many animals (such as Ficus variegata), as well as palm species, which are important resources for local communities.

Ecosystem Services

According to the Millennium Ecosystem Assessment (2005), ecosystem services, or contributions of nature, are classified into four categories: cultural services, which correspond to the benefits inspired by nature; provisioning services, which include goods produced by ecosystems; regulating services, which contribute to the regulation of environmental conditions; and supporting services, which encompass ecosystem functions that enable the other three ecosystem services. The forests of Nanthaburi Park and the surrounding community forests offer a diverse range of ecosystem services.

Cultural services are deeply rooted in the culture of local populations. Forests are considered sacred spaces closely linked to belief in spirits. Forest spirits are known as "Phi" in Thailand. The spirits are believed to reside in the natural world, in rivers, and in trees. They can be either benevolent or dangerous, so it is important to respect them and handle their natural habitats with care. Ceremonies with offerings placed in spirit houses are regularly held on the forest outskirts. Between August and October, villagers from a community near the park pay homage to the "Phi Khun Nam" (forest spirits). Pigs and chickens are sacrificed as offerings to ask the forest spirits to protect all the villagers, the village, agricultural crops, forests, and water resources.

A more recent cultural service focused on tourism has developed with hiking trails in Nanthaburi Park. Villages on the outskirts of the park take advantage of river outlets to set up observation stations for protected fish species, with the sale of fish feed pellets.

Provisioning services primarily involve the supply of wood, exclusively from community-managed forests. The park's buffer zones and community forests allow for the collection of edible and medicinal plants, mushrooms, and fruits. Hunting is tolerated as long as it is limited to local consumption and does not involve protected animal species, as well as livestock grazing, which is restricted to a peripheral buffer zone.

Regulating services are important. The forests of the park provide protection for the soil against erosion and improve the availability of water resources, while preventing landslides and floods. Reforestation programs initiated in the late 1990s aimed primarily at preserving the quality and consistency of water, both for human consumption and for agricultural crops.

The quality of these services depends on the ecosystem functions provided by the forest. It contributes to soil health, which supports the entire microbial, fungal, plant, and animal biodiversity. However, scientific studies are still limited in terms of characterizing these functions and their significance for the health of this ecosystem and all its inhabitants, including humans, who depend on it.

Benefits of the forest's natural resources

The village communities benefit from the living resources of the forest, primarily plants for their various uses and economic value.

The *Livistona speciosa* palm is a species that can grow from 10 to 25 meters. This palm is naturally found in the forests of the Nanthaburi Park and in some of the surrounding community forests. Its fruit, known as **mak kho**, is 2 to 3 cm in size and turns blue-black when ripe; it is edible. The fruits are sold for 30 baht per kilo (just under €1). Several preparation methods are possible: in the form of salted or sweetened paste to season sauces, dried in the sun, or pickled after blanching. The leaves and rachises of this palm are used to make mats and baskets.

Other palms, like *Arenga westerhoutii*, also provide benefits for the communities. **The seeds of *A. westerhoutii*, called mak tao**, are used to make palm sugar, which is particularly appreciated in Thailand. The seeds are extracted by splitting the fruits, boiling them in syrup, and then drying them. The fruits are also prepared for sale (20 baht per kilo) and for the production of sweets. Yields can reach 200 to 300 kg of fruit per tree, and 10 kg of fruit provides 3 to 3.5 kg of seeds. The young shoots or leaf buds are edible. Like other palms, the leaves are used for roofing and weaving. The wood is also used to make small utensils.

The seeds of these palms are dispersed by wild animals that eat the fruits, particularly civets. By maintaining these wild palms, the local communities contribute to preserving faunal diversity.

The collection of mushrooms, bamboo roots, and insects (such as bamboo worms) are also activities of substance and economic benefit for the local communities, with preparations and sales to both locals and tourists.

Tourism

Tourism development is still weak in the Nanthaburi Park and its surroundings. The park is relatively new, and it faces tough competition from larger national parks with better infrastructure. However, some village communities are turning to eco-tourism, offering guided tours of natural attractions (waterfalls, caves) in their community forests or on the edges of the park, and selling forest products (mushrooms, fruits), fruits from their orchards (lychee, rambutan, durian, longan), agroforestry products (coffee), or from their increasingly organic farms (rice, vegetables, and aromatic plants).

Biological invasions pose a major risk to the conservation of endemic species and the health of ecosystems. The high species diversity in the forests of Nanthaburi Park dilutes the risks of invasive species, both predatory or pathogenic to plants and wildlife. Significant efforts are being made to control biological invasions, such as the black chin tilapia (*Sarotherodon melanotheron*), which was first imported from Ghana by a private company for aquaculture experiments in 2010, and whose spread in the rivers of Thailand has proven to be particularly critical.

The forests of the park primarily face the threat of forest fires. Preventing and combating forest fires are essential activities, particularly during the dry and hot season. Traditionally, fire was used to clear deforested forest plots before they were cultivated. This slash-and-burn practice in shifting agriculture has increasingly been regulated and even banned in national forests. Fire is also used for hunting activities by mobilizing game, or for gathering activities, especially mushrooms. Fire is also employed to maintain pastures on the forest edges for cattle that are herded there during the rainy season.

Nanthaburi Park, the Department of Forestry, watershed management units, and also foundations, provide financial support to village communities for the maintenance of firebreaks or for surveillance patrols. The creation and maintenance of firebreaks are important moments for some village communities, which take advantage of these events to gather and educate younger generations on forest care and conservation. A study conducted in another province in northern Thailand has shown that forest fires are smaller and better managed when villages are located nearby.

A second issue that the park faces concerns environmental crimes, such as the hunting of protected species, the collection of protected plants, or the cutting of valuable trees, such as rosewood. The Department of National Parks, Wildlife and Plant Conservation, under which Nanthaburi Park falls, has established "smart patrols". These patrols aim to record all incidents related to environmental crime and also to report wildlife deaths. Tissues are collected according to a strict protocol and sent to the central

veterinary services of the Department of National Parks for thorough microbiological examination. National parks actively participate in the health monitoring of wildlife and potential zoonotic risks.

The ongoing climate disruption exacerbates the health of the forests in the park. Drought events are becoming more frequent and prolonged, worsened by anomalies in the climate variability of ENSO (El Niño/La Niña), which increases periods of water stress and the occurrence of forest fires. The risks to the health of the forest ecosystem increase the dangers to plant health, wildlife health, and the health and well-being of the surrounding communities.

Links with the Local Population

The creation of the Nanthaburi National Park is accompanied by support for the surrounding community forests. A survey of about fifteen villages shows the existence of at least two community forests per village. Not all of these are formally registered with the Department of Forestry. An essential aspect concerns the rules governing the usage rights to the resources of community forests, with a separation between use and conservation. Conservation areas do not allow logging or hunting of wild animals but do permit access to mushrooms and bamboo shoots. Offenders are fined, with the proceeds going to the community. The usage zones specify the rules for access and use, particularly for wood, which is strictly reserved for community members. It is prohibited to sell certain resources outside the village. Community forests are considered "common goods" in the sense defined by economist Elinor Ostrom.

The Future of Forests? The Future of Humans!

Didier Moreau

General Delegate of the Balanitès Institute

Is the "Dialogue of Forests" possible? It is an approach that does not come naturally, which, a priori, has no obvious reason to exist, except by going beyond usual visions, except by creating the conditions for an international initiative in favor of the world's forests. This idea is the result and conjunction of several movements intersecting within the Balanites Institute. Created in 2021, it has set itself the mission of putting knowledge back at the heart of the pan-African Great Green Wall project, launched by the OAU in 2006, which was from the start placed under the aegis of scientific knowledge and the involvement of local communities.

Members of the Balanites Institute thus lead, under the direction of Gilles Boëtsch, a project to compile knowledge on this route of more than 7,100 kilometres, twenty years later. It is part of a desire to place the triptych "education, science & culture" at the heart of a global project of dissemination and appropriation of knowledge and wisdom.

"The whole is greater than the sum of its parts," said the Greek philosopher Aristotle with insight. This is true for the forest, apparently just the sum and addition of trees growing in the same biotope, creating a complex, fragile ecosystem that we do not fully understand. But it is more than that. It is also true for the concept of "Forests" in the planetary, ancestral sense. None of them are alike, yet they face the same challenges regarding threats to their integrity by human activities. These have always existed but previously served to meet "local" needs, respecting cycles that allowed ecosystems to regenerate. The globalization of needs and exchanges has amplified tensions and

subjected these natural entities to new constraints imposed on local populations, very—too—often against their will.

As we see, bringing together under one movement and one issue all forests mean collecting, connecting data and information, knowledge, to undertake the unthinkable: to advocate for "Her." This process must be considered through testimonies that reveal and denounce ecocidal practices, but it cannot stop there. It must also aggregate the multitude of local attempts which represent hopes for the future, provided they organize globally.

At a time when multilateral cooperation is being deliberately undermined, we must take the paths described by Edgar Morin in his emblematic *Earth Homeland*: highlighting local particularities to better share a common spirit in a community of destiny. The strength of an alliance between the potential of science and the relevance of individual and collective mobilizations has been proven many times in the past. This capacity finds its relevance in the recognition of complex natural processes described by science, its legitimacy in respect for local lives.

Giving voice to the forests follows the idea of Bruno Latour, launched in 2015 at the Paris COP. He calls to place entities conceived as natural—the Amazon, the Ocean, seeds, cereals—in the realm of politics. This vision led him to propose a "Parliament of Things," where representatives of these "voiceless" entities would negotiate with defenders of lobbies, political institutions, and social groups. This is a "reasonable" utopia, pragmatic, deserving reflection despite all its contradictions.

Our past decades have been built on imaginations and habits that are now being drastically questioned. The institutions of multilateralism are becoming obsolete and must be reinvented, but they carry within themselves the conditions for a salutary transcendence provided they consider the inaudible, forgotten, and silenced voices. Those of "geo-social" groups confined in their current enclaves, those of natural entities, and also those of the young generation. It is this last one that will carry out—or not—the coming metamorphosis.

Since 2015, a movement has shown the way: the Global Youth Climate Pact. Inspired by Edgar Morin's "Seven knowledge for the education of the future," it is supported on five continents by sociologist Alfredo Peña Véga. More than a lesson, this network of several thousand high school youths proves the soundness of the approach. It has undertaken to build, through dialogue with the scientific community, from a planetary

perspective, a common method and vocabulary allowing for a new narrative that forgets nothing of its past and carries the potential for peaceful transformation.

Preparing the future means relying on the enlightened, conscious, documented mobilization of this young generation. An imperative still seeking its paths and means, its institutions and its heralds, its heroes as well. The Balanites Institute wished to take on this daunting but major challenge to go further in the Great Green Wall reconquest project, involving local communities while mobilizing knowledge, both inspiring each other. Only education, training, and respect for local cultures—including their contradictions—will guarantee the conditions for success.

"Que o coração não destrói

Respeitar a floresta

Que o coração não destrói

Replantar a floresta

Que o coração não destrói"

Gilberto Gil, "A floresta".

Contributors

Cédric Béraud
Association Francis Hallé pour la forêt primaire
cedric.beraud@foretprimaire-francishalle.org

Gilles Boëtsch
Président de l'Institut Balanitès
boetschgilles@gmail.com

Juste-L. Boussienguet
Président du CA de l'Agence d'Exécution des Activités
de la Filière Forêt-Bois, Gabon,
Coordonnateur du Plan national d'Action pour l'Environnement
justeboussienguet5@gmail.com

Charles Dereix
Président de l'association Forêt Méditerranéenne
contact@foret-mediterraneenne.org

Aly Diallo
Maître de conférences, Laboratoire d'Agroforesterie et d'Écologie,
Département d'Agroforesterie,
université Assane Seck de Ziguinchor, Sénégal
aly.diallo@univ-zig.sn

Surasak Kiatphattharaporn
Conservation et gestion des aires protégées,
Chief of Nanthaburi National Park, Thailand

Bożena Kornatowska
Institute of Environmental Protection-National Research Institute,
Warszawa, Poland
bozena.kornatowska@ios.edu.pl

Renata Krzyściak-Kosińska
Ministry of Climate and Environment,
Warszawa, Poland
renata@kosinscy.pl

Magali Maire
Directrice adjointe du GIP ECOFOR
magali.maire@gip-ecofor.org

Phurin Makaew
Conservation de la faune sauvage,
Forestry Technical Officer, Thailand
phurin.ppm@gmail.com

Étienne Massard Kabinda Makaga
Conseiller technique du ministre des Eaux et Forêts du Gabon,
chargé du Conflit Homme-Faune
Ancien DG Environnement et Président du Conseil Climat
massardetienne@gmail.com

Doyle McKey
Professeur émérite, université de Montpellier,
Centre d'Écologie fonctionnelle et évolutive
d_mckey@hotmail.com

Leila de Morais
Chefe de Gabinete do Advogado-Geral da União

Serge Morand
Écologie de la santé, directeur de recherche au CNRS
Directeur de l'IRL HealthDEEP - CNRS - Kasetsart University -
serge.morand@cnrs.fr

Didier Moreau
Délégué général de l'Institut Balanitès
didier.moreau.institut.balanites@gmail.com

Elimar Pinheiro do Nascimento
Professor do Centro de Desenvolvimento Sustentável
da Universidade de Brasília

Mikoja M. Rambinintsoa
Chercheur assistant, mention Foresterie et Environnement,
Université d'Antananarivo (Madagascar)
mikoja.rambinintsoa@gmail.com

Joelisoa Ratsirarson
Professeur titulaire, UFR Écologie et Biodiversité,
Université d'Antananarivo (Madagascar)
ratsirarson@gmail.com

To go further

Ashton Peter, Lee David, *Trees and Forests of Tropical Asia: Exploring Tapovan*, Chicago, The University of Chicago Press, 2022.

Bouka Dipelet Ulrich Gaël, Doumenge Charles, Loumeto Jean Joël, Florence Jacques, Gonmadje Christelle, McKey Doyle, « Des confusions entre espèces préjudiciables à la gestion durable des essences forestières : l'exemple des acajous d'Afrique (*Khaya*, Meliaceae) », *Bois et Forêts des Tropiques*, n°339, 2019, pp. 17-32.

Cires Eduardo, "Diversity and distribution of tree species in Asia", *Asian Journal of Botany*, vol. 1, janvier 2018.

Diallo Aly, Sambou Antoine, Ndiaye Landing, Bassene Jean, Sarr Thierno, Ngom Serigne S. M., Diedhiou Elhadji N. Y., "Woody Diversity in Cult Places (Cemeteries, Mosques, and Parishes) in Ziguinchor City (Senegal)", *American Journal of Plant Sciences*, vol. 16, n°1, 2025, pp. 114-132.

Diallo Aly, Ndiaye Saboury, Goudiaby Arfang O. K., Diatta Yaya, Ndao Mamadou, Diamanka Mamadou, Manga Gnima, "Grassland Pasture Composition and Quality in the Communes of Ziguinchor and Kolda, Senegal" *Open Journal of Ecology*, vol. 14, n°9, 2024, pp. 683-705.

Diallo Aly, Faye Ndiabou, Sylla Diara, Sagna Moustapha B., Badji Éric S., Kébé Ibrahima, Guissé Aliou, « Structure et dynamique de la végétation ligneuse des plantations de *Acacia senegal* (L.) Willd dans la zone sylvopastorale : cas des plantations de Asiyla Gum Company dans la zone de Dahra, Ferlo », *Journal of Animal & Plant Sciences*, vol. 57(3), 2023, pp. 10565 -10583.

Gardner Simon, Sidisunthorn Pindar, Anusarnsunthorn Vilaiwan, *A Field Guide to Forest Trees of Northern Thailand*, Bangkok, Thaïlande, Kobfai Publishing Project, 2007.

GIEC, « Rapport de synthèse », mars 2023.

Konijnendijk Cecil, Devkota Dikshya, Mansourian Stéphanie, Wildburger Christoph (eds.), "Forests and Trees for Human Health: Pathways, Impacts, Challenges and Response Options. A Global Assessment Report", Vienna, IUFRO World Series, vol. 41, 2023.

McKey Doyle, "Making the most of grasslands and heathlands. Unearthing the links between soil paring-and-burning, plaggen cultivation, and raised-field agriculture", *Revue d'ethnoécologie*, n°20, 2021.

MEDINA-SERRANO Natalia, HOSSAERT-MCKEY Martine, DIALLO Aly, MCKEY Doyle, "Insect–flower interactions, ecosystem functions, and restoration ecology in the northern Sahel: current knowledge and perspectives", *Biological Reviews*, 100 (2), 2024, pp. 969-995.

MILLENNIUM ECOSYSTEM ASSESSMENT, *Ecosystems and Human Well-being: Synthesis*, Washington DC, Island Press, 2005.

MORAND Serge, LAJAUNIE Claire, "Outbreaks of vector-borne and zoonotic diseases are associated with changes in forest cover and oil palm expansion at global scale", *Frontiers in Veterinary Science*, vol. 8, mars 2021.

PAN, Yude, *et al.*, "A Large and Persistent Carbon Sink in the World's Forests", *Science*, n°333, 2011, pp. 988-993.

PLAN NATIONAL D'ACTION POUR L'ENVIRONNEMENT, *Les 3 piliers de la durabilité*, Paris, L'Harmattan, 2002.

RANAIVONASY Jeannin, RATSIRARSON Joelisoa, RICHARD Alison F. (dir.), « Suivi écologique et socio-économique dans la Réserve Spéciale de Bezà Mahafaly (sud-ouest Madagascar) », *Malagasy Nature*, vol. 10, 2016.

RATSIRARSON Joelisoa, *et al.*, « Bezà Mahafaly : Écologie et réalités socio-économiques », *Recherches pour le Développement*, n°18, 2001, pp. 1-104.

RATSIRARSON Joelisoa, "The Réserve Spéciale de Bezà Mahafaly", dans GOODMAN Steven M., BENSTEAD Jonathan P. (dir.), *The Natural History of Madagascar*, Chicago, The University of Chicago Press, 2003, pp. 1520-1525.

TEEB, *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB*, 2010.

VANDE WEGHE Jean Pierre, STÉVART Tariq (éds.), *Le Delta de l'Ogooué*, Libreville, Agence nationale des parcs nationaux, 2017.

VANDE WEGHE Jean Pierre, *et al.*, *Biodiversité des parcs nationaux et réserves du Gabon. 2. Espèces, écosystèmes et populations*, Libreville, Agence nationale des parcs nationaux, 2017.

Iconographic credits
Book cover: ©Périclès Cocaul, « Forêt miroir, lac mémoire », Lake Braies, Italy, October 16, 2024. Winning photo from the photo contest organized by the Balanitès Institute.
pp. 1-5: ©PxHere; pp. 6-7: ©Layerace/Freepik; p. 8: ©FGtrade/Istock; p. 9: ©Freepik, ©Encyclopædia Universalis/Alain Pavé et Gaëlle Forret, 2010, ©PxHere; p. 11: ©Freepik; p. 13: ©DR, ©Wikimedia/Tatiana Gerus, ©DR; p. 14: ©Bruno Melo/Unsplash; p. 15: ©DR; p. 17: ©Marizilda Gruppe/Greenpeace; p. 18: ©Carl de Souza/AFP; p. 19: ©Ministerio del Ambiente/Flickr; p. 20: ©Wilfried Maurin/Flickr, ©Carsten ten Brink/Flickr; p. 21: ©DR; p. 22: ©Claude Tazibt; p. 23: ©Verlinden; p. 27: ©Max André, ©Hervé Parmentelat, ©Wirestock; p. 29: ©Claude Tazibt; p. 31: ©Gayard C./ONF; p. 32: ©ONF; p. 33: ©Sapeurs-pompiers du Var; p. 34: ©DR; p. 36: ©Gilles Boëtsch; p. 37: ©Institut Balanitès; p. 41: ©Doyle McKey, ©Michel Papinski, ©Doyle McKey; p. 42: ©Doyle McKey; p. 43: ©Martine Hossaert/McKey, ©Gilles Boëtsch; p. 44: ©Aliou Guissé; pp. 46-49: ©Gilles Boëtsch; p. 50: ©Arnaud Hitzer; p. 51: ©DR; p. 55: ©Marek Kosinski; p. 57: ©Jessica Buczek; p. 59: ©Renata Krzyściak-Kosińska; p. 61: ©Renata Krzyściak-Kosińska; p. 62: ©DR; pp. 64-76: ©Joelisoa Ratsirarson; p. 78: ©Flo Lorenz/Unsplash; p. 79: ©Jean Damien Mabba Makanga; p. 83: ©J. L. Doucet, ©DR, ©Gervais Banza/Pl@ntNet; p. 85: ©Kath Jafferey; p. 87: ©Théau Nicolas/Unsplash, ©DR; p. 89: ©Claude Wayne; p. 90: ©DR; pp. 92-93: ©Nanthaburi National Park; p. 96: ©Phurin Makaew; p. 97: ©Dieter Albrecht/Pl@ntNet, ©Serge Morand; pp. 99-100: ©Phurin Makaew; p. 101: ©Serge Morand; pp. 103-105: ©Phurin Makaew; p. 109: ©Maxx Gong/Unsplash; pp. 110-112: ©PxHere.

institut
Balanitès

Publishing director: Gilles Boëtsch
Project manager: Hala El Solh
Mission managers: Manon Terrin and Luca Venezia
Graphic design and editorial coordination:
Nathalie Cassou-Geay, ngeay@yahoo.com
Traduction: ChatGPT, DeepL and Google Translate
Revised by: Gwénaëlle Doré
Printed by:

In partnership with

cnrs
ÉCOLOGIE &
ENVIRONNEMENT

LABORATOIRE D'AGROFORESTERIE ET D'ÉCOLOGIE
LAFE

UNIVERSITÉ MONTPELLIER

LIZ CLAIBORNE
ART ORTENBERG
FOUNDATION

Madagascar
National Parks

Association Francis Hallé
pour la forêt primaire

irl 3189
ENVIRONNEMENT
SANTÉ
SOCIÉTÉS

Université d'Antananarivo
École Supérieure des Sciences Agronomiques
ESSA-BEZA MAHAFALY

UMR 5175
CENTRE D'ÉCOLOGIE
FONCTIONNELLE
& EVOLUTIVE

KU
KASETSART UNIVERSITY Faculty of
Veterinary Technology

HealthDEEP
HEALTH, DISEASE ECOLOGY, ENVIRONMENT AND POLICY
INTERNATIONAL RESEARCH LABORATORY
CNRS - KASETSART UNIVERSITY - MAHIDOL UNIVERSITY

institut Balanitès

AMAZON FOREST

THE MAURES FOREST

THE GREAT GREEN WALL

BIAŁOWIEŻA FOREST

FOREST OF MADAGASCAR

THE OGOOUÉ BASIN

NANTHABURI NATIONAL PARK

Book cover: © Périclès Cocaul, « Forêt miroir, lac mémoire »
Winning photo from the photo contest organized by the Balanitès Institute