FRONTIERS OF FIRE

AN OVERVIEW OF FIRE IN THE AMAZON REGION

OTCA
Organização do Tratado de Cooperação Amazônica

EXECUTION

STRATEGIC PARTNERS

FRONTIERS OF FIRE

AN OVERVIEW OF FIRE IN THE AMAZON REGION

PERMANENT SECRETARIAT OF THE AMAZON COOPERATION TREATY ORGANIZATION (SP/ACTO)
Secretary General: Martín Von Hildebrand
Executive Director: Vanessa Grazziotin
Administrative Director: Edith Paredes
Environmental Coordinator: Carlos Salinas
Scientific Coordinator of the Amazon Regional Observatory: Arnaldo Carneiro

DEUTSCHE GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT (GIZ) GmbH
CoRAmazonia Project
Gustavo Wachtel, Cristian Guerrero Ponce de Leon, Fernando Rodovalho, Fernando Orn, Daya Rodrigues, Maria Júlia Gois

Strategic Partners
Ministério do Meio Ambiente e Mudança do Clima (MMA) – Brasil
Instituto Nacional de Pesquisas Espaciais (INPE)
Grupo de Pesquisa Expossoma e Saúde do Trabalhador – eXsat, Faculdade de Saúde Pública da Universidade de São Paulo
Laboratório de Aplicações de Satélites Ambientais (LASA) – Universidade Federal do Rio de Janeiro
World Bank Group – Amazônia Viva
Instituto de Pesquisa Ambiental da Amazônia (IPAM)

Technical and Executive Coordination
Fernando Rodovalho – CoRAmazonia Project / Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Editors
Fernando Rodovalho – Lead Editor
Ane Alencar – Co-Editor
Christian Niel Berlinck – Co-Editor

Editorial Support
Editorial review and English translation: Vitor dos Santos Ribeiro
Spanish translation: Dafne Velazco
Design and layout: Karen Martinez / W5

Visual Credits
Cover photo – Mayangdi Inzaulgarat

Amazon Cooperation Treaty Organization (ACTO/OTCA)
SEPN 510, Block A, 3rd floor – Asa Norte, Brasília, DF, Brazil
ZIP 70.570-521. Tel. +55 61 3248-4119 / 4132

Cite as:
Rodovalho, F., Alencar, A., & Berlinck, C. N. (Eds.). (2025). Frontiers of Fire: An Overview of Fire in the Amazon Region. Amazon Cooperation Treaty Organization (ACTO/OTCA) & Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

ISBN 9 788561 873509

Disclaimer

This document is a technical and informational compilation on a topic of priority for the Amazon Cooperation Treaty Organization (ACTO), prepared to support and enrich regional discussions. The opinions, analyses, and interpretations expressed are solely those of the authors. The content does not necessarily represent the official views of ACTO or its Member Countries. The information presented has been technically reviewed to ensure its accuracy and reliability.

SUMMARY


©Augusto Dauster

PREFACE
FRONTIERS OF FIRE

It is with great satisfaction, yet also with a sense of urgency, that I present *Frontiers of Fire*, the result of a collective effort by the Amazon Cooperation Treaty Organization and its partners. This work sheds light on one of the greatest challenges facing our region: forest fires, a phenomenon that threatens not only the integrity of the forest, but also ancestral memory and the very continuity of life in the Amazon.

Since time immemorial, fire has been part of the forest's history. For indigenous peoples, it has never been merely a tool: it is a being, a living force, deeply woven into daily life, spirituality, and the stewardship of the land. It is fire that opens fields, cooks food, hardens tools, protects the crops with its smoke, and aids in hunting and fishing. In many cultures, it plays a role in healing rituals, invoked in dances and songs, and is ever present as a mediator between human beings and the territory.

This use, however, has always been guided by deep respect and by rules passed down through traditional knowledge. Burning only during certain times of the year, choosing specific areas, managing the wind, waiting for the rains: each technique shows that fire, when managed with wisdom, does not destroy, but sustains life. This is the pedagogy of the forest, preserved by the peoples of the Amazon for centuries.

However, this balance is breaking down. Climate change prolongs summers, intensifies winds, raises temperatures. Under these conditions, fire easily escapes from fields and farmlands, turning into large-scale wildfires. When this happens, it ceases to be an ally and becomes an enemy: an uncontrolled fire that destroys forests, threatens health, disrupts the rhythms of life, and weakens ecosystems. It is this frontier — between managed fire and devastating fire — that we must understand and confront.

This frontier, however, is not only ecological: it is also symbolic and spiritual. Amazonian traditions remind us that humanity has already lived through five previous worlds, destroyed either by water or by fire, always as a consequence of the selfish behavior of their inhabitants. The myth of Yuruparí, guardian of the forest and of the rules of balance, shows how disregarding for the care of nature brings catastrophe. When men, blinded by arrogance, decide to kill him, Yuruparí himself declares that only fire could destroy him. This ancestral narrative conveys a profound lesson: fire becomes the ultimate threat to the life of the forest when human beings break the pact of respect and reciprocity.

Now, that prophecy seems to echo in our own times. The flames advancing over the Amazon are the expression of an ethical and collective rupture. Each hectare of forest consumed by fire releases tons of carbon into the atmosphere, accelerates climate collapse, interrupts the flying rivers that bring rain to much of South America. Each burned tree is also a fragment of the cultural and spiritual memory of the amazonian peoples that is lost. Uncontrolled fire does not recognize political borders: it spreads as a symbol of the imbalance that threatens the entire planet.

For this reason, the response cannot be isolated. No country can face this challenge alone. Fire demands cooperation, integration of policies, mobilization of resources, and above all, the building of a common purpose. ACTO, as the collective forum of the eight amazonian countries, has the mission of strengthening networks such as the Amazon Network for Integrated Fire Management (RAMIF), supporting the exchange of sustainable practices, training governments and communities, and promoting joint actions that combine science, innovation, and, at the core, traditional knowledge.

The Amazon is resilient. Its greatest strength lies in the diversity of its cultures and the vitality of the knowledge systems accumulated over centuries by indigenous peoples, traditional communities, and local populations. But this resilience is not infinite. The accumulation of pressures — deforestation, degradation, changes in rainfall patterns, and rising temperatures — places the biome in a critical situation. The recurring fires are a warning sign: they show that we are approaching, dangerously, the point of no return, where the forest will no longer be able to regenerate.

Avoiding this collapse requires political courage, consistent financial resources, strengthened technical cooperation, and above all, an ethical pact involving governments, civil society, science, and amazonian peoples. Dialogue with the traditional guardians of the forest is indispensable, for they not only endure the direct impacts but also hold keys of knowledge for the prevention and balanced management of fire.

Frontiers of Fire thus fulfills a role that goes beyond diagnosis. This work reveals the historical and cultural dimension of fire, distinguishes between its age-old regulated use and its devastating force, analyzes its environmental, social, and economic impacts, and presents pathways for response. It also offers good practices for prevention, community experiences, and highlights the importance of integrating science and tradition.

More than a technical report, this book is a political instrument. It should guide national policies, inspire regional cooperation, and mobilize international solidarity. It reminds us that we still have the possibility to choose: to preserve the Amazon as a living interdependent system, or to succumb to the flames of selfishness, repeating the mistakes that, according to the myth, have already destroyed worlds before.

The myth of Yuruparí warns us: when balance is broken, fire can become the weapon of final destruction. But it also reminds us that there is a path of return, built through listening, respect, and shared wisdom. May *Frontiers of Fire* be, therefore, not only a publication, but a call to responsibility, an invitation to cooperation, and an appeal to conscience.

The Amazon still resists. It is up to us to ensure that it continues to be a living forest, a land of cultures, a source of water, a regulator of climate, home to the jaguar and to millions of species. May we, together, transform knowledge into action and ensure that fire becomes once again a force of life, not of destruction.

INTRODUCTION

Long before it was seen as a threat, fire was an ally. Tamed by our ancestors, it made cooking possible, brought people together, shaped the land, and enriched the soil. In the Amazon, traces and knowledge of this ancient relationship with fire remain: from its role in subsistence to the creation of *terra preta*.

Over the centuries, this relationship has changed, losing its balance as our connection with the environment became more exploitative. Today, fire often threatens the forest, sociobiodiversity, health, and life itself. In the Amazon, wildfires cross political boundaries, creating a shared challenge for all of us — peoples, communities, and governments alike.

Throughout this publication, we present a technical assessment that also serves as a call to rebuild alliances between traditional knowledge and science, between civil society and public authorities, between forest peoples and the institutions that work in their defense. We begin with an overview of the Amazon, move on to the patterns and impacts of fire in the region and its connection to climate, and conclude by outlining possible paths to confront this shared challenge.

The result is an invitation to dialogue among governments, communities, organizations, researchers, and guardians — people who, from their different places, roles, cultures, and worldviews, share the conviction that another relationship with the environment and with fire is not only possible but urgently necessary.

Fernando Rodovalho

chapter 1

THE AMAZON

Fernando Rodovalho[1], Bernardo Flores[2], Dolors Armenteras[3]

[1]CoRAmazonia Project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
[2]Amazon Cooperation Treaty Organization (ACTO), Amazon Regional Observatory (ARO)
[3]Universidad Nacional de Colombia

Few places on Earth hold as much life, complexity, and cultural diversity as the Amazon. Spanning about 7.9 million square kilometers, the region is home to a constellation of interdependent relationships, pulsing with intense connections, flows, and reciprocities, and bringing together the greatest biodiversity on the planet. Around 47 million people live there, including more than 420 ethnic groups of indigenous peoples, and traditional, afro-descendant, and riverine communities, forming a multiethnic and multicultural reality. For centuries, these peoples have developed ways of life deeply intertwined with the forest while also shaping the forest itself through their cosmologies and practices, in a co-evolutionary relationship[2].

The Amazon's vegetation is predominantly composed of dense tropical rainforests, but it also includes areas that flood with the ebb and flow of great rivers such as the dark-water igapós, the fertile várzeas, the natural grasslands on sandy soils, and the mangroves that line its Atlantic coast. This diversity of forms and landscapes gives rise to a unique ecological system in which everything is deeply interconnected — fauna, flora, waters, climate, people, and cultures functioning together as a single living mechanism[3].

Beyond its ecological and cultural wealth, the Amazon is a cornerstone of the planet's climate system. According to the Intergovernmental Panel on Climate Change (IPCC), the forest is one of our greatest allies in confronting the climate crisis. It stores billions of tons of carbon, helps cool the atmosphere, regulates rainfall across much of South America[4], and contributes to stabilizing atmospheric circulation patterns on a global scale.




These influences are embodied in the so-called "flying rivers": streams of water vapor that originate in the Atlantic ocean, are sustained by the forest's evapotranspiration, and travel thousands of kilometers, carrying moisture to distant regions such as central and southern Brazil, the Pantanal, and the Río de la Plata Basin. Without the Amazon, these areas would be drier and less able to support activities like agriculture and the supply of water for domestic, industrial, and energy use. Even faraway territories and people who have never set foot in the forest depend profoundly on its persistence[5,3].

Yet, the forest is under threat. Deforestation, wildfires, uncontrolled exploitation of its natural resources, the advance of the agricultural frontier, the spread of illegal activities such as mining and land grabbing, and the increasingly extreme effects of climate change are pushing the Amazon toward a point of no return. This critical threshold refers to the risk of an irreversible shift into a drier, degraded, and fragmented state, a forest no longer able to sustain current rainfall patterns, wildlife, or the traditional ways of life that depend on it[6,7].

Photographs from bottom to top: 1 and 2 ©Fernando Martinho
3 ©Diego Baravalli/Greenpeace | 4 ©Adobe Stock



The signs are already visible. The major droughts of 2005, 2010, 2015-2016, and more recently 2023-2024 revealed a forest growing increasingly vulnerable. Rivers reached historically low levels, some dried up completely in several areas, communities were cut off, and thousands of aquatic animals died in overheated lakes. Science shows that if nothing is done to reverse this trend, up to 47% of the Amazon could collapse under multiple disturbances by 2050, pushing the system as a whole past the point of no return and dramatically increasing the risk of cascading ecological breakdowns in other biomes and regions of the planet[9,10,7].

Still, there are possible paths forward. The IPCC itself highlights that effective public policies, ecological restoration, protection of indigenous territories, and a new development model based on the sustainable use of the forest can keep the Amazon alive, resilient, and standing. The forest has a remarkable capacity for regeneration as long as its rhythms, its territories, and the strength that rises from its roots are respected[4,3].

Understanding the risks facing the Amazon also requires acknowledging the ambivalent role of fire. Although it is generally not part of the forest's natural dynamics, fire has become an increasingly present element in amazonian territories. When it reaches forested áreas, especially under conditions of drought or degradation, it disrupts ecological cycles, consumes essential natural resources, and accelerates the fragmentation of the forest landscape[7].

However, fire is not only a problem to be fought when it gets out of control; it is a reality that must be understood and managed wisely, in ways that integrate scientific knowledge with the wisdom of indigenous peoples and local communities[11]. With proper governance and recognition of local knowledge, it can become part of sustainable solutions. In the chapters ahead, we will look more closely at where, how, and when fire occurs in the region, and why it has become a central issue for the Amazon, given its scale, its impacts, and its complexity.

Photographs from left to right: 1 ©Adobe Stock | 2 ©Valdemir Cunha/Greenpeace | 3 ©AdobeStock

THE FIRE

chapter 2

Fernando Rodovalho[1], Ane Alencar[2], Bibiana A. Bilbao[3] Christian Niel Berlinck[4]

[1]CoRAmazonia Project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
[2]Instituto de Pesquisa Ambiental da Amazônia, IPAM – Brazil,
[3]Departamento de Estudos Ambientais, Universidad Simón Bolívar – Venezuela
[4]Coordenação Geral de Políticas para o Manejo Integrado do Fogo, Ministério do Meio Ambiente e Mudança do Clima – Brazil

Fire is one of the planet's oldest inhabitants. It emerged more than 400 million years ago, during the Early Silurian period, when oxygen levels (the oxidizer) were high and terrestrial plants allowed the accumulation of biomass (fuel). At that time, lightning and volcanic activity were the sources of ignition that made combustion possible. Since then, fire has shaped ecosystems and influenced life on Earth[1,2].

Beneath its roots and layers of soil, the Amazon holds the memory of an ancestral relationship with fire. Across vast areas of the amazonian territory, there is evidence of *terra preta*, soils enriched through successive cycles of low-intensity burning and the accumulation of organic matter, an expression of ancient agroecological management technologies and the domestication of the forest[3,4,5]. Paleo-events of mega-fires have also left their mark on amazonian history[6].

Most of the Amazon is made up of humid tropical forests that evolved virtually without fire and are extremely sensitive to it: even small, low-intensity burns can cause lasting ecological damage and slow recovery[7]. Yet in some parts of the region, such as *lavrados*, open *campinaranas*, savannas, and amazonian grasslands, fire can play a functional role in maintaining ecological cycles when properly managed[8]. Despite these differences, fire has become a tool used across all ecosystems, leaving deep and lasting imprints not only on the landscape but also on the cultures of the peoples who live within it.

©Rodrigo Falleiro

Fire has always been present in daily life, in traditional medicine, in food systems, and in the spirituality of ancestral amazonian Indigenous peoples — fire that gives life, managed with care and respect[9]. Its use is guided by traditional knowledge passed down through generations, reflecting subsistence strategies and deep connections to the spiritual and cosmological dimensions of their territories[10,11,12].

Fire is also a tool for agricultural production for the peoples who colonized the Amazon. The large-scale conversion of forests into farmland, driven by road expansion, and the practice of slash-and-burn agriculture only became possible through the use of fire[13,14,15].

Although wildfires are the most visible face of fire in the context of climate change and extreme events, the presence of fire in the Amazon also reflects balanced relationships with the land, especially when managed in traditional and collective ways. The use of fire, regulated by ecological calendars, community agreements and knowledge passed down through generations, challenges the notion that fire is always destructive[16]. When managed responsibly, fire can contribute to soil fertility, pest control, vegetation renewal, and protection against large-scale wildfires, particularly in non-forest vegetation[17,18,19].

Even today, fire remains a constant, multifaceted presence in amazonian life. Its uses appear in different contexts, forms, and for multiple purposes (Table 1). Indigenous peoples, local communities, farmers, managers of protected areas, and public institutions are among the actors who employ fire as a tool. Yet there is also predatory and destructive use of fire. This diversity of purposes and intentions reveals that fire itself is not a villain, but rather an agent of transformation whose impact depends on how, where, when, and why it is used[17,18,19].

TABLE 1. **FIRE TYPOLOGIES ACCORDING TO THEIR USES AND PURPOSES**

TYPE OF FIRE	DEFINITION	WHO MANAGES	MAIN PURPOSE	KEY FEATURES	POTENTIAL IMPACTS
CULTURAL FIRE	Use of fire based on traditional knowledge and cultural values for landscape management and preservation of cultural practices	• Indigenous peoples • Traditional communities • *Quilombola/* afro-descendant groups	• Vegetation management • Lland renewal • Stimulation of biodiversity • Cultural, spiritual and infrastructure protection	• Planned • With defined timing and location • Passed down through generations • Integrates local socioecological knowledge	Maintains vegetation mosaics, prevents large-scale wildfires, conserves sociobiodiversity, and poses low risk if properly conducted
SUBSISTENCE/ PRODUCTIVE FIRE	Use of fire to support subsistence activities and agricultural or livestock production	• Family farmers • Rural communities • Agricultural producers • Livestock breeders	• To prepare fields, renew pastures, and control pests or invasive plants	• Generally seasonal • Based on simple techniques; aimed at self-consumption or local production • Not always following formal environmental protocols	It can have low impact when well managed, but carries the risk of escaping and causing larger wildfires if poorly planned
ECOLOGICAL FIRE	Planned, technical, monitored, and controlled use of fire for conservation or research purposes	• Environmental managers • Protected areas • indigenous peoples • Local communities	• Reduce the occurrence of wildfires • Protect sensitive environments and species • Conserve ecosystems that have evolved with fire	• Planned and controlled • With defined timing and location • Clear ecological objectives	Low negative impact and high positive impact on the environment, climate, and biodiversity
PREDATORY FIRE	Intentional use of fire for illegal or destructive purposes, in violation of environmental laws and with negative impacts on ecosystems	• Land grabbers • Land invaders • Actors involved in illegal activities	• To promote degradation that facilitates deforestation, the displacement of communities, illegal land occupation, and land speculation	• Intentionally destructive • With no concern for control • Often associated with illegal activities such as land grabbing and illegal mining	Extremely high environmental, social, and economic impact; destruction of habitats, loss of biodiversity, massive carbon emissions, and health risks

From the symbolic to the practical use, fire is ever-present, crossing different dimensions of life, from everyday domestic activities such as cooking and preserving food to productive practices like material processing and agricultural management. Fire also plays important agroforestry, pastoral, and ecological roles, particularly in controlled burns aimed at agroforestry-livestock systems production, and in prescribed burns used to conserve fire-adapted ecosystems — such as savanna and vegetation physiognomy — and to prevent large-scale wildfires. In addition, it appears in contexts of resource extraction, health, and protection, as well as in spiritual rituals, oral traditions, and moments of community gathering. Finally, it is present in recreational practices and contemporary uses that, while common, can also pose risks.

Table 2 organizes these multiple dimensions into categories that illustrate the diversity of meanings and uses of fire in the Amazon.

Photos from bottom to top: 1 ©AugustoDauster/Prevfogo | 2 ©Rodrigo Falleiro
3 ©Adobe Stock | 4 ©Rodrigo Falleiro

TABLE 2. **EXAMPLES OF FIRE USES IN THE AMAZON**

Examples of fire uses in the Amazon are drawn from the publications referenced throughout this chapter, as well as from oral accounts documented by the authors through their professional practice and field experience.

1 DOMESTIC	**1.1 FOOD PREPARATION**	A daily practice among peoples around the world, the use of fire in cooking is also an expression of identity and of the relationships that connect people.
	1.2 FOOD PRESERVATION	Food smoking, carried out over slow-burning fires, is a traditional method of preserving its quality.
	1.3 HOUSEHOLD LIGHTING AND HEATING	Fire is used for providing light and heat, especially on areas with no electricity access.
	1.4 WASTE DISPOSAL	A common practice in rural areas and urban outskirts, where fire is used to eliminate household or organic waste, thereby reducing disease vectors and pests, usually due to the lack of regular waste collection services or adequate sanitary landfills.
2 PROCESSING	**2.1 FIBER AND TOOLS PROCESSING**	The heat from fire is used to soften plant fibers, making it easier to weave baskets, sieves, ropes, and other items. It is also used to craft and harden tools.
	2.2 COAL PRODUCTION	The use of open-air or underground charcoal pits for charcoal production is an age-old practice with ecological value and soil-fertilizing potential, an ancestral agroecological technology linked to *terra preta*.
	2.3 CLAY POTTERY	To fire ceramic utensils essential for daily household life and cultural rituals.
	2.4 BRICKS AND HARD CLAY PRODUCTION	Fire is used to dry and harden clay bricks, commonly used in regional construction, imparting strength and durability.

3 LIVESTOCK FARMING PRODUCTION

3.1 CONTROLLED BURNING, FIELD CLEARING (*ROÇADO*), AND AGRICULTURAL CLEANING WITH FIRE

Controlled burning refers to the planned, monitored, and regulated use of fire for agroforestry-livestock systems purposes in designated areas and under specific climatic conditions. Fire is applied to burn vegetation in order to prepare the environment and soil for agricultural production, forestry, and pasture renewal, as well as to eliminate unwanted plant residues and pests. The practice is planned according to weather conditions and often accompanied by safety measures, such as firebreaks. When carried out properly, it reduces the need for fertilizers and pesticides.

4 ECOLOGICAL

4.1 MOSAIC BURNING AND ITS MORE TECHNICAL FORM, PRESCRIBED BURNING

Planned, monitored, and controlled use of fire carried out for conservation, research, or management purposes under specific conditions and with predefined objectives, in fire-prone ecosystems such as grasslands and savannas. Prescribed burning is used to stimulate the regrowth, flowering, and fruiting of native vegetation species, as well as fauna, to protect sensitive environments and species, conserve sociobiodiversity, and reduce and fragment fuel loads, preventing wildfires.

5 EXTRACTIVISM

5.1 HUNTING

Fire is used to open pathways, drive animals and/or attract them through the regrowth of tender vegetation.

5.2 FISHING

Fire is used to clear and access fishing areas, and to drive insects onto the water's surface, making it easier to catch fish.

5.3 HONEY COLLECTION

Smoke is used to calm bees during honey harvesting, allowing sustainable hive management without harming the colonies.

6 HEALTH AND PROTECTION

6.1 CLEANING OF DOMESTIC AREAS

Burned areas and small fires lit around houses, fields, and trails are useful for keeping poisonous and dangerous animals away. They also help protect structures from wildfires.

6.2 MOSQUITOES AND INSECTS CONTROL

Smoke is used as a natural insect repellent. Specific leaves, such as andiroba or tobacco leaves, are chosen to enhance this effect.

6.3 MEDICINAL USE

Fire is used for inhalation and for the preparation of medicinal substances.

7 TRADITIONAL AND SPIRITUAL

7.1 SPIRITUAL RITUALS AND PROTECTION

Fire holds a central place in rituals of healing, transition, and spiritual protection. It is used in smudging, prayers, ceremonies, and celebrations, symbolizing purification, vital energy, rites of passage, and connection with the spiritual world.

7.2 SMOKING

Inhaling the smoke of plants, especially tobacco, is a traditional practice in many cultures, associated with ritual, medicinal, and social uses.

7.3 SOCIAL INTERACTION AND ORAL TRADITION

Fire gathers people together. By the fire, conversations, stories, songs, and teachings from the elders take place. It is a space of memory, togetherness, and the strengthening of community bonds.

7.4 LEARNING AND PASSING ON PRACTICAL KNOWLEDGE OF FIRE AND ITS USE

Children and young people observe the use of fire in different contexts, learning from their elders when, how, and why to use it, strengthening both their autonomy and the continuity of traditional knowledge.

7.5 SMOKE SIGNALING

Smoke is used as a visual code among communities to announce, for example, events, visits, or successful hunts.

7.6 TERRITORIAL MARKING

Fire is also used to mark territorial boundaries, trails, and sacred sites. These markings carry symbolic value and reinforce the relationship between people and their land.

8 RECREATIONAL

8.1 RECREATIONAL AND LEISURE

Fire is often used in recreational activities such as bonfires, children's games, fireworks, and sky lanterns.

Over time, driven by predatory and unregulated patterns of land occupation, the balance in the relationship with fire was lost. Outside traditional contexts, fire has become the main tool for land management among most producers in the Amazon, from small farmers and settlers from other regions to medium and large landowners and ranchers, used both to expand production areas and to manage them afterward[20,21,22].

It is important to remember that in Brazil, which contains about 60% of the Amazon, the occupation of the region during the 1960s and 1970s was promoted as a state policy, through land grants and the slogan "Integrate to avoid surrendering". Land use was demonstrated mainly through deforestation and the widespread, uncontrolled use of fire, giving rise to what we now know as the Arch of Deforestation, which remains today as one of the main frontiers of forest loss and degradation in the Amazon[24,25].

Another group of relevant actors that must be considered are the grileiros — land grabbers who speculate on land prices by occupying it illegally. They use fire to set intentional fires that promote forest degradation, allowing them to later claim the land unlawfully. Unlike traditional fire management, they do not follow the socioecological calendars that guide the sustainable use of fire[26], making this predatory practice one of the main drivers of deforestation and environmental degradation in the Amazon[27].

Degradation is the progressive loss of a forest's ecological integrity, affecting its structure, biodiversity, and ecosystem services, even when the vegetation remains standing. It can result from careless use of fire, selective logging, fragmentation, or extreme droughts[28]. Deforestation, on the other hand, involves complete removal of forest cover, usually for agricultural, infrastructure, or urban expansion purposes, and is often accompanied by fire as the final stage of land conversion. Although distinct, degradation and deforestation frequently act together, reinforcing cycles of environmental disturbance[29].

When combined with land-use changes and climate change, fire can assume a highly destructive character[30]. These processes alter fire regimes, which were once rare in humid forests, making them more frequent, intense, and unpredictable[31]. As a result, the Amazon becomes more flammable, especially in fragmented or degraded areas with dry vegetation and accumulated fuel loads[32], which in turn fuels large-scale fires with extreme behavior, high severity, and occurrence in places where they did not previously exist.

Table 3 presents the main predatory uses of fire, their driving forces, and their consequences for increasing deforestation and environmental degradation in the Amazon.

TABLE 3. **PREDATORY USES OF FIRE AND THEIR DRIVING FORCES**

ILLEGAL FIRE IN RECENTLY DEFORESTED AREAS

 **LAND SPECULATION**	 **ILLEGAL PASTURE FORMATION**	 **ILLEGAL MINING**
The use of fire in land grabbing occurs as a strategy for illegal occupation aimed at appropriating public lands or collective territories. The practice involves the intentional burning of vegetation to signal control over the area, hinder natural regeneration, and facilitate the later introduction of cattle or crops. In many cases, fire is used repeatedly to keep the area “clean” and create the appearance of productive use, as a way to legitimize the occupation before land agencies or those interested in its regularization. This type of action is directly associated with land conflicts, environmental degradation, and the advance of deforestation, especially in agricultural frontier regions.	The use of fire as a deforestation tool involves the intentional burning of native vegetation to convert forested areas into pasture or cropland, usually for monocultures. This practice is associated with the expansion of large-scale, predatory agribusiness and is one of the main drivers of forest loss in the Amazon and other biomes. Burning typically occurs after vegetation has been cut and dried, serving to eliminate residues and prepare the soil for productive activities. In addition to harming biodiversity and ecosystem services, this use of fire generates significant greenhouse gas emissions and increases the risk of wildfires in surrounding areas.	Fire is used to remove vegetation and facilitate access to soil layers in mining areas, preceding the degradation caused by mineral extraction.

Predatory forms of fire use, such as deforestation and land grabbing, are currently the main drivers of extreme wildfires in the Amazon[28]. These unregulated practices, associated with illegal land occupation and the conversion of forests into productive areas, disregard climatic and ecological factors and drastically increase the risk of fires getting out of control[33].
In these contexts, fire ceases to be a tool for integrated management and becomes a consequence of poor land governance: the wildfire, defined as any uncontrolled fire that spreads through vegetation areas and requires a response.

It is important to notice that every use of fire involves risk. Even when guided by good intentions and by ancestral and scientific knowledge, fire can turn into a wildfire if safety measures are not observed, such as building firebreaks, maintaining constant monitoring, and paying close attention to weather conditions. These risks vary in both intensity and origin.
To provide insight into wildfire occurrence, we present their main sources and causes in the Amazon region.

MAIN CAUSES AND ORIGINS OF WILDFIRES

ACCIDENTAL

Wildfires often originate from uses of fire like those mentioned earlier, when they get out of control due to lack of attention to weather conditions or safety measures. Other sources include short circuits in power lines, fires in infrastructure, and the use of ammunition during land and air military training. In the Amazon, most occurrences are of human origin, although some, on a smaller scale, can also be caused by lightning.

CRIMINAL ACTIONS, CONFLICTS, AND DISPUTES

Intentional burning is often linked to conflicts and territorial disputes. It can be used to distract authorities, facilitate illegal activities, destroy crops, restrict access, or intimidate communities. In some cases, fires are started with delayed-ignition devices or even originate from military training exercises, eventually spreading into wildfires.


©Augusto Dauster

In light of the growing intensity of wildfires and their increasingly severe impacts across the Amazon, it has become urgent to understand this phenomenon in depth. We have seen that fire is part of both the region's past and its present. A concrete and multifaceted element, it can be at once a tool for life or a force of destruction. Today, its presence spreads uncontrollably across many territories, driven by the predatory ways humanity has related to its ancestral home.

In the following section, we embark on a journey through the countries of the Amazon region, seeking to understand where, when, and why wildfires have intensified, searching for answers and for pathways to restore balance in our relationship with fire and with the environment.

chapter 3

FIRE IN THE AMAZON REGION

Ane Alencar[1], Ana Carolina M. Pessôa[1], Wallace Vieira da Silva[1], Armando Manuel Rodriguez-Montellano[2], Silvana Di Liberto Porles[3], Diana Zuley Caceres Lima[3], Adriana Rojas Suárez[4], Galia Selaya[5], Juan Pablo Iñamagua Uyaguari[6]

[1]Instituto de Pesquisa Ambiental da Amazônia (IPAM) – Brazil
[2]Fundación Amigos de la Naturaleza (FAN) – Bolivia
[3]Instituto del Bien Común (IBC) – Peru
[4]Fundación Gaia Amazonas (FGA) – Colombia
[5]ECOSCONSULT – Bolivia
[6]Universidad de Cuenca – Ecuador

In 2024, wildfires became the leading driver of tropical forest loss worldwide, surpassing deforestation[*]. The Amazon region, although it contains about 6% of non-forest natural areas, is composed mostly of humid tropical forests (79%)[1,**]. These forests have structural and microclimatic characteristics that make them highly fire-sensitive ecosystems[8,9]. As highlighted in the previous chapter, fire has been part of the Amazon's socioecological history for millennia, used by indigenous peoples as a management tool[10,11]. Traditional communities and rural producers have also incorporated its use into their productive practices. The multiple uses of fire by different actors make the Amazon one of the most intensively managed tropical forests through this practice, despite being highly vulnerable to its impacts[12].

In recent years, wildfires in the region have increased in intensity, driven by factors such as deforestation, land grabbing, forest fragmentation, and climate change[13,14,15]. Most of these fires originate from human activity and the various ways fire is used[16,17], with pasture management standing out among them[18]. The impacts of wildfires include soil degradation, disruption of hydrological cycles, reduced forest regeneration capacity, and threats to traditional ways of life, making them one of the main drivers of forest degradation in the Amazon[21].

* Available at: https://www.wri.org/insights/global-trends-forest-fires
** MapBiomas data for the Amazon region considered a mosaic of the national collections for Bolivia (collection 2)[2], Brazil (collection 9)[3], Colombia (collection 2)[4], Ecuador (collection 2)[5], Peru (collection 3)[6], and Venezuela (collection 2)[7], together with MapBiomas Amazon data (collection 6)[1] for Guyana, French Guiana, and Suriname. To maintain fluency in the text, the citation was simplified to "MapBiomas Mosaic"; however, the references for each collection can be found in the bibliography. All datasets are updated through 2023, except for Peru, which includes data up to 2024. For 2024, we used the 2023 land cover data.

In addition, they contribute significantly to carbon emissions and air pollution, extending their effects far beyond the boundaries of the Amazon[22,23,24].

The intensification of climate change and severe droughts has increased the flammability of landscapes, creating situations in which fire, especially when used in agricultural and livestock practices, goes out of control[25,26]. This scenario favors the spread of fires that reach increasingly large forest areas, with greater frequency and intensity[23,15]. Once the humid tropical forest burns, its structure and composition change, making it more susceptible to new fires, prolonging the time needed for regeneration, and compromising the ecosystem's ecological integrity and environmental service[s27,28,29].

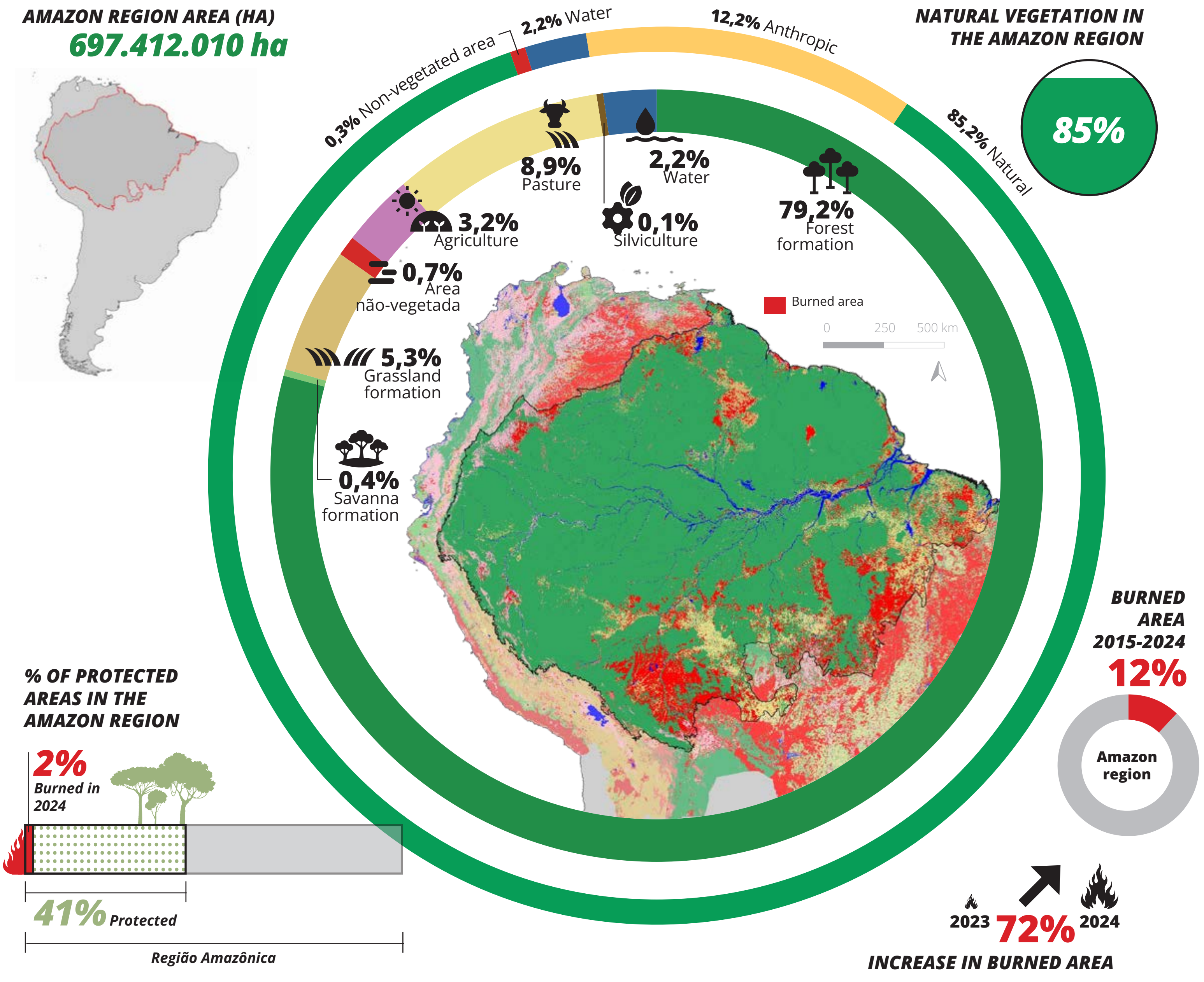
To assess the magnitude of this phenomenon, this chapter analyzes fire dynamics and the extent of burned areas in the Amazon region over the past two decades. The burned area estimate cover the period from 2015 to 2024, while the analysis of fire occurrences, focusing on seasonality, uses data from 2005 to 2024. Both datasets were obtained from the Terra and Aqua[*] satellites. The analysis seeks to answer four central questions: how much burns, when it burns, what burns, and where it burns. This information is essential for understanding recent changes in fire patterns and regimes, identifying their main drivers, and supporting more effective public policies for prevention, control, and management, with the goal of mitigating environmental, social, and economic impacts across the Amazon.

For the purposes of the analyses presented in this chapter, and throughout the publication, we adopted the biogeographic limit/biome of the Amazon as our reference[32,33]. This definition refers to the Amazon region characterized by similar vegetation, climate, and ecological dynamics, distinct from the boundaries of the Amazon Basin (defined by the hydrological catchment area) and Pan-Amazonia (understood as a broader geopolitical region). The choice of the biogeographic/biome framework is justified by the connectivity of vegetation, which allows the Amazon to be understood as a continuous and integrated system, essential for analyzing fire dynamics. It is worth noting that French Guiana, although included in this analysis, is not part of the Amazon Cooperation Treaty Organization (ACTO).

* The MCD64A1 dataset employed to calculate burned area in this chapter has limitations in detecting small burned patches, which may lead to underestimation — especially in countries where fire dynamics are characterized by controlled burns on small agricultural properties. Even so, it remains the only product available for the entire extent of the Amazon region, with mapping performance closest to that of regional products[31].

FIGURE 1. **Distribution of the accumulated burned area between 2015 and 2024 (in red on the map) in the northern portion of South America, highlighting the Amazon region (black outline). The figure shows the proportions of land use and land cover and of the burned area in the region, the occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024.**

Source: RAISG, Mosaico MapBiomas, MCD64A1



HOW MUCH BURNS IN THE AMAZON

Burned areas in the Amazon have historically been concentrated along the southern and northwestern edges of the basin. These regions include the Arch of Deforestation in the Brazilian Amazon, north-central Bolivia, and southeastern Peru, and they largely coincide with zones dominated by agricultural and livestock activities (Figure 1). In addition to the southern portion of the basin, fires also affect natural non-forest ecosystems such as savannas, *lavrados*, and *campinaranas*, found in the northwest of the region and encompassing areas of Brazil, southern Venezuela, and western amazonian colombia. Over the past decade, these fire fronts have advanced even further into forested areas. Overall, regardless of national borders, fire activity remains strongly associated with deforested zones, agricultural expansion fronts, and patches of non-forest native vegetation and/or pasture.

Between 2015 and 2024, the countries of the Amazon region together burned approximately 267 million hectares. Of this total, about 83 million hectares, nearly one-third, were within the Amazon region itself (Table 1). Brazil accounted for the largest share, with 54% of the total (45 million hectares). Bolivia followed with 36%, then Venezuela (5%), Colombia (3%), Guyana (1.3%), and Peru (0.8%) (Figure 2A). Both Brazil and Bolivia recorded a high proportion of burned areas within their amazonian territories (Figure 2B), highlighting the intense environmental pressures and the urgent need for coordinated fire management strategies at the regional scale (Table 1, Figure 2).

FIGURE 2. (A) Cumulative burned area in the Amazon region by country between 2015 and 2024, and proportional contribution of each country to the total burned area in the Amazon region; (B) Proportion of burned area within the Amazon region by country.
(Source: MCD64A1)

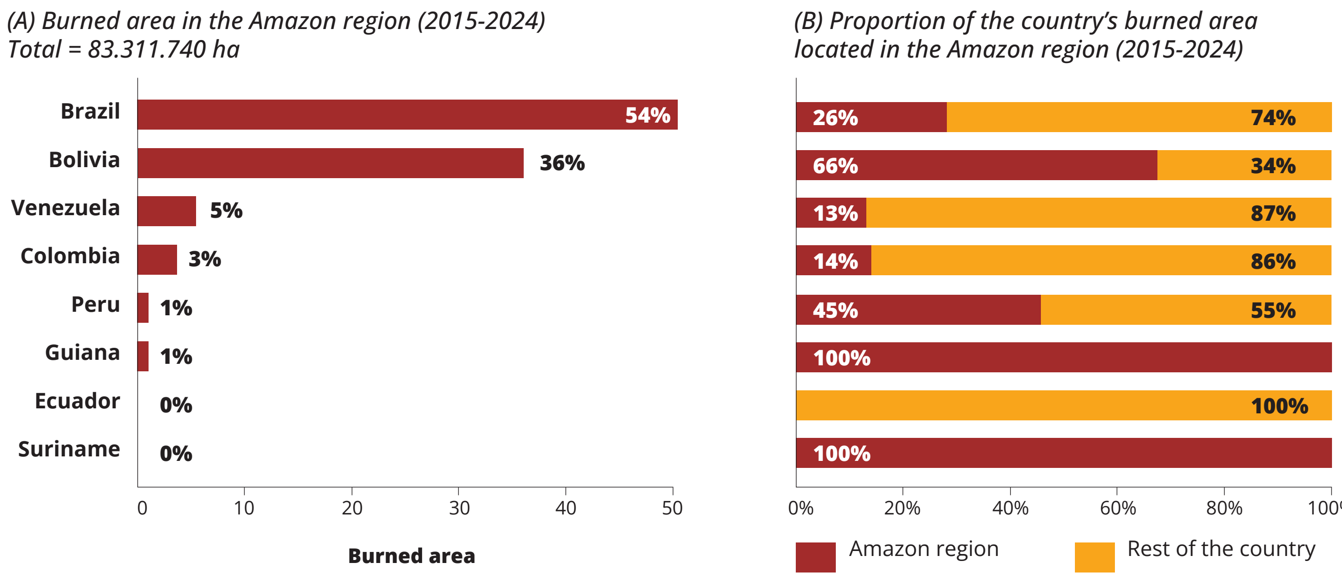


TABLE 1. Number of fire hotspots and burned area from 2015 to 2024 in the countries of the Amazon region and within the Amazon region itself. (A) Proportion of national territory burned; (B) Proportion of total burned area among countries; (C) Proportion of burned area located within the Amazon region of each country; (D) Proportion of the total burned area in the Amazon by country.

Source: MCD64A1, reference satellite AQUA M-T

Fire hotspots and burned area extent between 2015 and 2024 in the Amazon region

					Região Amazônica				
Country	Total area of the country (ha)	Total burned area (ha)	A	B	Amazonian area in the country (ha)	Fire hotspots (N)	Burned area (ha)	C	D
Brazil	847.386.994	169.998.627	20%	64%	418.062.524	991.160	44.979.559	11%	54%
Bolivia	108.653.448	45.234.519	42%	17%	49.528.978	224.810	29.812.746	60%	36%
Venezuela	91.162.367	31.492.732	35%	12%	46.757.145	49.205	4.044.910	9%	5%
Colombia	113.567.603	17.170.653	15%	6%	50.377.229	60.169	2.450.866	5%	3%
Peru	129.087.436	1.482.759	1%	1%	78.470.892	111.503	663.745	1%	0,8%
Guiana	21.067.963	1.094.389	5%	0,4%	21.082.882	13.944	1.094.388	5%	1,3%
Ecuador	25.584.953	477.238	2%	0,2%	10.337.853	1.121	2.132	0%	0%
Suriname	14.501.772	263.939	2%	0,1%	14.472.950	5.158	263.395	2%	0,3%
French Guiana	8.362.502	11.988	0%	0%	8.321.556	2.272	11.988	0%	0%
Total	**1.359.375.038**	**267.226.300**		**100%**	**697.412.010**	**1.459.342**	**83.323.728**		**100%**

The amazonian portions of Brazil and Bolivia were also the regions that recorded the highest number of fire hotspots between 2015 and 2024 (Table 1). While the Brazilian Amazon had 11% of its territory burned and registered 991.160 fire hotspots during this period, Bolivia saw 60% of its amazonian portion burned, with 224.810 hotspots. These results suggest that, although Brazil shows the highest absolute values in both burned area and number of fire hotspots, proportionally Bolivia experienced a significantly greater impact of fire on its amazonian biome (Table 1).

Between 2015 and 2024, the Amazon recorded an average of 138 thousand fire hotspots and 7.5 million hectares burned per year (Figures 3A and 3B). During this period, 2024 stood out as the most critical year, with 215 thousand fire hotspots and 16 million hectares burned in the Amazon alone. These numbers represent a 55% increase in hotspots and a 116% increase in burned area compared to the average of the previous nine years (Figures 3A and 3B).

Considering all the countries of the Amazon region, 2024 also marked a significant peak, with 452 thousand fire hotspots, 59% above the historical average of 284 thousand. The burned area reached 43 million hectares, 72% above the average of 25 million (Figures 3C and 3D). These numbers reflect a substantial worsening in the occurrence of wildfires both within the Amazon and across its countries in 2024.

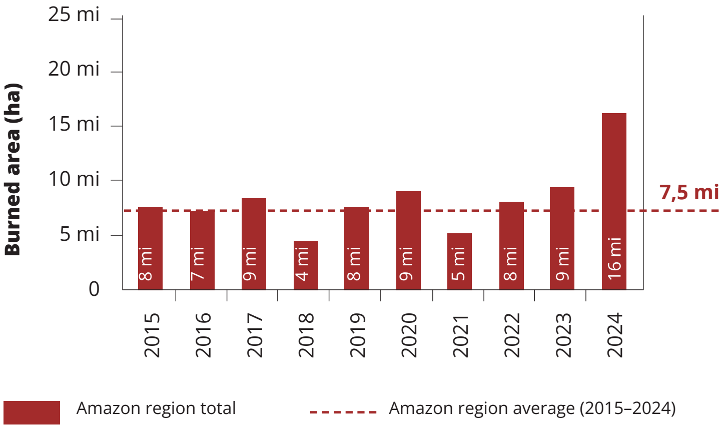
In addition to 2024, several other years in the historical series also showed values above the average for fire hotspots and burned area. The exceptions were 2018 and 2021, both La Niña years, when wetter conditions reduced the occurrence of fires across much of the region. In contrast, 2015, marked by the so-called “Godzilla” El Niño, and 2016 recorded sharp increases in both indicators, followed by 2017, which, even without El Niño, reflected its climatic legacy. High fire activity was also observed in 2019 and 2020, driven mainly by the expansion of deforestation. More recently, 2022 and 2023 showed exponential increases in burned area and fire hotspots above the average. Outside the Amazon biome, the trend was different, with a decline in both indicators between 2021 and 2023. In the Amazon, however, the proportion rose sharply over the past three years, accounting for 55%, 54%, and 47% of total fire hotspots and 35%, 42%, and 38% of the total national burned areas in 2022, 2023, and 2024, respectively.

FIGURE 3. **(A) Annual burned area in the Amazon region (orange); (B) Number of fire hotspots in the Amazon region (green); (C) Annual burned area in the Amazon region (orange) and burned area in the rest of the Amazon region countries (orange dashed line); and (D) Number of fire hotspots in the Amazon region (green) and number of fire hotspots in the rest of the Amazon region countries (green dashed line).**

Source: MCD64A1, reference satellite AQUA M-T

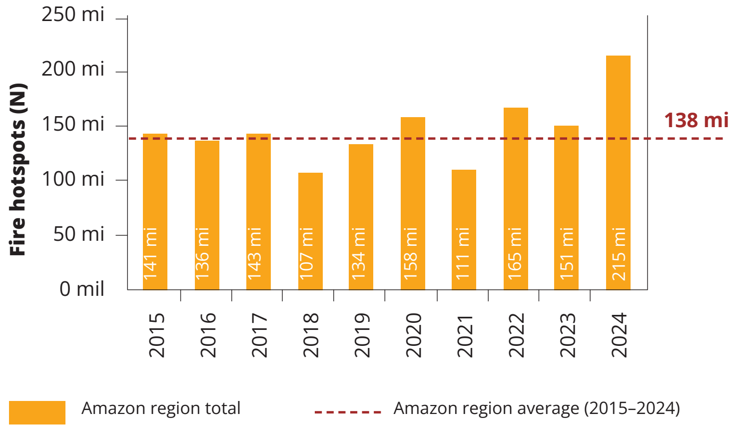
(A) Burned area anual na região amazônica

Source: MCD64A1



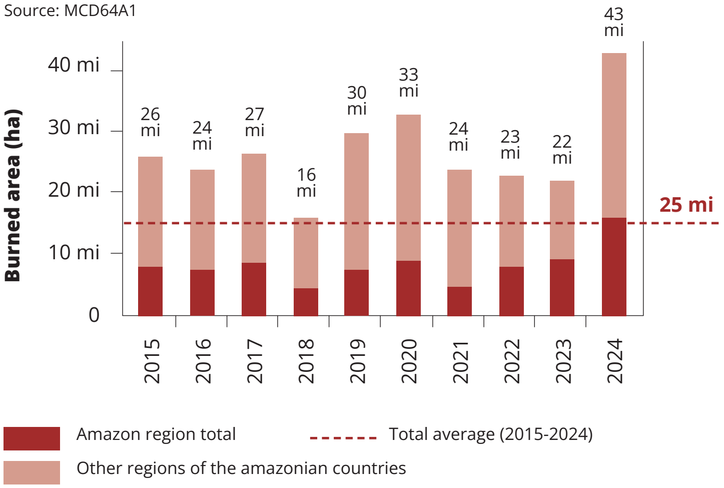
(B) number of fire hotspots in the Amazon region

Source: Reference satellite: AQUA M-T



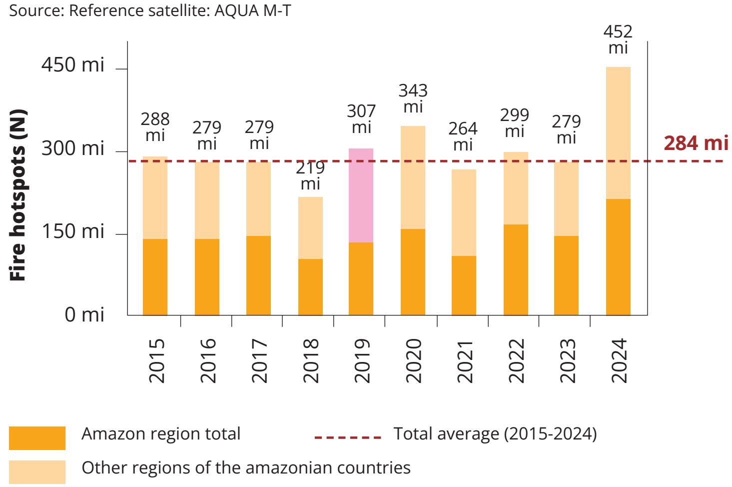
(C) Annual burned area in amazonian countries

Source: MCD64A1



(D) Number of fire hotspots in amazonian countries

Source: Reference satellite: AQUA M-T

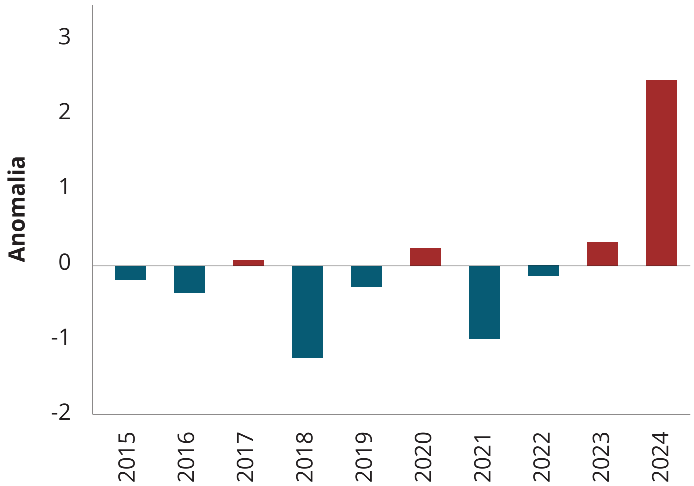


In terms of interannual* anomalies over the past decade, 2024 recorded the highest values above the monthly average for both burned area and fire hotspots (Figures 4A and 4B). The years that diverge in the comparison between fire hotspots and burned area are likely associated with the type of area burned, such as fire related to deforestation versus fire associated with forest wildfires later in the decade. Both are captured with different frequency and intensity in fire hotspot data.

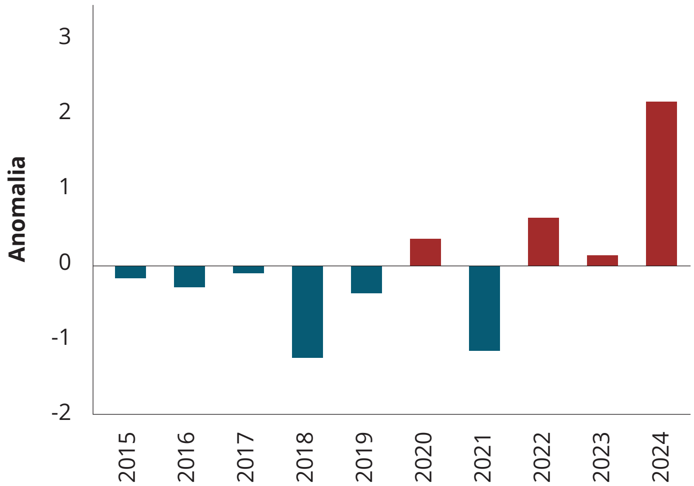
FIGURE 4. Interannual anomalies of (A) burned area and (B) fire hotspots in the Amazon region.

Source: MCD64A1, reference satellite AQUA M-T

(A) Interannual anomalies in burned area in the Amazon region



Interannual anomalies in fire hotspot occurrence in the Amazon region



* The anomaly is calculated using the following formula: anomaly = (annual value − period mean) / standard deviation

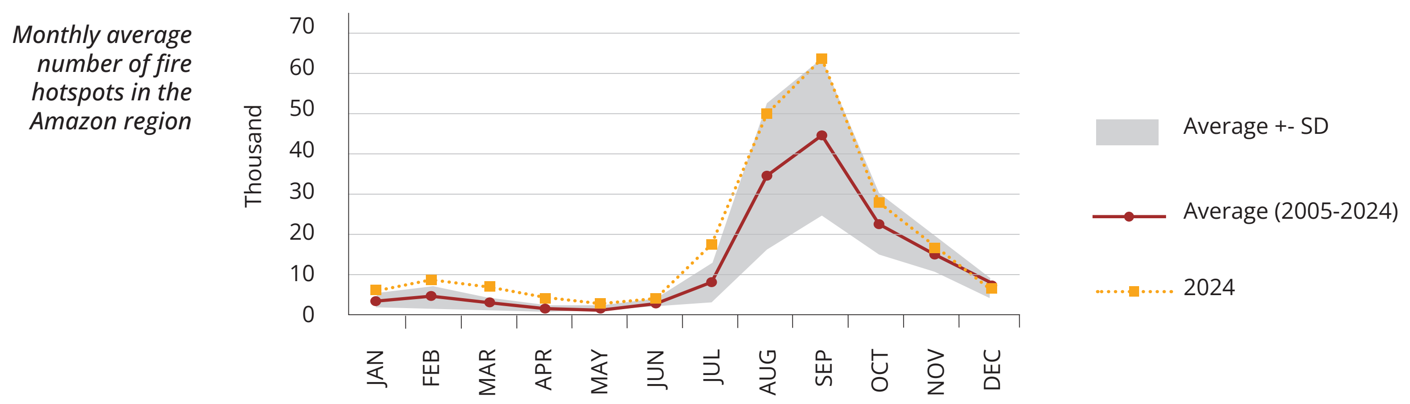
WHEN THE AMAZON BURNS

Seasonality is an important characteristic of fire regimes. In the Amazon, knowing when fires occur is essential for effective actions in fire prevention, rapid response, and long-term management. Seasonal patterns, often linked to climatic conditions and land-use practices, allow authorities to anticipate high-risk periods, position resources strategically, implement temporary fire-use bans or awareness campaigns, and strengthen law enforcement by focusing monitoring efforts during periods of heightened activity.

To assess the intra-annual temporal pattern of fires and wildfires in the Amazon, a longer historical series of fire hotspot data, from 2005 to 2024, was analyzed. Fire activity in the Amazon region shows a strong seasonal pattern, with peaks concentrated in August, September, and October, the most critical months of the dry season across the region. This seasonality, however, is not uniform throughout the Amazon, following a characteristic local climatic gradient34. The average monthly curve of fire hotspots, with variability represented by one standard deviation, confirms this pattern: activity remains low from January to June, rises sharply in July, peaks between August and September, and declines between November and December. These results show that in 2024, fire hotspot occurrences were significantly above the historical average and exceeded the upper limit of the standard deviation, indicating an exceptional fire season in both magnitude and persistence (Figure 5).

FIGURE 5. Monthly average number of fire hotspots in the Amazon region (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (orange dashed line).

Source: reference satellite AQUA M-T



The analysis of the average monthly distribution of fire hotspots by country between 2005 and 2024 shows that, although the aggregated pattern for the Amazon region reveals a strong concentration of fire activity in August (22%) and September (29%), there are significant variations among countries (Table 2). Brazil and Peru concentrate more than 60% of their annual fire activity in these two months, reflecting the direct influence of the peak of the central dry season. In Bolivia, the peak occurs in September (34%), but with high values also in August and October (21% each), indicating a longer fire season. In contrast, Colombia and Venezuela show maxima early in the year, with February accounting for 48% and March for 22% of activity, respectively, due to distinct climatic regimes. Guyana, Suriname, and French Guiana record most of their fire hotspots between October and November, as they are closer to the Equator and under the influence of the Intertropical Convergence Zone. These patterns reinforce the need for fire prevention and control strategies tailored to the climatic calendar of each country.

TABLE 2. Average monthly distribution (%) of fire hotspots in the Amazon region and its constituent countries between 2005 and 2024. The values represent the average proportion of fire hotspots recorded each month relative to the annual total for each territory. The data highlight the seasonal and spatial variability of fire occurrence, emphasizing the differences in peak periods among countries.

Source: Reference satellite Aqua M-T

	AVERAGE MONTHLY DISTRIBUTION OF FIRE HOTSPOTS BETWEEN 2005 AND 2024											
Country / Region	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Bolivia	0%	0%	0%	1%	2%	4%	9%	21%	34%	21%	6%	1%
Brazil	2%	1%	1%	1%	1%	2%	5%	24%	30%	16%	12%	6%
Colombia	20%	48%	14%	2%	0%	0%	1%	2%	3%	2%	2%	4%
Ecuador	18%	16%	2%	2%	1%	1%	1%	7%	15%	14%	16%	8%
French Guiana	1%	1%	1%	1%	0%	0%	1%	2%	19%	52%	2%	1%
Guyana	9%	7%	12%	10%	2%	2%	2%	2%	11%	24%	14%	6%
Peru	2%	1%	1%	1%	1%	2%	7%	32%	40%	10%	3%	1%
Suriname	4%	3%	5%	5%	1%	0%	0%	2%	15%	42%	21%	3%
Venezuela	16%	18%	22%	17%	5%	1%	1%	1%	3%	4%	5%	8%
Região Amazônica	**3%**	**3%**	**2%**	**1%**	**1%**	**2%**	**6%**	**22%**	**29%**	**15%**	**10%**	**5%**

WHAT BURNS IN THE AMAZON

Over the past decade, agriculture and pasture have maintained a relatively stable share of the burned area, ranging between 5% and 20% and between 16% and 30%, respectively (Figure 6). In contrast, 2024 recorded a significant increase in the proportion of burned area in forest formations, reaching 39%, the highest value in the historical series. This increase reflects the growing impact of fire on forest ecosystems, which have historically accounted for a smaller share compared to agricultural areas.

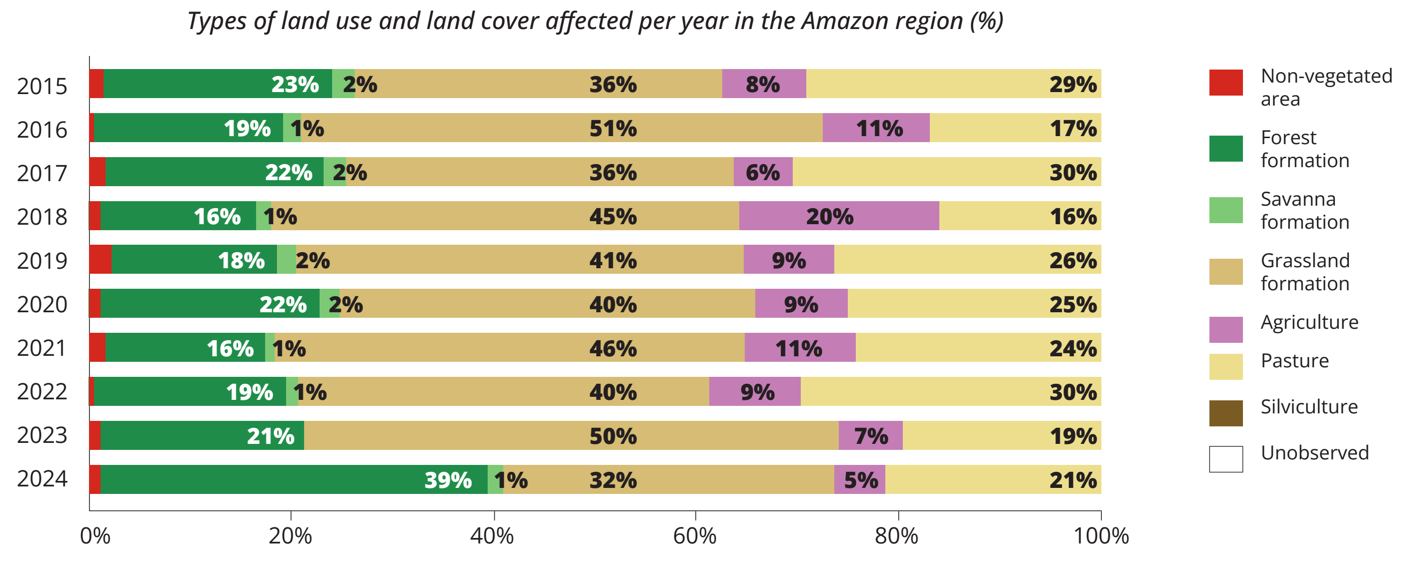
In 2024, of the 16.1 million hectares burned in the Amazon, 73% corresponded to natural vegetation, 26% to anthropic areas such as pastures, agriculture, and urban zones, and 1% to other uses (Table 3).

Bolivia and Brazil accounted for the largest burned extents, both in absolute values and in the proportion of natural vegetation affected. Bolivia recorded 5.5 million hectares of native vegetation burned (91% of the country's total), while Brazil accounted for 4.9 million hectares (58% of the burned area within its amazonian portion). However, in Brazil, the share of anthropic areas was proportionally higher (41%) compared to Bolivia (9%), reflecting differences in ignition drivers and fire-use practices. Ecuador (73%), French Guiana (93%), and Colombia (85%) also showed a predominance of burning in natural vegetation, although on smaller absolute scales (Table 3). Peru and Venezuela displayed a more balanced distribution between natural vegetation and anthropic areas.

Between 2023 and 2024, the burned area over natural cover increased by 73% in the Amazon, while

FIGURE 6. Proportion of burned area by land use and land cover from 2015 to 2024 in the Amazon region.

Source: Mosaico MapBiomas, MCD64A1



in anthropic areas the increase was 72% (Table 3). The expansion of fire over natural vegetation was observed in all amazonian countries except French Guiana. Burning in anthropic areas increased in Brazil, Ecuador, Guyana, Peru, and Venezuela, but decreased in Bolivia, Colombia, French Guiana, and Suriname. Brazil, Bolivia, and Venezuela, which have historically concentrated the largest burned areas, also recorded the greatest absolute increases during this period.

The most significant proportional increases in burned area over natural vegetation during this period occurred in French Guiana (+624%), Suriname (+295%), Colombia (+152%), and Peru (+62%). In absolute terms, Brazil, Bolivia, and Venezuela led with substantial increases. In Brazil, burning in anthropic areas grew by 94%, while in natural areas it rose by 152%. Bolivia, in turn, recorded a 25% increase in native vegetation but a 3% decrease in anthropic areas. Venezuela followed a trend similar to Brazil's, with a 173% increase in anthropic areas and 253% in natural ones.

Peru and Ecuador, although with smaller absolute areas, showed significant proportional increases in both land-cover classes (+295% in Peru and +624% in Ecuador). This scenario reveals a concerning expansion of fire over natural ecosystems, spreading beyond areas traditionally associated with productive activities, and reinforces the urgency of integrated management strategies, especially in countries that experience the greatest impacts and pressures.

TABLE 3. Type of land cover burned (natural and anthropic)* in the Amazon region, and its percentage change in 2024, including the difference in burned area from 2023 to 2024.
Source: Mosaico MapBiomas, MCD64A1

	Burned area in 2024 (ha) by land cover type						Difference in burned area from 2023 to 2024 (%) by land cover type	
Country	Anthropic		Natural		Others		Anthropic	Natural
Bolivia	522.679	9%	5.505.145	91%	41.532	1%	-3%	25%
Brazil	3.438.520	41%	4.917.424	58%	88.796	1%	94%	152%
Colombia	21.001	13%	135.045	85%	3.678	2%	-1%	70%
Ecuador	289	23%	921	73%	60	5%	323767%	624%
French Guiana	0	0%	399	93%	28	7%	-100%	-89%
Guyana	45.021	19%	190.654	80%	3.663	2%	6%	62%
Peru	86.414	44%	108.305	55%	3.638	2%	236%	295%
Suriname	8.017	16%	43.121	84%	192	0%	-55%	91%
Venezuela	145.492	15%	811.727	84%	8.582	1%	173%	253%
Total	**4.267.433**	**26%**	**11.712.742**	**73%**	**150.169**	**1%**	**73%**	**72%**

* For this table, both natural (native vegetation) and anthropic (agriculture and pasture) land use and land cover classes were considered. Representing a small percentage of the burned area, the classes "non-vegetated area, water, and unobserved were grouped under others.

WHERE IT BURNS IN THE AMAZON

The Amazon region has more than 280 million hectares under some form of protection, distributed between indigenous lands and other Protected Natural Areas (PNA) . Brazil contains the largest extent of these protected areas in the region, with 107 million hectares of ILs and 50 million hectares of PNA* (in Brazil, these areas are referred to as Conservation Units), followed by Venezuela with 39 million protected hectares and Colombia with 28 million (Table 4).

In total, 6.5 million hectares were burned within protected areas (indigenous lands and PNA) of the Amazon in 2024, representing 41% of the total area burned in the region, with 3.9 million hectares (25%) in indigenous lands and 2.6 million hectares (16%) in PNA. Between 2023 and 2024, there was a significant increase in burned area within these zones, particularly in indigenous territories, which saw an 81% rise over the period, while PNA showed a 52% increase (Table 4).

In absolute terms, Bolivia led in the extent of burned area within protected zones, with more than 1.9 million hectares in indigenous lands and 1.7 million in PNA, representing about 60% of all the area burned in the country in 2024 and 56% of the total burned within protected areas across the Amazon as a whole (Table 4). Brazil ranked second in burned area within protected areas in 2024, accounting for 37% of the total in this category, with 1.6 million hectares (19%) burned in indigenous lands and 854 thousand hectares (10%) in PNA. Venezuela ranked third, contributing 6% of all burned area within amazonian protected areas in 2024, with 37% occurring in indigenous lands and 2% in PNA (Table 4).

Considering the variation by country, with the exception of French Guiana and Suriname, most amazonian nations recorded an increase in burned area within indigenous lands between 2023 and 2024. For PNA, an upward trend was also observed in Bolivia, Brazil, Colombia, Peru, and Venezuela, while the remaining countries recorded no burned areas in these zones over the past two years (Table 4). Among the largest relative increases were Ecuador, with a 1687% rise in indigenous lands; Colombia, which jumped from less than one hectare burned in PNA in 2023 to 117 hectares in 2024; Peru, with a 594% increase in PNA; and Venezuela, where the burned area grew by 5065%. These figures reveal a concerning intensification of burned area within the protected areas of the Amazon.

* Area calculated using maps provided by RAISG, available at: https://www.raisg.org/pt-br/mapas/.

TABLE 4. Total burned area in Indigenous Lands (IL) and Protected Natural Areas (PNA) in the Amazon region. (A) Proportion of the burned area within IL+PNA relative to the total burned area in the Amazon portion of each country; (B) Proportion burned within protected areas in each country relative to the total burned area in this category; (C) Proportion of the burned area within IL relative to the total burned area in the Amazon portion of each country; and (D) Proportion of the burned area within PNA relative to the total burned area in the Amazon portion of each country.

Source: RAISG, MCD64A1

Area affected by fire in indigenous lands and other protected areas in the Amazon region

	Área (ha)		Total burned area in 2024 (ha)	Total burned area within IL and PNA			Burned area in 2024 (ha)				Difference in burned area from 2023 to 2024 (%)	
Country	IL	PNA			(A)	(B)	IL	(C)	PNA	(D)	IL	PNA
Bolivia	13.215.691	9.097.062	6.069.356	3.645.673	60%	56%	1.943.610	32%	1.702.063	28%	↑ 28%	↑ 54%
Brazil	10.676.442	50.348.756	8.444.741	2.453.677	29%	37%	1.599.669	19%	853.981	10%	↑ 218%	↑ 44%
Colombia	27.471.650	1.627.759	159.723	135.948	85%	0%	25.383	16%	117	0%	↑ 61%	↑ 32750%
Ecuador	6.422.845	29.508	1.270	747	59%	0%	747	59%	0	0%	↑ 1687%	624%
French Guiana	699.749	460	427	0	0%	0%	0	0%	0	0%	↓ -100%	0%
Guyana	3.177.742	29.754	239.338	17.702	7%	0%	17.702	7%	0	0%	↑ 84%	594%
Peru	28.524.745	2.544.820	198.357	29.410	15%	0%	26.126	13%	3.248	2%	↑ 206%	↑ 594%
Suriname	13.439	702	51.330	172	0%	0%	47	0%	0	0%	↓ -32%	0%
Venezuela	36.114.143	2.662.989	965.081	836.466	87%	6%	361.784	37%	212.882	9%	↑ 170%	↑ 5065%
Total	**222.402.507**	**64.841.680**	**16.130.343**	**6.557.395**	**41%**	**100%**	**3.976.004**	**25%**	**2.581.391**	**16%**	↑ **81%**	↑ **52%**

©AdobeStock

CONCLUSION

Evidence from the past decade clearly indicates that in the Amazon region, fire is no longer confined to traditional agricultural and savanna frontiers, increasingly advancing into dense forest areas and protected zones within the basin. The year 2024 stood out as an exceptional milestone, both for the magnitude and persistence of the fires. The combination of climatic extremes, land-use changes driven by human activity, and governance weaknesses has intensified fire pressure beyond national borders, shaping a shared regional challenge. This reinforces the need for coordinated, transboundary fire management strategies that integrate prevention, monitoring, rapid response, and post-fire recovery.

The data also highlight the diversity of fire seasonality among amazonian countries, shaped by local climatic regimes. This variability means there is no single policy applicable to the entire region; effective strategies must be adapted to national and subnational fire calendars, directing prevention and enforcement measures toward periods of highest risk. Strengthening monitoring systems, expanding satellite-based early warning capacities, and integrating them into operational decision-making processes are critical steps to reducing impacts.

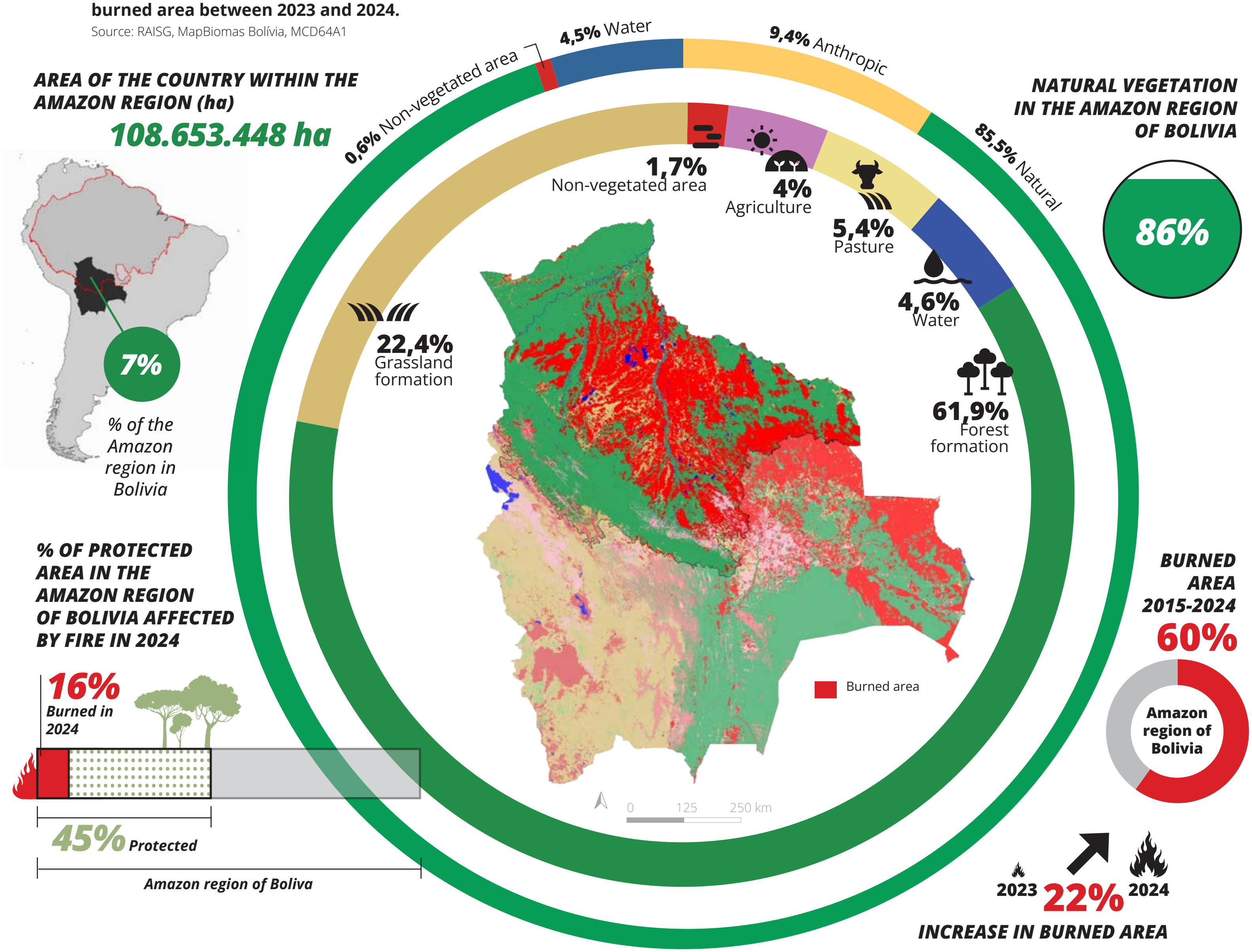
Finally, the sharp increase in burned forest area, especially in 2024, signals a dangerous shift toward greater ecological damage and carbon emissions. Addressing this trajectory requires tackling both the immediate factors, such as deforestation and pasture expansion, and the structural causes, including land tenure insecurity and insufficient protection of indigenous territories and conservation areas. The urgency is clear: without immediate, coordinated and sustained action, fire will continue to erode the Amazon's ecological integrity, undermining its role in climate regulation, biodiversity conservation, and the livelihoods of millions of people who depend on it.

//// BOLIVIA

In Bolivia, between 2015 and 2024, a large portion of the Amazon was burned (60%), and the affected area within this region accounts for more than half (66%) of the country's total burned area (Table 1, Figure 7). These fires originate from slash-and-burn agriculture and forest clearing for industrial livestock and crop production. They are also linked to land invasions and illegal settlements on private lands, public lands, indigenous territories and protected areas[35], and in some locations, to illicit coca cultivation and gold mining activities[36,37]. Added to this are the loosening of deforestation and fire-use permits under the controlled burning regulations, a context of prolonged droughts, and weak local and cross-border governance[39,40]. The widespread practice of chaqueo (agricultural burning) provides the ignition source, while periods of severe drought, intensified by climate change, serve as triggers that allow these fires to spread uncontrollably, turning local burn events into large-scale regional disasters[41].

FIGURE 7. Distribution of the accumulated burned area between 2015 and 2024 (in red on the map) in Bolivia, highlighting the Amazon region (black outline). The figure shows the proportions of land use and land cover and of the burned area in the region, the occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024.

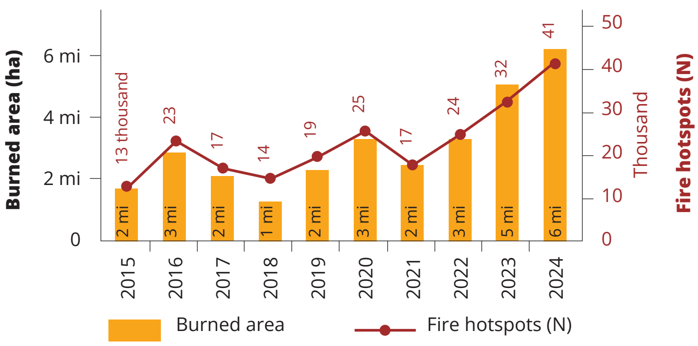
Source: RAISG, MapBiomas Bolívia, MCD64A1



HOW MUCH

Between 2015 and 2024, Bolivia burned an average of about 3 million hectares per year in the Amazon region. The year 2024 recorded the largest burned area, with 6 million hectares, representing a 106% increase compared to the decade's average. It was also the year with the highest number of recorded fire hotspots (40.807) (Figure 8).

FIGURE 8. **Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Bolivian Amazon region**
Source: MCD64A1, reference satellite Aqua M-T



WHERE

In 2024, 32% of the burned area in the Bolivian Amazon occurred within indigenous lands, 28% in other protected areas, and 40% in other land tenure categories, totaling more than 6 million hectares affected by fire (Figure 11). A particularly relevant aspect is that part of this burned area in the Amazon forest of northern Santa Cruz originated in the *Bosque Seco Chiquitano* (chiquitano dry forest), from where the fire spread until it reached those regions.

WHEN

The Bolivian Amazon region has a well-defined fire season concentrated between August and October, especially in September (34%), with more than 75% of fire hotspots historically occurring during these three months (Figure 9).

FIGURE 9. **Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (orange dashed line) in the Bolivian Amazon region.**
Source: reference satellite Aqua M-T

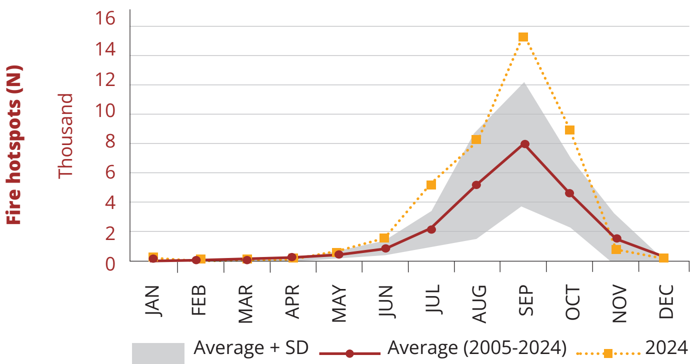
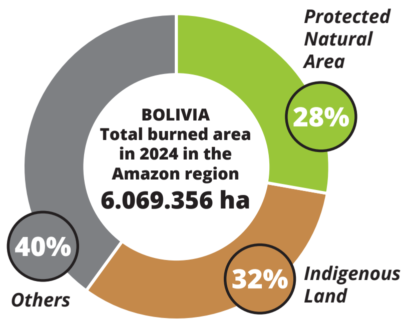


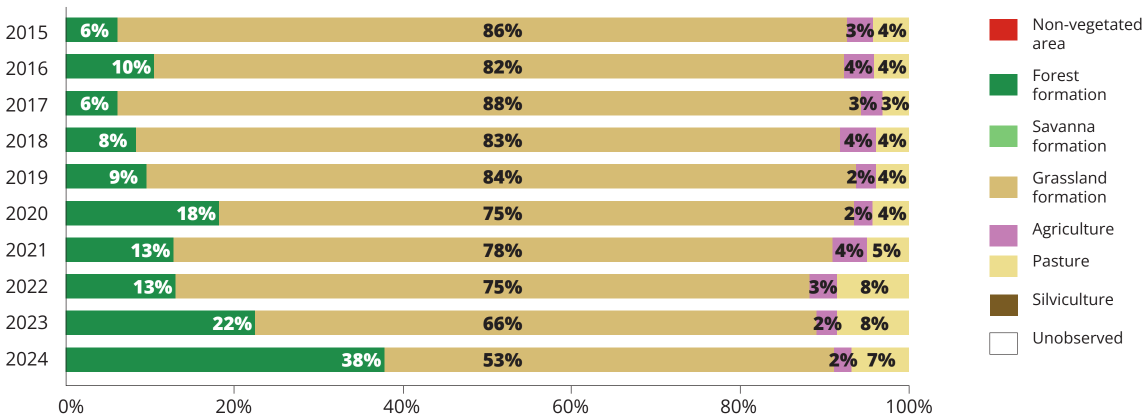
FIGURE 10. **Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas in the Bolivian Amazon region.**
Source: MCD64A1, RAISG



WHAT

Grassland formations are the most affected category by fire, accounting for 53% of the total burned area in 2024, a decrease compared to the 86%–88% recorded in the early years. Forest formations rank second, with 38% in 2024, showing continuous growth since 2015 (when it was 6%). Pastures occupy third place, with 7% in 2024, remaining relatively stable (Figure 10).

FIGURE 11. **Proportion of burned area by land use and land cover from 2015 to 2024 in the Bolivian Amazon region.** Source: MCD64A1, MapBiomas Bolivia

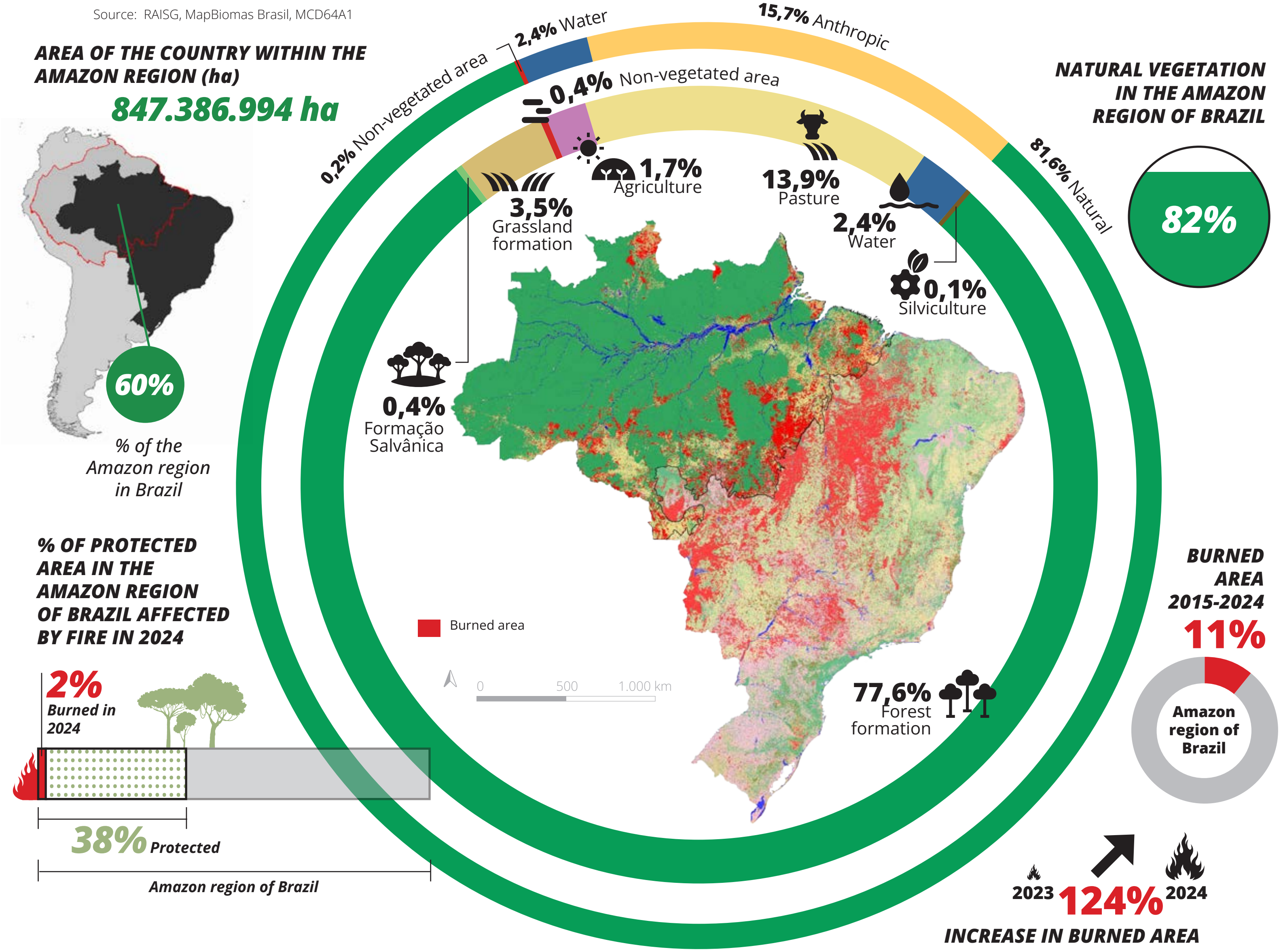


//// BRAZIL

In Brazil, cattle ranching accounts for up to 80% of historical deforestation[42] and represented 93.4% of deforestation in the Legal Amazon in 2015[43]. This impact was further amplified by the expansion of soybean cultivation in the 2000s, which increased the demand for large deforested areas and intensified the use of fire as a management practice[44,45]. Land grabbing has also contributed to fire occurrence in the country, as public lands are illegally occupied and burned to signal ownership, a practice facilitated by weak legislation and repeated amnesties[46]. Over the last decade (2015–2024), fire occurrence in the Brazilian Amazon has been concentrated mainly in the southern and southeastern portions, coinciding with the Arch of Deforestation. In addition, the lavrados in the northern part of the biome have also shown a high incidence of fire (Figure 12).

FIGURE 12. Distribution of the accumulated burned area between 2015 and 2024 (in red on the map) in Brazil, highlighting the Amazon region (black outline). The figure shows the proportions of land use and land cover and of the burned area in the region, the occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024.

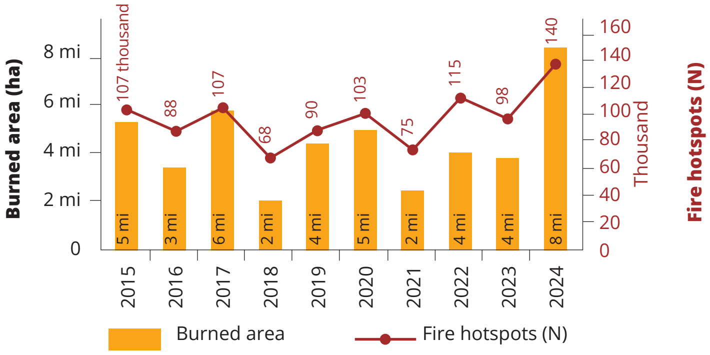
Source: RAISG, MapBiomas Brasil, MCD64A1



HOW MUCH

In the Brazilian Amazon region, the annual average burned area between 2015 and 2024 was 4.6 million hectares. The largest value was also recorded in 2024, with 8.6 million hectares burned, representing an 88% increase compared to the average. The number of fire hotspots in 2024 was also the highest of the decade (139,883) (Figure 13).

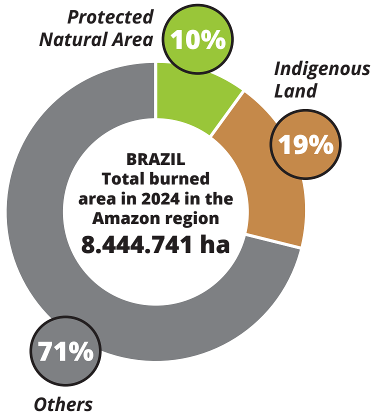
FIGURE 13. Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Brazilian Amazon region.
Source: MCD64A1, reference satellite Aqua M-T



WHERE

Where. In Brazil, 19% of the burned area in the Amazon region in 2024 occurred within indigenous lands, 10% in other protected areas, and the majority (71%) in unprotected territories (Figure 16).

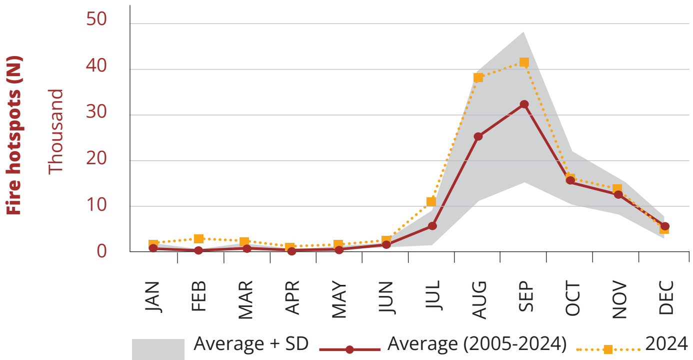
FIGURE 16. Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas in the Brazilian Amazon region
Source: MCD64A1, RAISG



WHEN

The Brazilian Amazon also shows a marked seasonality, with peaks in August (24%) and September (30%), indicating a fire season concentrated in the second half of the year (Figure 14).

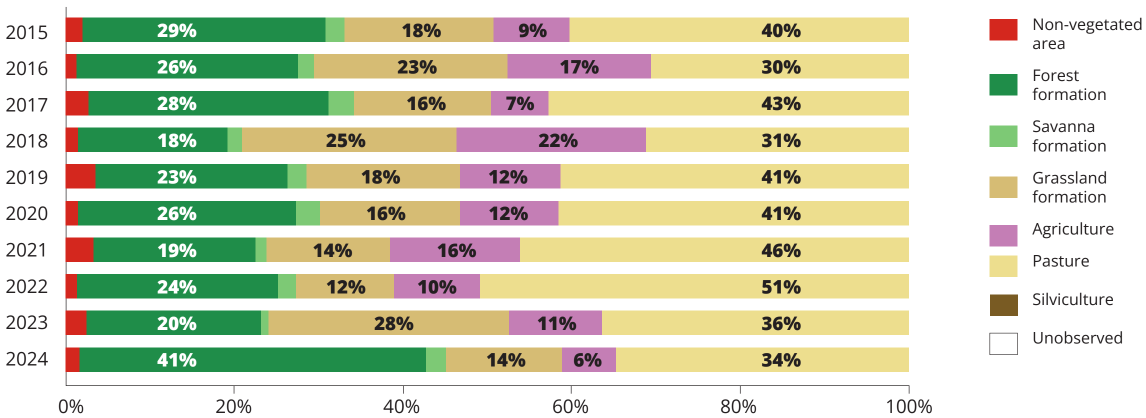
FIGURE 14. Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (orange dashed line) in the Brazilian Amazon region.
Source: reference satellite Aqua M-T



WHAT

The land use and cover category most affected by fire is pasture, accounting for 34% of the burned area in 2024, although it has lost ground compared to previous years, when it reached up to 51%. Forests rose from 20% in 2023 to 41% in 2024, taking the second position. Grassland formations dropped to 14%, ranking third after representing up to 28% in 2023 (Figure 15).

FIGURE 15. Proportion of burned area by land use and land cover from 2015 to 2024 in the Brazilian Amazon region. Source: MCD64A1, MapBiomas Brasil

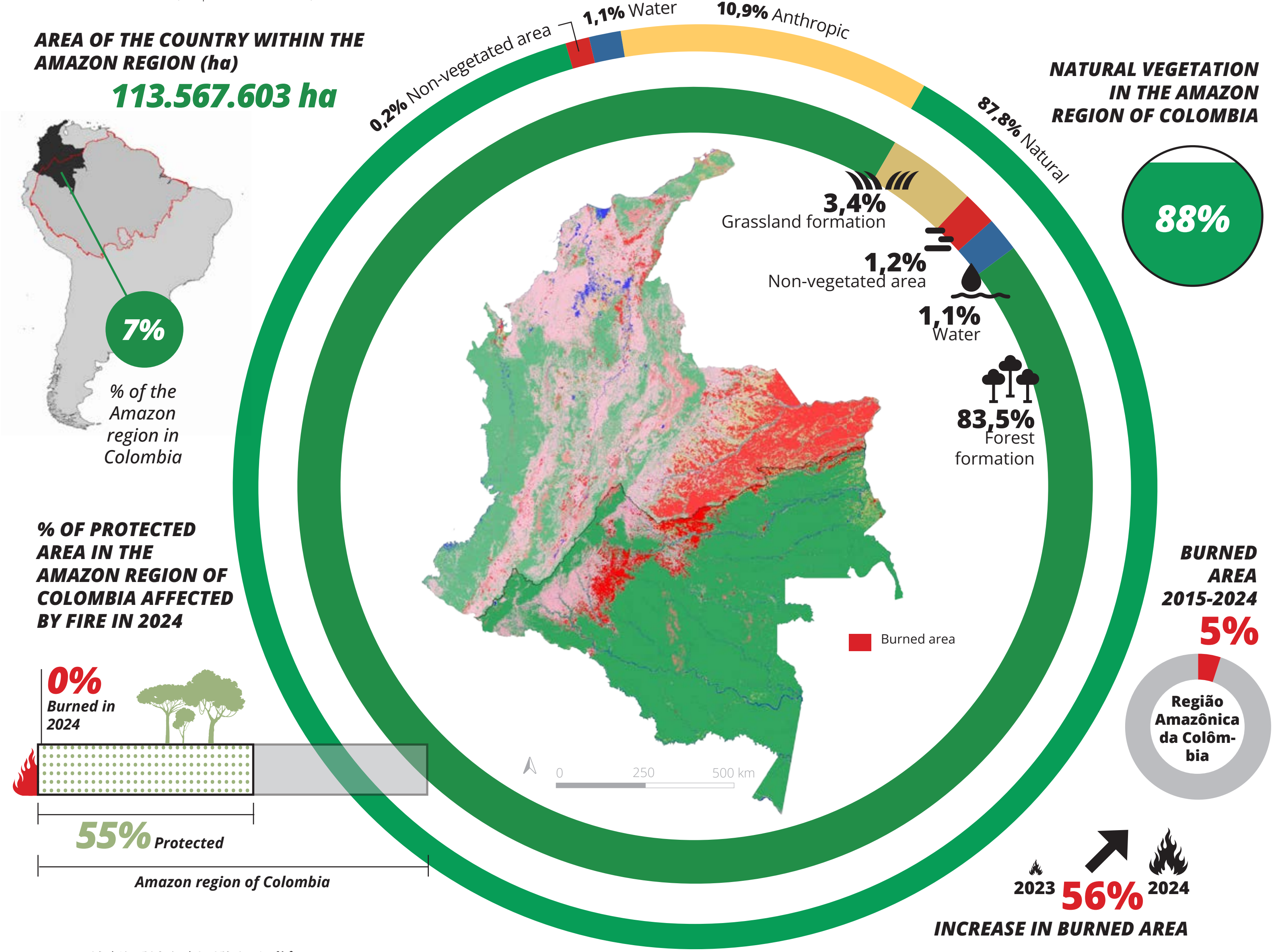


//// COLOMBIA

In Colombia, rural violence and insurgencies — such as those of the Revolutionary Armed Forces of Colombia (FARC) — had long hindered the advance of deforestation until the signing of the 2016 peace accords. In 2017, in the absence of adequate compensatory measures, these agreements led to a 52% increase in deforestation within protected areas[47]. In addition, land grabbing poses a significant threat to the country's forests, as institutional incentives, lack of cadastral information on rural properties, and extreme inequality in land tenure regularization fuel land speculation and have become major drivers of deforestation[48]. Over the past decade, at the national level, fire occurrence has been concentrated mainly in the central-eastern part of the country, northwest of the Amazon region (Figure 17).

FIGURE 17. Distribution of the accumulated burned area between 2015 and 2024 (in red on the map) in Colombia, highlighting the Amazon region (black outline). The figure shows the proportions of land use and land cover and of the burned area in the region, the occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024.

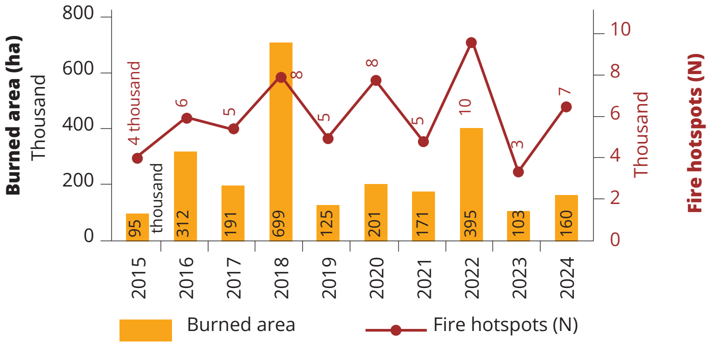
Source: RAISG, MapBiomas Colombia, MCD64A1



HOW MUCH

The Colombian Amazon recorded an average of 250 thousand hectares burned per year. The peak occurred in 2018, with 711 thousand hectares. In 2024, 162 thousand hectares were burned, a 35% reduction compared to the average. The year with the highest number of fire hotspots was 2022 (9.617) (Figure 18).

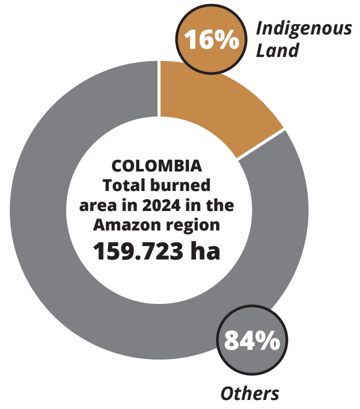
FIGURE 18. **Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Colombian Amazon region.**
Source: MCD64A1, reference satellite Aqua M-T



WHERE

In the Colombian Amazon region, 16% of the burned area in 2024 was recorded within indigenous lands, virtually none in protected natural areas, and 84% in other land tenure categories (Figure 21).

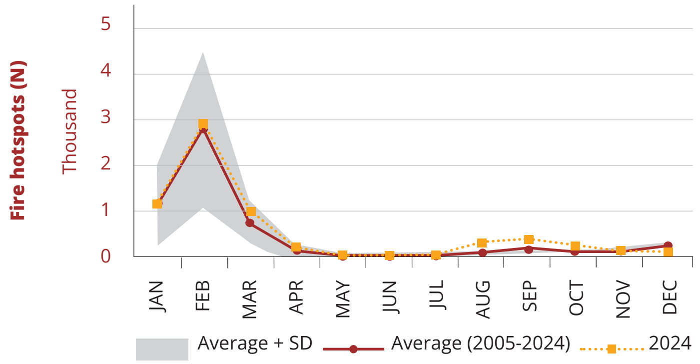
FIGURE 21. **Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas in the Colombian Amazon region.**
Source: MCD64A1, RAISG



WHEN

This region has a fire season concentrated at the beginning of the year, with February (48%) and January (20%) together accounting for nearly 70% of fire hotspots (Figure 19).

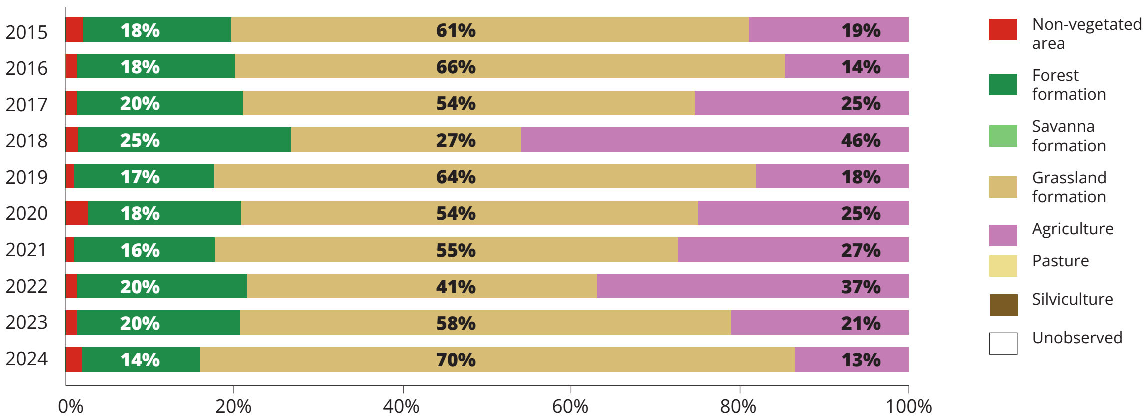
FIGURE 19. **Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (orange dashed line) in the Colombian Amazon region**
Source: reference satellite Aqua M-T



WHAT

Grassland formations dominate fire occurrence in the Colombian Amazon region, accounting for an impressive 70% in 2024 and remaining the main category since 2015. Agriculture ranks second with 13%, although its share has been decreasing. Forest formations ranked third with 14%, also showing a recent decline (Figure 20).

FIGURE 20. **Proportion of burned area by land use and land cover from 2015 to 2024 in the Colombian Amazon region.** Source: MCD64A1, MapBiomas Colômbia



//// ECUADOR

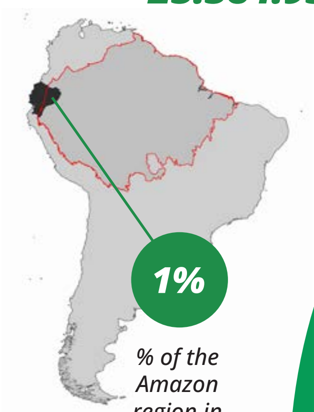
In Ecuador, government efforts toward land redistribution, along with oil exploitation since the 1970s, have caused profound changes in forest cover[49,50], transforming large areas into pastures, mainly distributed along highways[51]. These changes are slowly altering the region's physical environment from one dominated by classic humid tropics to one more similar to the eastern Amazon Basin, with cyclical gradients of humidity and temperature and, consequently, emerging wildfire regimes and persistent deforestation. Over the past decade (2015–2024), fire occurrence has been concentrated in agricultural areas and natural ecosystems (such as páramo and forests) outside the country's Amazon region (Figure 22).

FIGURE 22. Distribution of the accumulated burned area between 2015 and 2024 (in red on the map) in Ecuador, highlighting the Amazon region (black outline). The figure shows the proportions of land use and land cover and of the burned area in the region, the occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024.

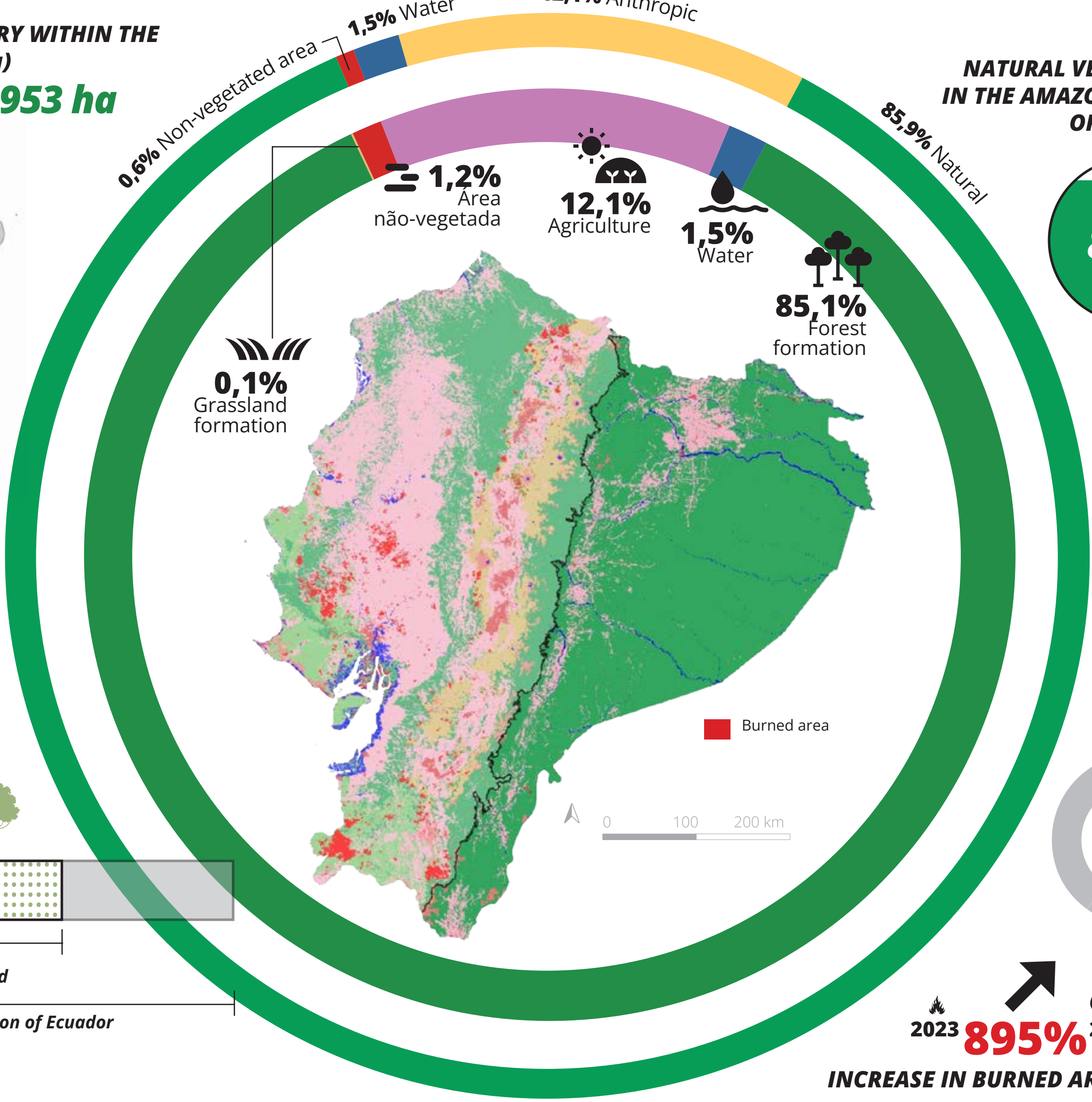
Source: RAISG, MapBiomas Ecuador, MCD64A1

AREA OF THE COUNTRY WITHIN THE AMAZON REGION (ha)

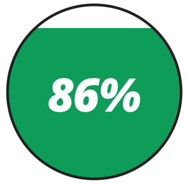
25.584.953 ha



% of the Amazon region in Ecuador



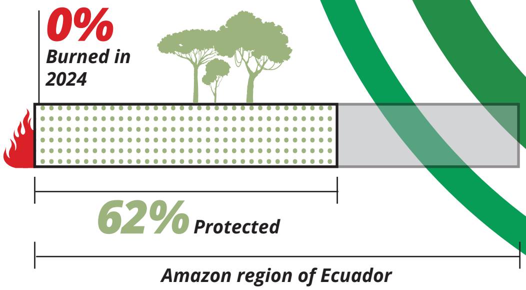
NATURAL VEGETATION IN THE AMAZON REGION OF ECUADOR



BURNED AREA 2015-2024

0%

% OF PROTECTED AREA IN THE AMAZON REGION OF ECUADOR AFFECTED BY FIRE IN 2024



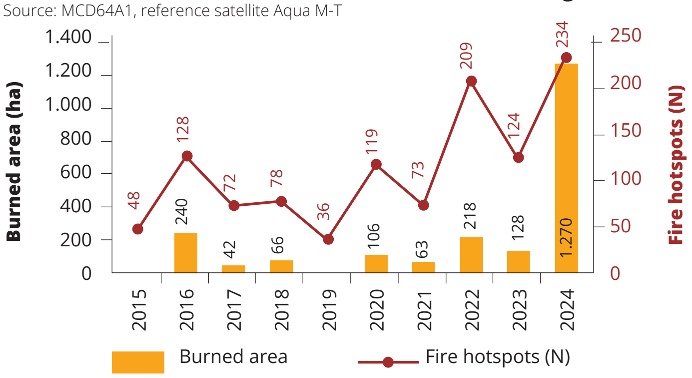
2023 895% 2024

INCREASE IN BURNED AREA

HOW MUCH

Between 2015 and 2024, the annual average burned area in the Ecuadorian Amazon region was only 213 hectares. The highest value occurred in 2024, with 1.264 hectares burned, an increase of more than 493%. This was also the year with the highest number of fire hotspots (234) (Figure 23).

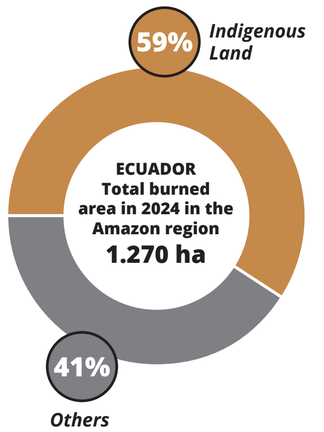
FIGURE 23. Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Ecuadorian Amazon region.
Source: MCD64A1, reference satellite Aqua M-T



WHERE

In Ecuador, 59% of the burned area in the Amazon region in 2024 occurred within indigenous lands, while the remaining 41% affected areas outside protected territories (Figure 26).

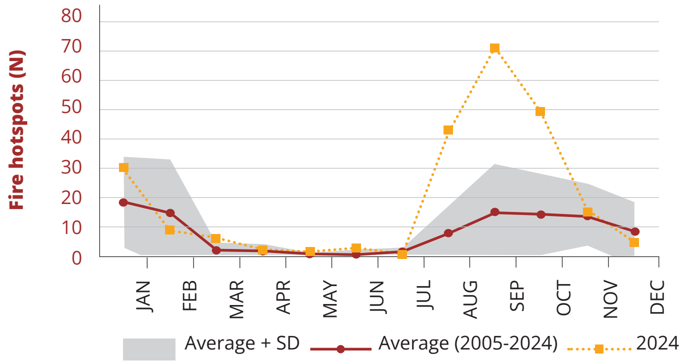
FIGURE 26. Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas in the Ecuadorian Amazon region.
Source: MCD64A1, RAISG



WHEN

The Ecuadorian Amazon shows a more dispersed pattern, with fire recorded in several months of the year, but with modest peaks between January and February and another slight increase between September and November (Figure 24).

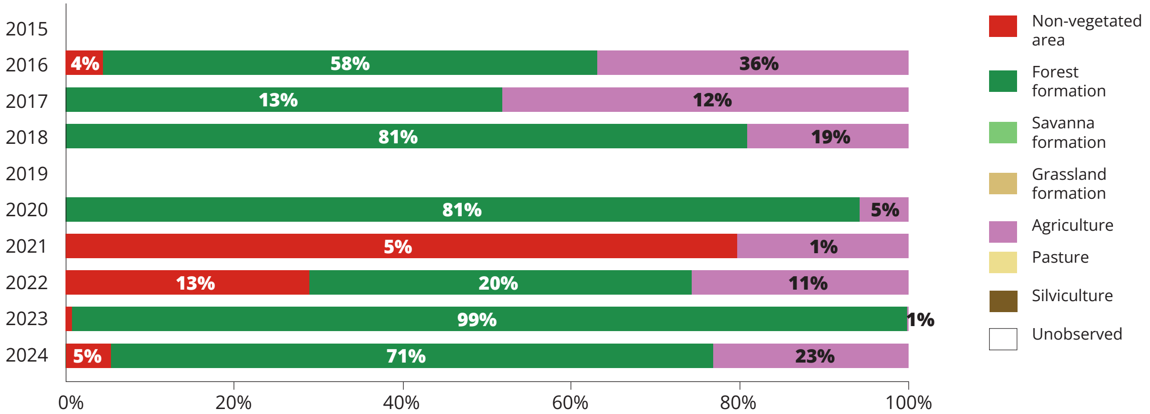
FIGURE 24. Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (orange dashed line) in the Ecuadorian Amazon region.
Source: reference satellite Aqua M-T



WHAT

In this region, the forest formation category was the most affected by fire in 2024, accounting for 71% of burned areas and consolidating an upward trend since 2021. Agriculture ranked second, with 23%, while non-vegetated areas occupied the third position with 5% (Figure 25).

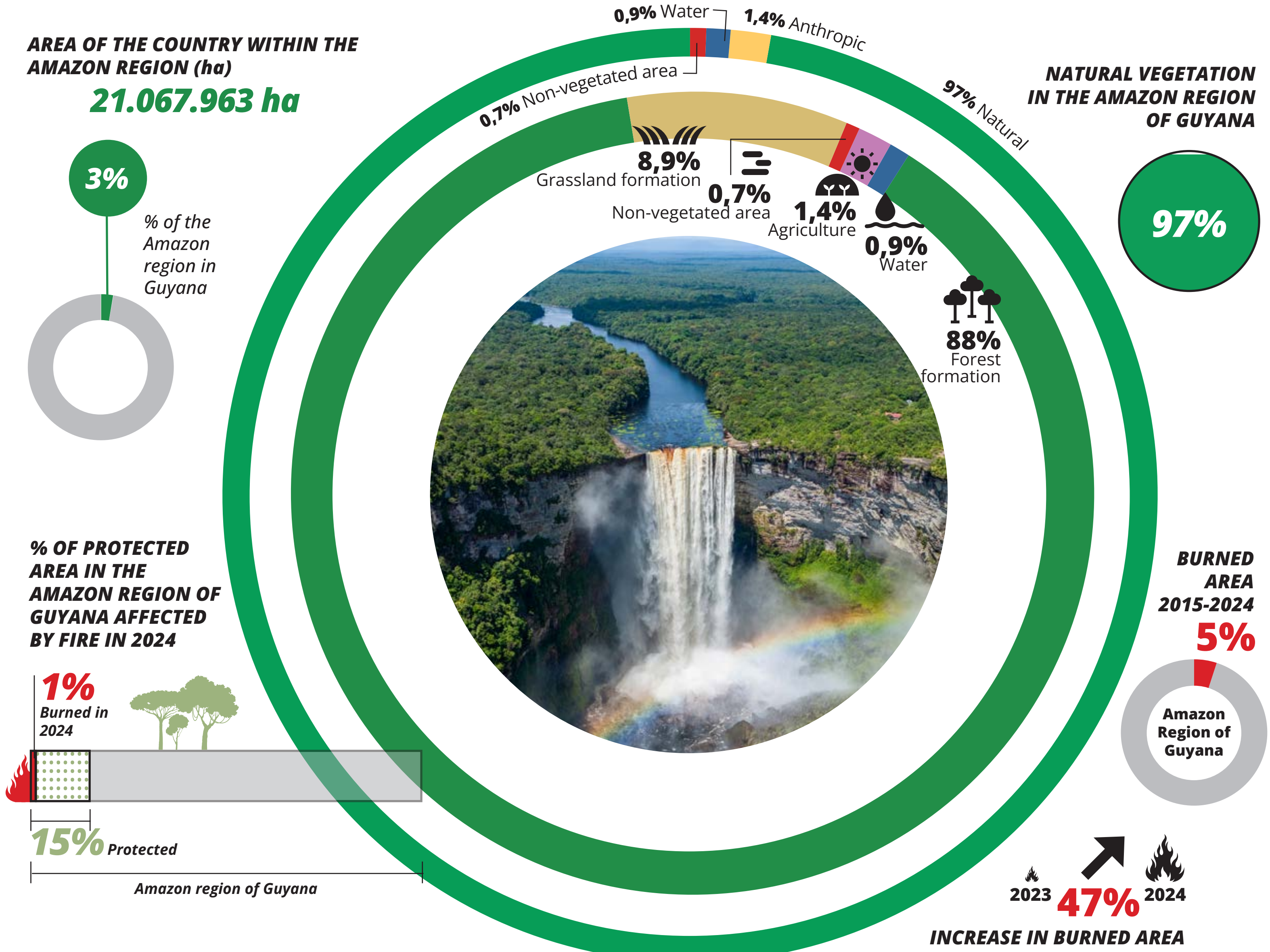
FIGURE 25. Proportion of burned area by land use and land cover from 2015 to 2024 in the Ecuadorian Amazon region. Source: MCD64A1, MapBiomas Ecuador



//// GUYANA

In Guyana, gold mining is responsible for more than 90% of recent deforestation and is considered the main driver of land-use change in the country. The activity, largely artisanal, also contributes to forest degradation and is strongly associated with increased deforestation during periods of high gold prices[52]. Over the past decade (2015–2024), fire in Guyana has been concentrated mainly in the northeastern and southwestern portions of the country, occurring primarily in areas of non-forest native vegetation (Figure 27).

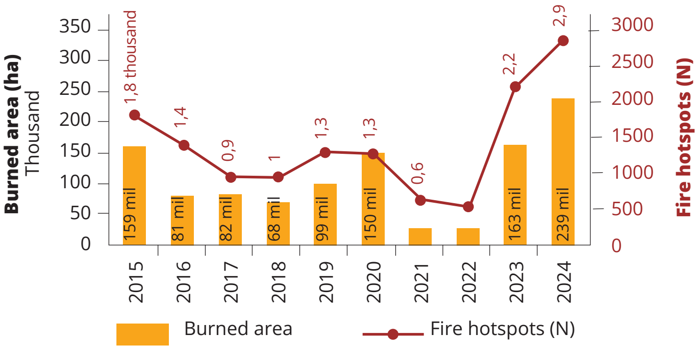
FIGURE 27. Distribution of the proportions of land use and land cover burned area, occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024 in the Amazon region of Guyana.
Source: RAISG, MapBiomas Guiana, MCD64A1



HOW MUCH

The average annual burned area over the past decade was 114 thousand hectares. The highest value occurred in 2024, with 248 thousand hectares burned, an increase of 117% compared to the decade's average. That same year also recorded the highest number of fire hotspots (2.861) (Figure 28).

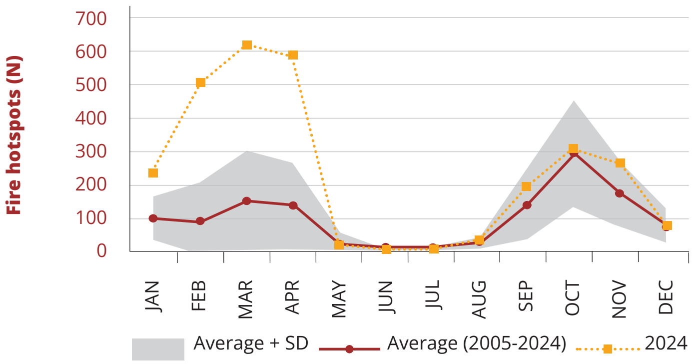
FIGURE 28. Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Amazon region of Guyana.
Source: MCD64A1, reference satellite Aqua M-T



WHEN

Guyana has a relatively spread-out fire season, with multiple smaller peaks throughout the year, although October (24%) and November (14%) stand out (Figure 29).

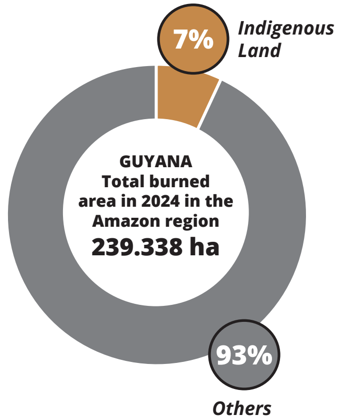
FIGURE 29. Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (blue dashed line) in the Amazon region of Guyana.
Source: reference satellite Aqua M-T



WHERE

Only 7% of the burned area in 2024 occurred within indigenous lands, while 93% affected areas outside protected territories (Figure 31).

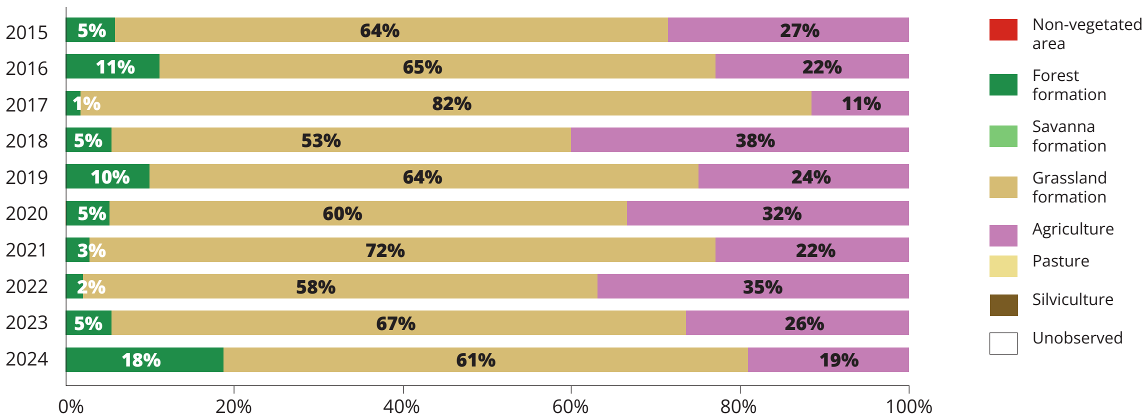
FIGURE 31. Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas (PNA) in the Amazon region of Guyana.
Source: MCD64A1, RAISG



WHAT

In Guyana, grassland formations continued to dominate, accounting for 61% of the burned area in 2024, though showing a slight decline. Agriculture represented 19%, continuing its downward trend since 2022. Forest formations increased, reaching 18% in 2024, marking their highest value in the past decade (Figure 30).

FIGURE 30. Proportion of burned area by land use and cover type from 2015 to 2024 in the Amazon region of Guyana. Source: MCD64A1, MapBiomas Amazonia



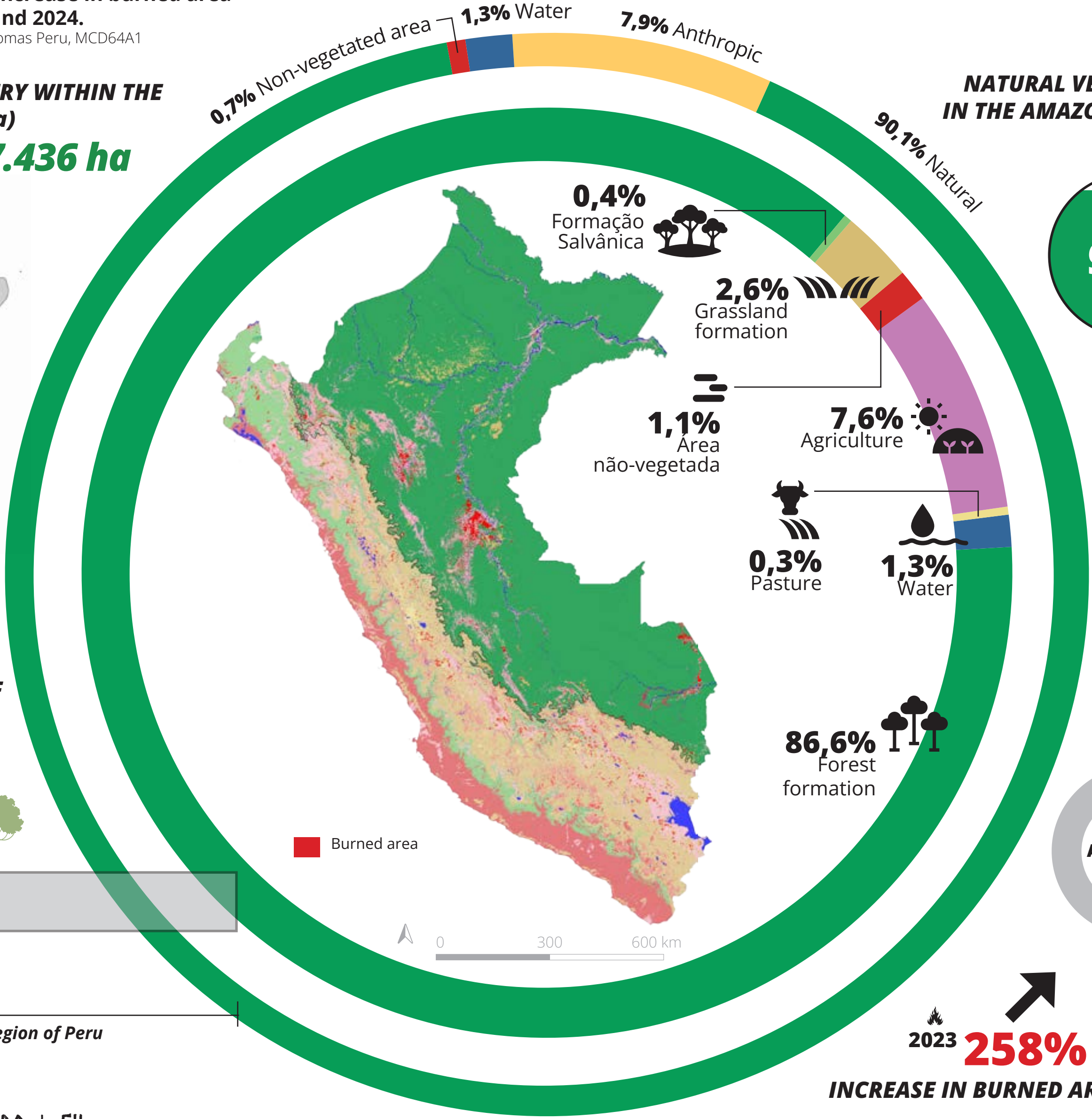
//// PERU

In Peru, traditional slash-and-burn agriculture and the expansion of cattle ranching, combined with prolonged droughts, are strongly linked to the growing use of fire. Non-categorized zones, untitled permanent production forests, agricultural properties, indigenous territories, and logging concessions are among the areas most affected by fires[53]. Road construction has facilitated encroachment on land and illegal activities such as gold mining, coca production, and drug trafficking, particularly in sparsely populated regions[54,55,56,57]. Additionally, the oil sector remains an important economic activity in the region and is closely associated with road expansion and the consequent increase in wildfires across the Peruvian Amazon. Although burning is officially prohibited in Peru, except under special authorization, fire management remains limited by a lack of enforcement and the difficulty of reaching remote areas. As a result, those responsible for the fires often go unpunished. Over the past decade (2015–2024), fire activity has been concentrated mainly in agricultural areas in the central part of the country (Figure 32).

FIGURE 32. Distribution of the accumulated burned area between 2015 and 2024 (in red on the map) in Peru, highlighting the Amazon region (black outline). The figure shows the proportions of land use and land cover and of the burned area in the region, the occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024.
Source: RAISG, MapBiomas Peru, MCD64A1

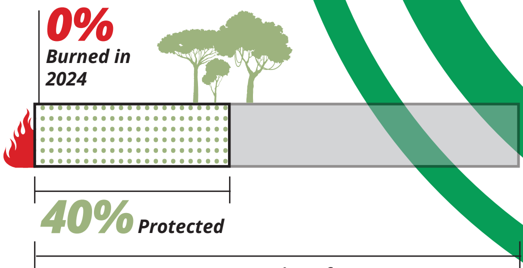
AREA OF THE COUNTRY WITHIN THE AMAZON REGION (ha)

129.087.436 ha



NATURAL VEGETATION IN THE AMAZON REGION OF PERU

% OF PROTECTED AREA IN THE AMAZON REGION OF PERU AFFECTED BY FIRE IN 2024



BURNED AREA 2015-2024

1%

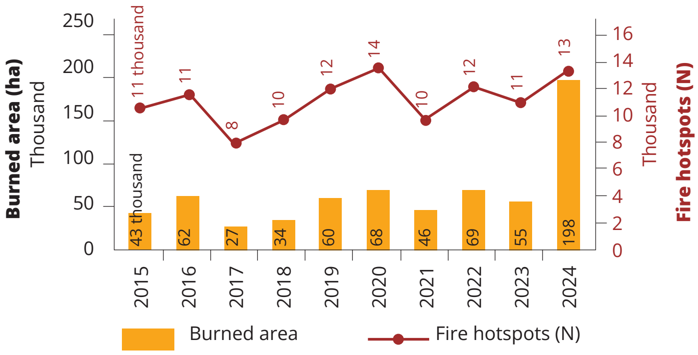
2023 **258%** 2024

INCREASE IN BURNED AREA

HOW MUCH

Peru recorded an average of 66 thousand hectares of burned area per year in the Amazon region. In 2024, the country reached its highest value, with 199 thousand hectares burned, an increase of 199% compared to the decade's average. Despite this, 2020 registered the highest number of fire hotspots (13.576) (Figure 33).

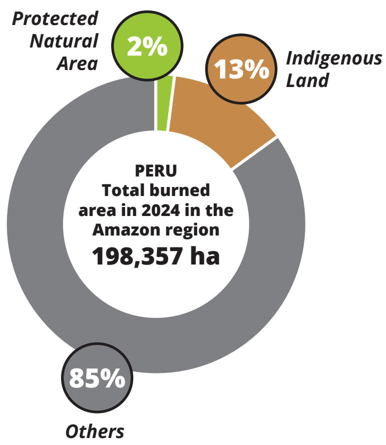
FIGURE 33. **Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Amazon region of Peru.**
Source: MCD64A1, reference satellite Aqua M-T



WHERE

In the Peruvian Amazon, 13% of the burned area in 2024 occurred within indigenous lands, 2% within other protected areas, and 85% in non-protected territories (Figure 36).

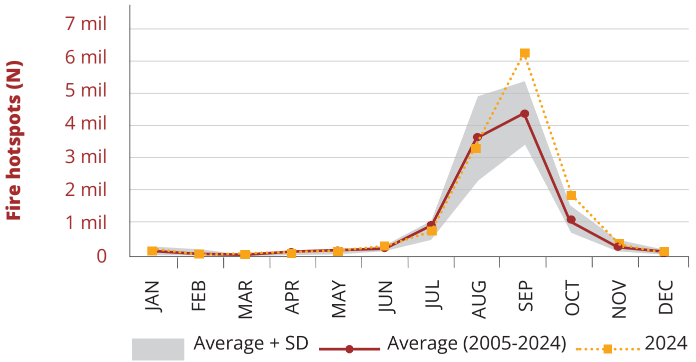
FIGURE 36. **Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas in the Amazon region of Peru.**
Source: MCD64A1, RAISG



WHEN

The Peruvian Amazon has a well-defined and concentrated fire season, with clear peaks in August (32%) and September (40%), together accounting for more than 70% of recorded occurrences (Figure 34).

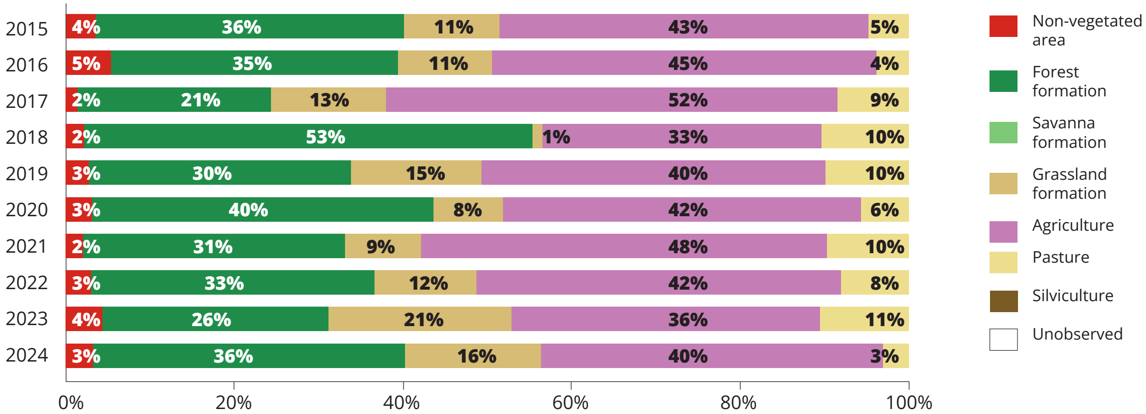
FIGURE 34. **Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (blue dashed line) in the Amazon region of Peru.**
Source: reference satellite Aqua M-T



WHAT

Agriculture remains the category with the largest burned area in the Peruvian Amazon region, accounting for 40% in 2024 and maintaining stable levels over the years. Forest formations increased to 36% in 2024, nearly matching the leading category, while natural non-forest formations ranked third with 16%, showing an upward trend (Figure 35).

FIGURE 35. **Proportion of burned area by land use and cover type from 2015 to 2024 in the Amazon region of Peru.** Source: MCD64A1, MapBiomas Peru



//// SURINAME

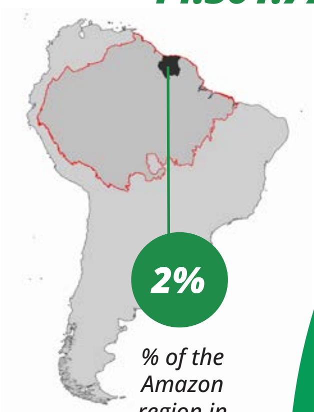
In Suriname, small-scale gold mining is also a leading driver of deforestation. It is estimated that between 2000 and 2019, approximately 11% of forest loss was directly linked to industrial mining, with even broader indirect impacts on the landscape[58]. The unregulated expansion of these activities, often preceded by vegetation burning, increases the risk of wildfires in deteriorated areas. Over the past decade (2015–2024), fire activity has been concentrated in agricultural zones and native non-forest vegetation, mainly in the northern part of the country and in the south near the brazilian border (Figure 37).

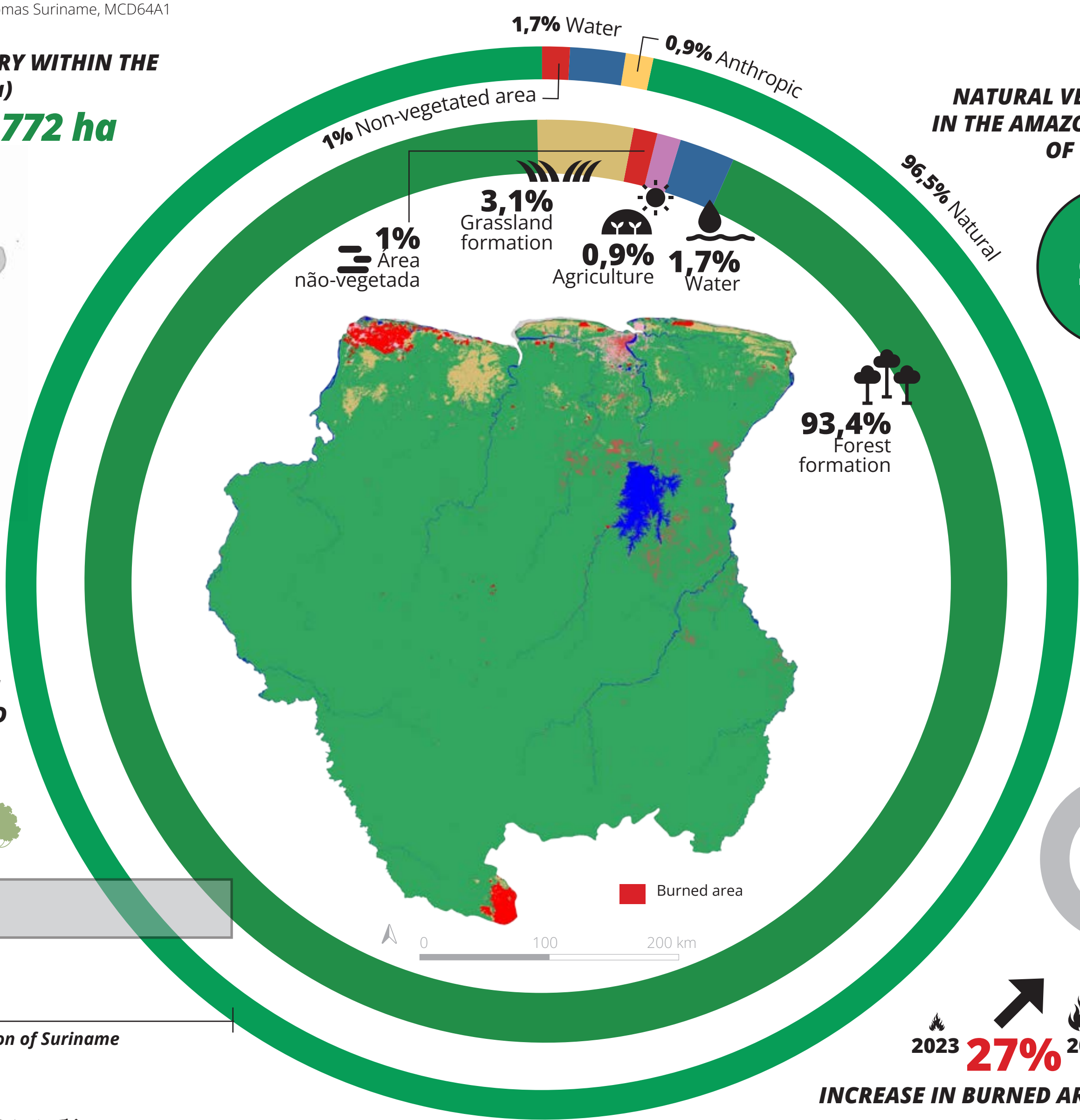
FIGURE 37. Distribution of the accumulated burned area between 2015 and 2024 (in red on the map) in Suriname, highlighting the Amazon region (black outline). The figure shows the proportions of land use and land cover and of the burned area in the region, the occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024.

Source: RAISG, MapBiomas Suriname, MCD64A1

AREA OF THE COUNTRY WITHIN THE AMAZON REGION (ha)

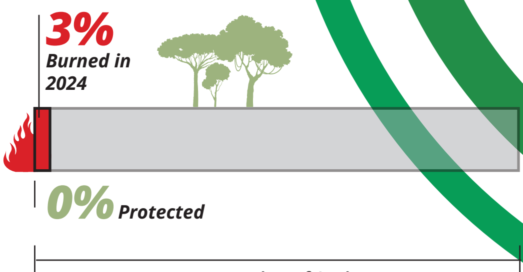
14.501.772 ha





NATURAL VEGETATION IN THE AMAZON REGION OF SURINAME

% OF PROTECTED AREA IN THE AMAZON REGION OF SURINAME AFFECTED BY FIRE IN 2024



BURNED AREA 2015-2024

2%

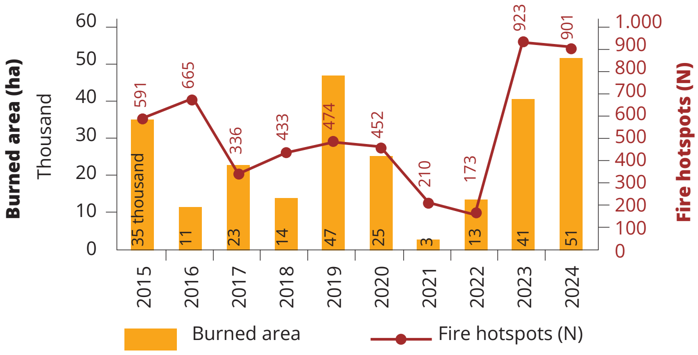
2023 **27%** 2024

INCREASE IN BURNED AREA

HOW MUCH

Suriname recorded an average of 28 thousand hectares of burned area per year. The peak occurred in 2024, with 53 thousand hectares burned, an increase of 91% compared to the average. The years 2023 and 2024 also showed high levels of fire hotspots relative to previous years, with 923 and 901 detections respectively (Figure 38).

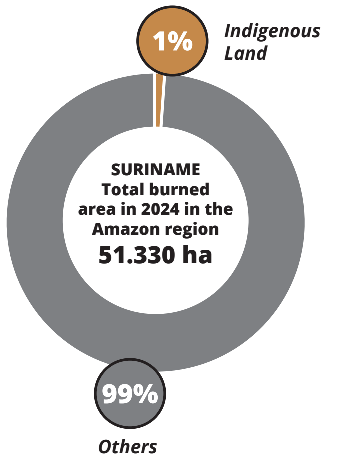
FIGURE 38. Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Amazon region of Suriname.
Source: MCD64A1, reference satellite Aqua M-T



WHERE

In 2024, only 1% of the burned area in Suriname occurred within indigenous lands, while 99% affected other land categories outside protected areas (Figure 41).

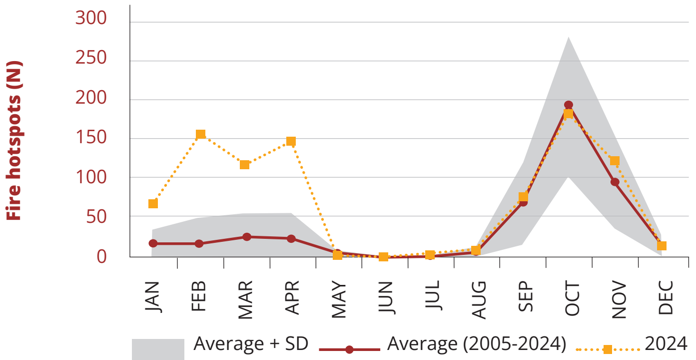
FIGURE 41. Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas in the Amazon region of Suriname.
Source: MCD64A1, RAISG



WHEN

Suriname has a fire season concentrated at the end of the year, with October (42%) and November (21%) being the most critical months (Figure 39).

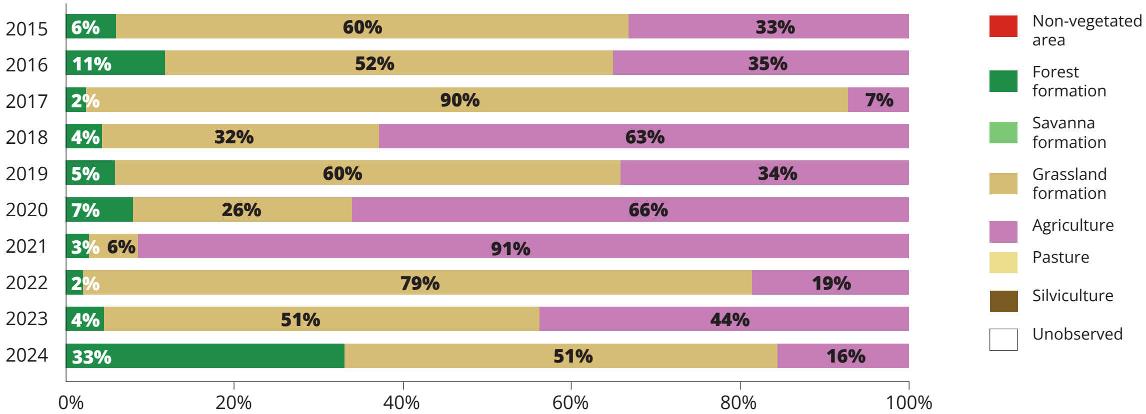
FIGURE 39. Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (blue dashed line) in the Amazon region of Suriname.
Source: reference satellite Aqua M-T



WHAT

Grassland formations are the main category affected by fire in Suriname, accounting for 51% of the burned area in 2024. Forests are increasingly being impacted, rising to 33% in 2024 (compared to only 2%–7% in previous years), surpassing agriculture, which dropped to 16% after having reached as much as 91% in 2021 (Figure 40).

FIGURE 40. Proportion of burned area by land use and cover type from 2015 to 2024 in the Amazon region of Suriname. Source: MCD64A1, MapBiomas Amazônia)

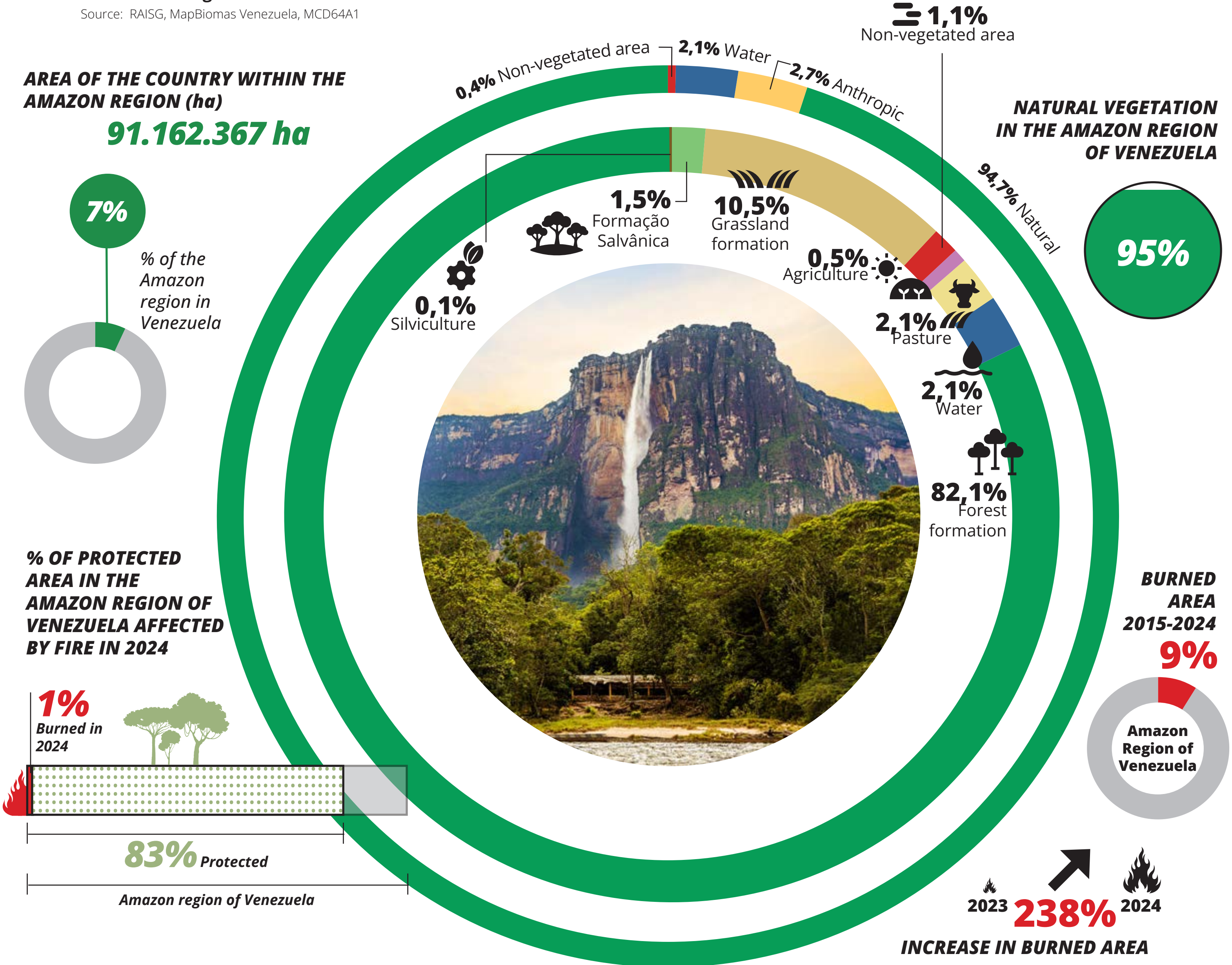


//// VENEZUELA

Finally, in Venezuela, historically less affected by deforestation, the recent expansion of the agricultural frontier has also increased the occurrence of wildfires, making the country the third most affected in the Amazon between 2001 and 2018[59]. Over the past decade (2015–2024), fire activity has been concentrated north of the Orinoco river. In the Venezuelan Amazon, the burned area was mainly concentrated in native non-forest vegetation (Figure 42).

FIGURE 42. **Distribution of the proportions of land use and land cover, burned area, occurrence of fire within protected areas, and the increase in burned area between 2023 and 2024 in the Amazon region of Venezuela.**

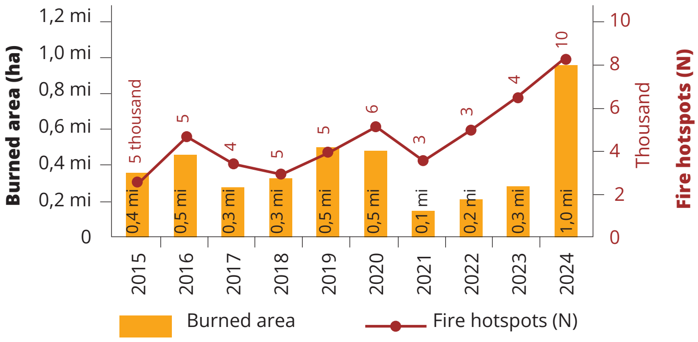
Source: RAISG, MapBiomas Venezuela, MCD64A1



HOW MUCH

The annual average of burned area in the Venezuelan Amazon between 2015 and 2024 was 411 thousand hectares. The highest value was recorded in 2024, with 977 thousand hectares burned, a 138% increase compared to the average. This was also the year with the highest number of fire hotspots (9.869) (Figure 43).

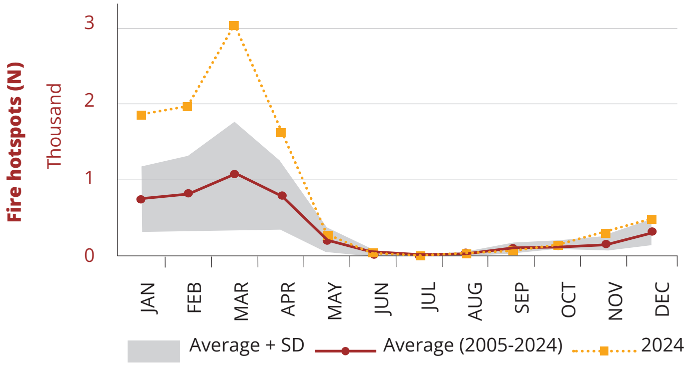
FIGURE 43. Annual burned area (bars) and fire hotspots (line) between 2015 and 2024 in the Amazon region of Venezuela.
Source: MCD64A1, reference satellite Aqua M-T



WHEN

The Venezuelan Amazon is one of the few cases where the fire season is concentrated in the first quarter of the year, with moderate but consistent peaks in March (22%), February (18%), and January (16%). This indicates a more dispersed yet still seasonal distribution (Figure 44).

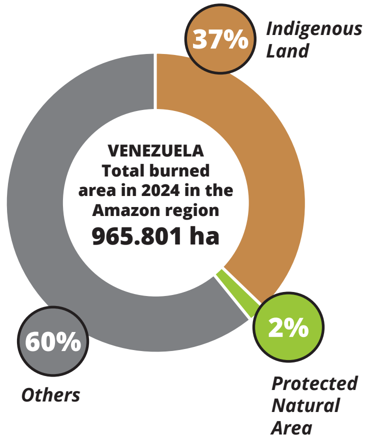
FIGURE 44. Monthly average number of fire hotspots (2005–2023), with ±1 standard deviation (gray shaded area) and 2024 values (blue dashed line) in the Amazon region of Venezuela.
Source: reference satellite Aqua M-T



WHERE

In Venezuela, 37% of the burned area in 2024 occurred within indigenous lands, 2% within other protected areas, and 60% in other territories (Figure 46).

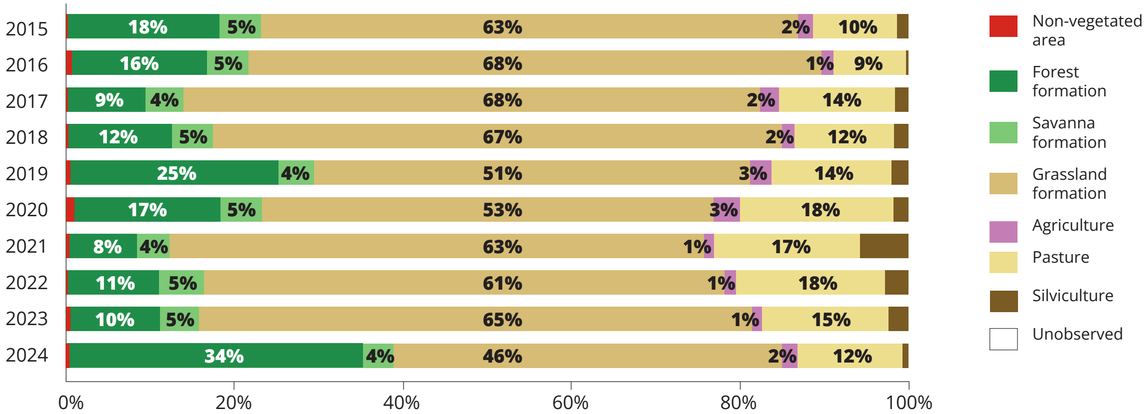
FIGURE 46. Total burned area in 2024 and proportion burned within indigenous lands and Protected Natural Areas in the Amazon region of Venezuela.
Source: MCD64A1, RAISG



WHAT

In the Venezuelan Amazon, grassland formations remain predominant, accounting for 46% of burned areas in 2024, although this represents a decline from previous years (up to 68%). Forest formations more than tripled their share, reaching 34% in 2024. Pastures remain the third most affected category, with 12%, showing relative stability over the past decade (Figure 45).

FIGURE 45. Proportion of burned area by land use and cover type from 2015 to 2024 in the Amazon region of Venezuela. Source: MCD64A1, MapBiomas Venezuela



chapter 4

CLIMATE AND FIRE

Renata Libonati[1,2], Ana Nunes[1], Ronaldo Albuquerque[1]
[1]Departamento de Meteorologia, Universidade Federal do Rio de Janeiro – Brazil
[2]Instituto Dom Luiz (IDL), Universidade de Lisboa – Portugal

The line between cause and consequence is thin: wildfires and climate change go hand in hand. As global temperatures rise, extreme events such as prolonged droughts and heatwaves become more frequent and intense, creating increasingly favorable conditions for wildfires[1,2,3] to occur in a self-reinforcing cycle. In the Amazon, the combination of degraded landscapes and extreme climate conditions has paved the way for fires that are ever more intense and difficult to control.

It is important to note that climate is not the only factor at play: deforestation and land-use changes remain the main drivers behind the expansion of burned areas in the region[4,5]. The synergy between landscape fragmentation, environmental degradation, and the intensification of the climate crisis has increased the biome's vulnerability and drastically altered its fire regimes[6], pushing the Amazon ever closer to the tipping point of no return[7,8].

The Earth's average surface temperature has risen by approximately 1.2 °C since 1950, driven mainly by greenhouse gas emissions and land-use changes. The years 2023 and 2024 were the hottest ever recorded in the entire historical series, marking a new critical threshold in the global climate crisis[9]. Scientific evidence indicates that in a scenario of warming above 4 °C, parts of the tropics, including the Amazon, could become uninhabitable for humans due to extreme heat stress, where the combination of temperature and humidity prevents the body from dissipating heat, surpassing the physiological limits of human survival[10]. In the Amazon, air temperatures have been steadily increasing over recent decades. This warming has been accompanied by a higher frequency of extreme heat days and heatwaves[11,12,13,14]. During the dry season, the southern part of the Amazon rainforest has shown a warming trend of 0.49 °C per decade between 1979 and 2012, with an even sharper trend of 1.12 °C per decade since 2000[15].

As temperatures continued to rise, between 2020 and 2024 much of the Amazon experienced an almost continuous period of extreme heat. About 20% of the days during this period were marked by heatwaves, meaning that one in every five days recorded abnormally high air temperatures. This frequency is unprecedented in the past four decades, although a gradual increase in the number of heatwave days had already been observed over time (Figure 1).

In parallel with the heatwaves, the Amazon has been facing increasingly severe droughts[16]. Among the most significant events were those of 1998, 2005, 2010, 2015/2016, and more recently, the 2023/2024 drought, considered one of the most severe ever recorded in the region[17]. According to the Standardized Precipitation Evapotranspiration Index (SPEI), which measures drought by accounting not only for rainfall deficit but also for air temperature, the 2023/2024 drought was the most intense since 1980 in the Amazon. In 2024, the SPEI showed the largest negative anomalies for hydrological drought, reflecting low precipitation rates and river drying (Figure 2a), indicating a prolonged drought scenario[18,19]. By December 2024, the central Amazon region displayed an extensive area with strong drought conditions (Figure 2b).

FIGURE 1. Percentage of days under heatwave conditions (HW) across the decades of 1980, 1990, 2000, and 2010, and during the five-year period from 2020 to 2024.

Source: ERA5 Reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF)

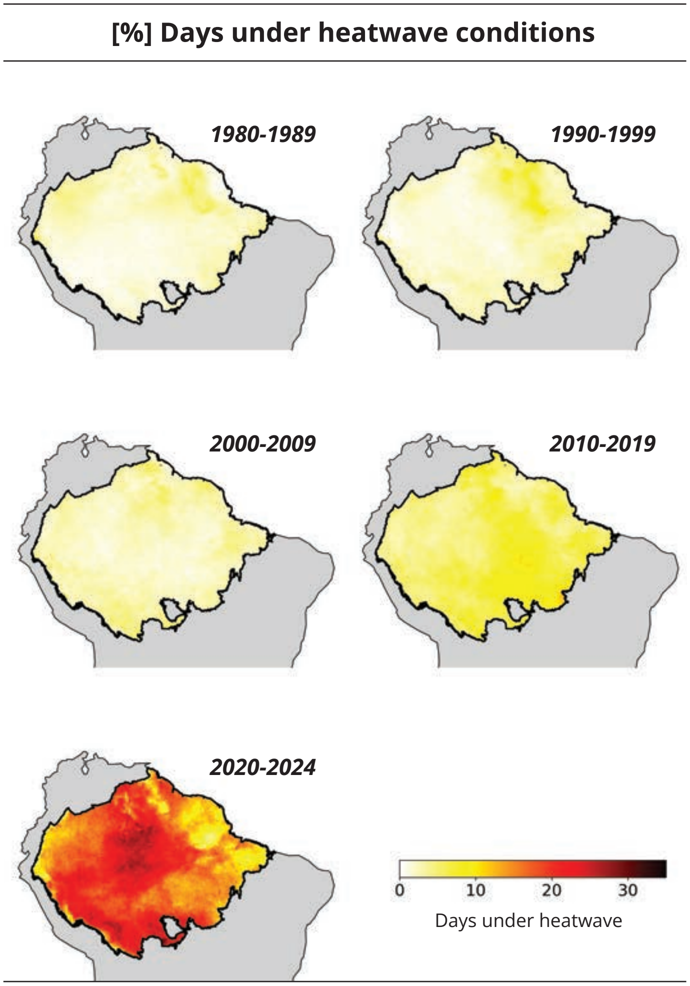
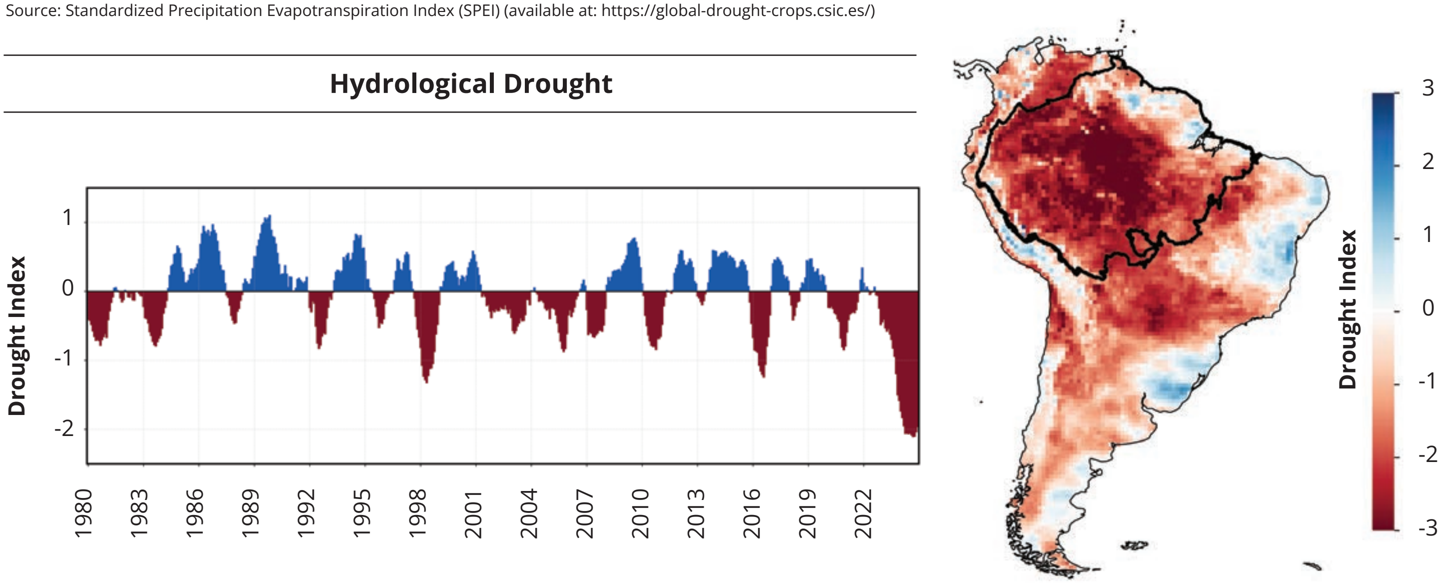


FIGURE 2. **Interannual variability of hydrological droughts (SPEI-12 Index) for the period 1980–2024 (a). Spatial distribution of hydrological drought in December 2024 (b). The black outline highlights the biogeographical boundaries of the Amazon.**

Source: Standardized Precipitation Evapotranspiration Index (SPEI) (available at: https://global-drought-crops.csic.es/)



There is growing evidence that heatwaves are becoming increasingly associated with drought events[20,21,22,23,24]. Over the past two decades, many regions across the Americas have had more than two-thirds of their areas under higher susceptibility to heatwaves during drought periods[25]. Studies show that the hottest years and the most intense heatwaves in the Amazon have also coincided with severe droughts[15,26], and these events can be further intensified by other environmental variables, such as the occurrence of El Niño.

With the intensification of the greenhouse effect, excess heat in the atmosphere has been absorbed by the oceans, causing abnormal warming of ocean waters across the planet. For the Amazon, this warming is particularly relevant in the equatorial regions of the Pacific ocean, where the phenomenon known as El Niño occurs, and in the Atlantic ocean. When these areas become significantly warmer than normal, they can reduce cloud formation over the Amazon, hindering rainfall and creating conditions that favor periods of extreme drought[27].

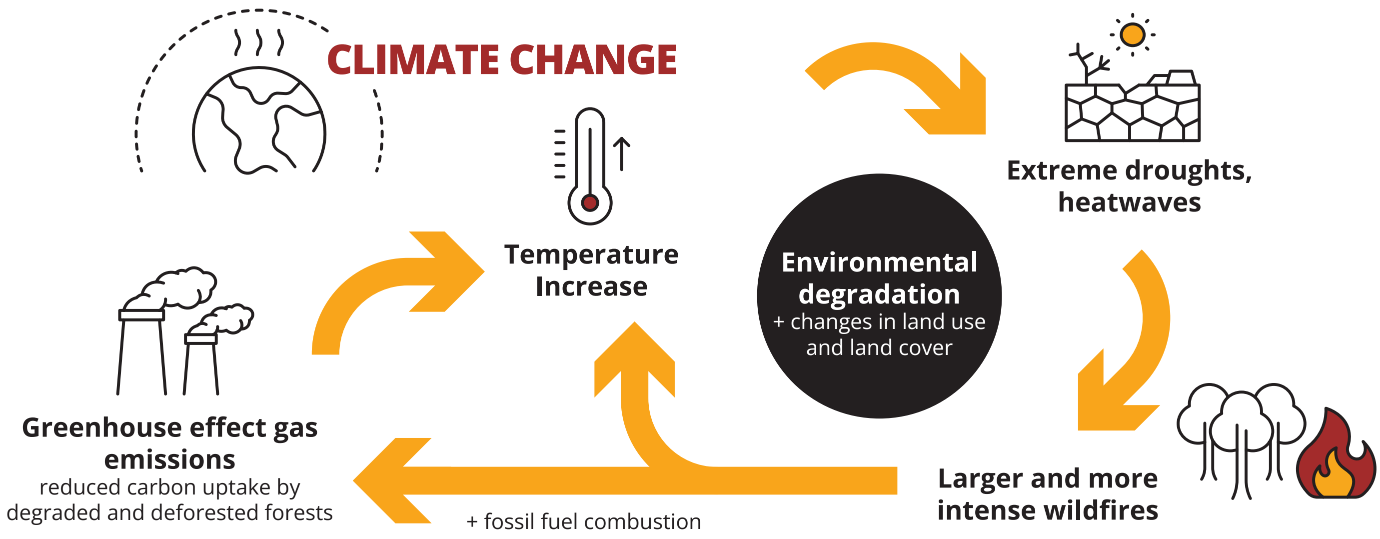
In 2010, 2015, and 2023, for instance, intense El Niño events contributed to historic droughts across the region, bringing about economic and social consequences on an unprecedented scale[28]. This situation may worsen as climate change progresses, since these climatic anomalies are expected to become more frequent and intense, increasingly disrupting the planet's climate balance[29].

The combination of two or more phenomena, such as extreme heat, droughts, and wildfires, is referred to as a compound event[21]. This type of situation poses a new challenge, as the effects multiply and interact, leading to more severe impacts than if they occurred independently[23]. In recent years, compound events have become increasingly frequent, affecting larger areas and lasting longer periods. They are driven not only by climatic factors but also by human-driven ones, such as deforestation and climate change[32].

During the 2015/2016 mega-drought event, more than 80% of the Amazon was affected[33], a situation that expanded further in 2024 (Figure 2c, Figure 2d). This type of event develops through a feedback cycle: rising air temperatures dry out the soil, intensifying drought conditions and further reducing air and soil moisture. As the soil dries, its ability to release heat diminishes, leading to even higher temperatures.[16] In the southern part of the Amazon, for example, droughts have been shown to amplify air temperature, and vice versa[26].

When wildfires enter this cycle, their effects become even more pronounced. Heatwaves, droughts, and degraded landscapes create conditions that favor the spread of wildfires, which in turn release large volumes of greenhouse gases, alter land cover, and further destabilize the climate system. The expansion of the critical wildfire season around the world has been documented over the past decades, with an increase in the duration, frequency, and intensity of these events[1].

In the Amazon, forests that once rarely burned have become increasingly flammable due to excessive heat, reduced humidity, and environmental degradation[30]. Wildfires are no longer just consequences of climate conditions; they have become active agents in transforming both ecological and atmospheric systems[3], as illustrated in the diagram below.



To monitor and anticipate the growing risk of wildfires, the Fire Weather Index (FWI) is used. This index takes into account air temperature, relative humidity, wind speed, and precipitation to determine the susceptibility to fire occurrence and spread[36]. When analyzing this indicator over time, it is evident that northern Amazonia has shown a decreasing trend in extreme fire danger over the past 45 years. However, the rest of the region, particularly the central portion, which coincides with the course of the Amazon River, shows a strong upward trend, standing out even when compared with other regions of South America (Figure 3). Between 1980 and 2024, there was an overall increase of 30 days in the number of days with extreme fire danger, which in practice represents one additional month per year under conditions favorable to fire.

Climate assessments, both past and future, are based on climate models that simulate possible pathways of societal development, taking into account factors such as population growth, land use and energy mix. These scenarios, known as Shared Socioeconomic Pathways (SSPs), form the basis for the climate projections included in the Sixth IPCC Assessment Report (AR6)[38].

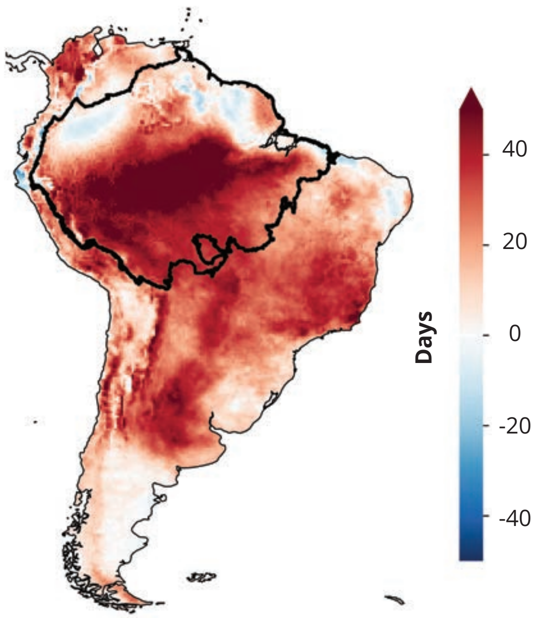
From these scenarios, the models project changes in temperature, precipitation, and other parameters. This information is essential for estimating the Fire Weather Index, as it captures the anthropic effects on Earth's climate.

Five narratives describe different possible futures. The scenarios SSP1-2.6 (sustainable development), SSP3-7.0 (regional rivalries), and SSP5-8.5 (fossil fuel dependence) represent low, medium-high, and high climate risk pathways, respectively[37]. In the most extreme scenario (SSP5-8.5), the Amazon could face more than 200 days per year with maximum temperatures above 35°C. Even under the sustainable scenario (SSP1-2.6), an increase of at least 50 hot

FIGURE 3. Absolute linear trend in the number of days per year with extreme fire danger (FWI above the 95th percentile threshold) for the period 1980-2024. The black outline highlights the biogeographical boundary of the Amazon.

Source: Fire Weather Index (FWI) (available at: https://ewds.climate.copernicus.eu/datasets/cems-fire-historical-v1?tab=overview)

Trend in the Annual Number of Days with Extreme Fire Occurrence and Spread Danger



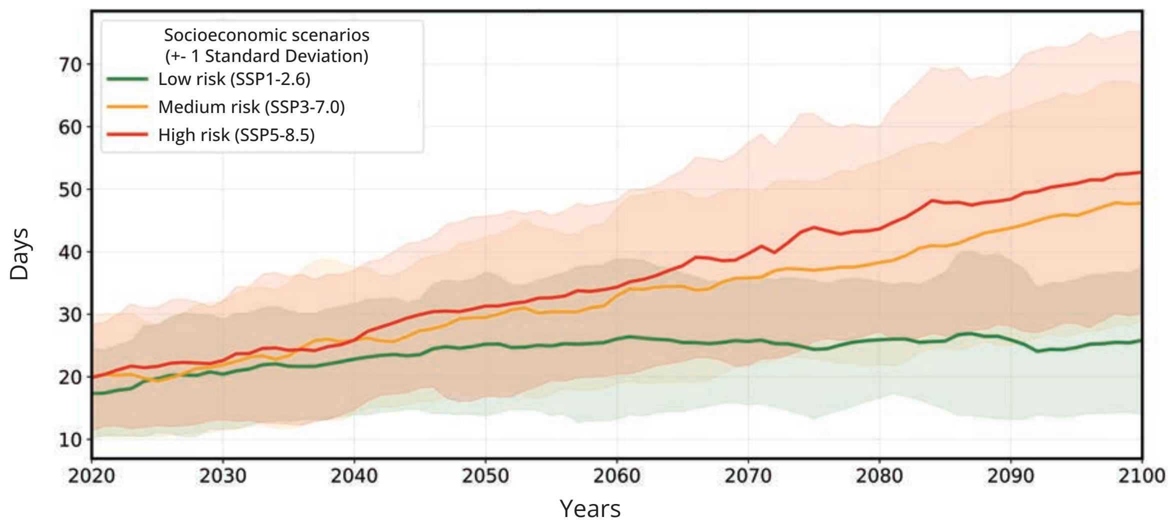
days per year is expected compared to the 1995-2014 period39,40, along with greater intensity of these events[41].

The IPCC[38] estimates that the planet's average temperature will rise by at least 2°C by 2100, with more frequent and severe droughts. Studies indicate that a warming of at least 3°C could increase the duration and frequency of fires by 66%42. South America, particularly the Amazon, ranks among the regions of greatest concern, with projections of significant increases in drought, aridity, and wildfire rates39. It is estimated that by the end of the 21st century, the number of days with extreme fire danger could exceed 48 days under the SSP3-7.0 scenario and reach more than 50 days under SSP5-8.5. In contrast, the SSP1-2.6 scenario projects stabilization below 30 days per year by the end of the century (Figure 4).

FIGURE 4. **Interannual variability in the number of days with extreme fire danger (FWI > 95th percentile) for the period 2020–2100 (pre-industrial reference period: 1850–1900).** The lines represent the six-year moving average of the multi-model global climate ensemble for three Shared Socioeconomic Pathway scenarios: SSP1-2.6 (low risk; green), SSP3-7.0 (medium-high risk; orange), and SSP5-8.5 (high risk; red). The shaded areas indicate variability, represented by the standard deviation (±1σ) for each scenario. Projected data on extreme FWI days were obtained from Quilcaille and Batibeniz[43].

Source: Quilcaille; Batibeniz, 2022 (https://doi.org/10.3929/ethz-b-000583391)

Annual number of days with extreme fire danger



Protecting the Amazon in face of projected increases in temperature, extreme drought, and fire danger requires not only curbing human pressures on the forest but also deepening the understanding of interactions between climate and human activity. There are still many uncertainties about how climatic and anthropic factors interact, underscoring the need for further research and monitoring[20]. Available precipitation and temperature data often have limitations and/or biases in the Amazon, reflecting the scarcity of meteorological stations and the difficulty of adequately representing the region's environmental diversity[11]. Gaining a deeper understanding of the complex interplay between climate and human activity is essential for protecting the Amazon and for understanding the increasingly severe impacts on its territories, ecosystems and populations.

THE BILL OF FIRES

chapter 5

Mariana Conte Grand
Senior Environmental Economist, Latin America and the Caribbean – World Bank Group*

In recent years the scale of Amazonian fires has been unprecedented. As detailed in Chapter 3, between 2019 and 2024, countries across the Amazon basin experienced burned areas consistently above historical averages, with 2024 standing out as especially severe: 43.4 million hectares (ha) burned in total, including 16.4 million hectares within the Amazon itself. In 2024, fires affecting forested areas reached record levels. As discussed in Chapter 4, these trends are expected to intensify under ongoing climate change. This makes it increasingly urgent to recognize and address the far-reaching damages caused by fires throughout the Amazon, with the goal of raising awareness and shaping more efficient policies.

This chapter has three main goals. First, to break down the different impacts from fires into three categories — environmental, social, economic — and illustrate them in both physical and monetary terms across the Amazon. Second, to show the extent of wildfire damage at the international level, to understand the scale of losses. And third, to present — hrough some examples — why understanding the monetary costs and benefits of fires is crucial for designing and evaluating public policies, particularly through cost-benefit and cost-effectiveness analysis.

* This work was financed by the *Improving prevention and response to Amazon Forest Fires* Global Facility for Disaster Reduction and Recovery Trust Fund (TF0C3707) within the Regional Action Program to Protect the Amazon (P180939). The author thanks the insights by Fernando Rodovalho, Joao Moura Estevao Marques, Aldana Joel Canton and Judith Sardinas.

CONSEQUENCES OF WILDFIRES IN THE AMAZON

It is acknowledged that fire is not always bad, in fact, it often plays a positive role in many natural and human-managed ecosystems[1]. Indigenous communities along the Amazon have been particularly successful in their traditional use of fire to achieve benefits related to soil enhancement, territory protection and cleaning, and spiritual and aesthetic purposes[2]. Fire itself is a natural ecological element that, when supervised or occurring at appropriate intervals, can yield a range of important benefits, while uncontrolled or excessively frequent fires can cause significant harm.

The occurrence of wildfires in forested lands, agricultural areas, and locations near human settlements can have a wide range of direct and indirect impacts. These include human injury or fatalities from flames, destruction of property such as homes, buildings and infrastructure, and negative effects on economic productivity including forestry, agriculture, and livestock production[3]. Fires can also lead to temporary increases in greenhouse gas (GHG) emissions, changes in ecosystem services, and impacts on human health through worsened air quality, among others[4]. While classifications of the impacts may vary, they can be grouped into the following categories (summarized in Figure 1):

THE BILL OF FIRE

1

ENVIRONMENTAL

- **BIODIVERSITY**
  Wildfires in the Amazon degrade habitats and disrupt ecological interactions, leading to local extinctions and long-term biodiversity loss. Repeated burns reduce forest structure and complexity, affecting canopy-dependent species such as pollinators, seed dispersers and endemic fauna. Fire events also displace wildlife, increasing road crossing attempts and related mortality.

- **ECOSYSTEM SERVICES**
  Fire-induced degradation reduces evapotranspiration and alters rainfall dynamics, reinforcing a drying–burning feedback loop. Other affected services include hydrological regulation, soil fertility, pollination, and the availability of non-timber forest products and cultural values.

- **CARBON EMISSIONS**
  Results from the release of carbon stocks stored in the biomass present in forests, different types of vegetation, and soil.

2

SOCIAL

- **HEALTH**
  Direct exposure to flames or radiant heat can cause injuries or fatalities, including burns, dehydration, or heat stroke. Wildfires also contribute to poor air quality, leading to respiratory illnesses and other health problems that can affect both current and future income. Mental health impacts, such as post-traumatic stress disorder, depression, and insomnia, are also commonly reported post-fire[5].

- **COMMUNITY DISPLACEMENT/ MIGRATION**
  Large-scale wildfires can lead to the displacement of communities, disrupting lives and livelihoods. It can also lead to permanent migration.

All testimonies included in this publication were collected by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and were previously approved by the speakers. They do not originate from the chapter authors or their respective institutions. We extend our heartfelt thanks to the speakers, as well as to David Torres, Laurenz Romero, Sergio Cobos, and Camilo Andres Acosta for their collaboration.

©Central Ashaninka del Rio Ene

PERU

*My name is **Querenia Claudio Bustamante**, and I am from the native community of Tsiquireni (Peru).*

Last year, there was a fire that deeply worried me because of the damage it caused to the forest and the animals. The community members were unable to put it out because the fire had already spread too far. It lasted for more than a month and came very close to the neighboring community of Pitsiquia.

After what happened, all the members of our community gathered to strengthen prevention and safety measures when carrying out burns. We value the forest greatly because it is our source of food and life.

ECONOMIC

- **PRODUCTIVE ACTIVITIES**
  Wildfires can cause losses in agriculture, timber, and other products from forest-related industries, along with economic impacts related to short-term business interruption and disruptions to systems such as power, water, public safety, and schools.

- **PROPERTIES**
  Fires can destroy homes, infrastructure and other assets.

- **FISCAL IMPACTS**
  On the expenditure side, governments face increased costs to fund wildfire prevention, aid relief and evacuation services, immediate road and landscape stabilization, and fire suppression. On the revenue side, wildfires can reduce public revenue due to reduced exports, and a lower capacity of affected businesses and people to comply with tax obligations.

Amazon wildfires have profound and far-reaching impacts on all those various aspects of society and the environment. Many of these impacts have been documented, and several have been quantified in both physical and monetary terms. The following examples, drawn from across the region, help illustrate how wildfires affect biodiversity, carbon emissions, human health, education, livelihoods, public finances, among other areas, in the Amazon countries.

ENVIRONMENTAL IMPACTS OF FIRES

Wildfires can trigger irreversible ecological shifts and reduce ecosystem functionality[6]. In tropical rainforests like the Amazon, a single fire event may initiate the transition to degraded systems, with drastic reductions in forest cover and habitat complexity[7]. Fires also increase tree mortality and open forest canopies, creating favorable conditions for the spread of exotic species that outcompete native flora and hinder natural regeneration[8]. This shift not only degrades biodiversity but also reinforces a cycle of increased flammability and ecological instability[9]. These changes compromise essential ecosystem services such as evapotranspiration, rainfall regulation, nutrient cycling, and the availability of non-timber forest products.

Biodiversity also suffers significant losses: wildfires, as stated above, reduce the abundance of functional species such as seed dispersers and pollinators, and disrupt mutualistic ecological networks[10,11]. These effects are intensified at forest edges and in fragmented landscapes, where vertebrate populations—particularly large mammals, frugivorous birds, and amphibians sensitive to microclimatic changes—undergo marked declines. As these pressures accumulate, fire poses a serious threat to the long-term viability of species and ecosystems across the region[12].

In Bolivia, studies have found that wildfires cause significant environmental impacts. Wildfires between 2001 and 2020 affected the distribution of 54 threatened species and 15 endemic species in Key Biodiversity Areas[13]. Notably, the highest richness of threatened bird species is concentrated in the Amazonian rainforest of eastern Bolivia, which was significantly impacted by wildfires. Vegetation impacts are highly variable depending on the ecosystem and location. Ledezma-Vargas (2021) reports a low impact on the Chiquitano Transitional Forest toward the Amazon[14].

Beyond biodiversity, wildfires also release substantial carbon emissions. Over a 30-year period, in Brazil, wildfires released a significant amount of carbon dioxide (CO_2) into the atmosphere: 33.7 Mg CO_2/ha during the fire and 92.4 Mg CO_2/ha from tree deaths and decay afterward.* Although forest regrowth absorbed some CO_2 (45 Mg CO_2/ha), it only offset about 36% of the total emissions[15].

Wildfires contribute to cross-border air pollution through long-range transport of smoke. Biomass-burning plumes were detected at altitudes above 10 km over Suriname, originating from fires near the Brazil–Venezuela border. This injected large amounts of pollutants into the upper troposphere. Despite the removal of 80–95% of aerosols during ascent, substantial gas-phase pollutants remained aloft.

* Note that tree mortality is the death of trees in a forest, and decomposition is the process of breaking down organic matter.


©Acervo pessoal

BRAZIL

*I am **Tainan Kumaruara**, from the Muruary Village, located within the Tapajós-Arapiuns Extractive Reserve in Santarém, Pará (Brazil).*

In 2016, a forest fire broke out in our territory, and we were unable to fight it due to the lack of techniques and equipment. That fire caused spiritual, cultural, emotional, and social harm; it burned the entire Muruary Village, including orchards, crops, and flour houses. And even before that, the community was already suffering the consequences of previous fires that had burned the headwaters of our streams, causing them to dry up.

For this reason, every day we strengthen our ancestral techniques through the Kumaruara Guardians of the Territory Brigade, caring for Mother Nature and protecting the environment in order to safeguard our territory — the home of our enchanted beings, our sacred soil, and the well-being of those who live from the forest.

This vertical transport extends the lifetime of fire-related emissions, amplifying their impact on climate at regional and global scales[16]. Likewise, there was a marked increase in smoke levels in February 2018, driven by intense biomass burning along the Amazon Rainforest borders of Colombia, Ecuador, and Peru[17].

SOCIAL IMPACTS OF FIRES

Numerous studies document the health impacts of fires, particularly for Brazil. In relation to smoke-related health impacts and costs, different studies have estimated the health burden attributable to fires. Some of them only assess mortality, others morbidity, others have both health outcomes, while others focus on the cognitive and educational impacts of fires.

For mortality, it was estimated that during the 2019 Amazon fire season, there were 4,966 premature deaths attributable to fire-related fine particulate matter (PM2.5), equivalent to 10% of all $PM_{2.5}$-related premature deaths in Brazil. Biomass burning emissions largely driven by Amazonian deforestation contribute significantly to premature deaths[18]. Similarly, it was found that the increase in fire activity resulted in 3,400 additional deaths in 2019, primarily driven by deforestation-related wildfires across the Brazilian Legal Amazon[19].

Regarding morbidity, it was noted for the brazilian Amazon biome that, in 2019, there were a total of 2,195 hospitalizations due to respiratory diseases linked with ambient air pollution from deforestation-related fires, and the estimated costs to the public health system was USD 1.4 million[20].

Then, concerning educational impacts that derive from fetal exposure in Brazil due to agricultural fires (in the Amazon and other biomes), based on 5th grade students, it was estimated that a 10% reduction in PM2.5 during the whole gestational period would increase test scores by 1.3% in Portuguese and by 0.9% in Mathematics, which, using estimates on returns to schooling, would mean a 2.6% increase in wages later in life[21].

There is also evidence of the impact of wildfires on health for other countries in the region. In Peru and Bolivia, estimate that exposure to fire-related PM2.5 places over 1.8 million people above the annual safe threshold, with significant health consequences[22]. We will take a deeper dive on these matters in the next chapter.

ECONOMIC IMPACTS OF FIRES

There are also estimates of the economic production affected by wildfires. For example, in the Brazilian Amazon, economic losses to sustainable timber production due to fires have been calculated.* Findings show that fire would affect 2% of the timber production areas that would be harvested between 2012 and 2041, causing losses of USD 39 ha/year on average (measured as the equivalent annual annuity), representing 0.8% of expected rents. In some areas, losses can reach up to USD 183 ha/year. For the affected areas, the annual average loss was estimated at USD 29 million[23].

Among economic consequences, wildfires can also place a significant burden on low income population. Severe wildfires in Bolivian territory between 2005 and 2020 caused a short-term revenue shortfall of about 8%, mainly driven by a decline in agricultural income of approximately 121 Bolivianos (Bs) one year after the event and 186 Bs two years later. The effect fades and becomes negligible after three years, suggesting the impact is temporary. These impacts are particularly relevant for the Bolivian Amazon, as the most affected areas, Beni and northern Santa Cruz, are located within the southwestern edge of the Amazon basin[24].

* Sustainable timber production refers to reduced impact logging (RIL), which corresponds to the legal norms and practices in place in Brazil to minimize the environmental impacts in timber concessions.

©Instituto Boliviano de Investigación Forestal

BOLIVIA

***My name is Osvin Yangui Guisicoi**, an indigenous Gwarayú community member from Salvatierra, in the municipality of Urubichá, Santa Cruz.*

My name is Osvin Yangui Guisicoi, an indigenous Gwarayú community member from Salvatierra, in the municipality of Urubichá, Santa Cruz (Bolivia).

Last year, a wildfire approached our community. Under the leadership of the sub-mayor, the Central of Indigenous Guarayo Women of Salvatierra, and the Communal Central of Salvatierra, we decided to form firefighting brigades, and all of us — men, women and youth — joined together to control the fire.

We were exhausted and affected by the smoke and heat. The fire was enormous and difficult to extinguish; it started outside our community, far from here, and we do not know who caused it. The blaze burned our crops, our forest, and wildlife, and it affected the health of our residents — even the pahuichis (houses made of straw and wood) that we had in our chacos (cropland areas).

We remain vigilant and hope it does not happen again. We are strengthening our community firefighting brigade through training and by monitoring who enters our forests.

Amazonian governments face significant fiscal pressure, partly due to increased expenditure on emergency services, fire suppression activities and recovery efforts. There is no systematic compilation of how funds are spent in wildfire management, but, for example, in 2023, the Brazilian government spent 63.5 million reais (approximately 13 million USD) in prevention and combat of wildfires.*

In summary, there is evidence of the wide-ranging impacts of fire on the Amazon. However, these impacts are more often measured in physical terms (e.g., area of soybeans burned, tons of CO_2 emitted, number of deaths or hospitalizations) rather than in monetary ones (e.g., losses from burned soybean land , the opportunity cost of carbon that could have been sold in markets, healthcare costs, and wage losses). Moreover, it is more common to find highly specialized assessments that focus on a single impact (e.g., number of deaths) rather than a comprehensive study that evaluates multiple impacts simultaneously (i.e., health, production and ecosystem services impact for the same period). This pattern is observed not only for the Amazon region but also in studies at the international level.

DAMAGE FROM FIRES AT THE INTERNATIONAL LEVEL

Only a small number of international studies provide comprehensive monetary estimates that account for multiple types of impacts for the same wildfire event. Instead, most analyses tend to focus on a single type of damage.** The scale of impacts and damage depends on fire intensity, extent, and location. Hence, an appropriate characterization of which impacts might lead to the greatest damage will depend on which of those are included, and on the data sources and methodologies used.

As shown in Table 1, the relative importance of different impacts varies significantly depending on the damage considered, making it challenging to identify a pattern of wildfire damage. In Canada, health accounted for 75% of losses25 whereas in California, health costs only accounted for 22% of losses[25],***. Similarly, CO_2 emissions represented 40% of losses in Indonesia[27] while they accounted for 64.3% of damages in the state of Acre in Brazil.

Despite the differences regarding which type of loss dominates, the order of magnitude of damage, when expressed as a share of annual GDP, is relatively consistent across studies, ranging between 0.5 and 3.4%. However, when expressed as per area burned (USD/ha burned), the variation is much greater. In that case, estimates go from 1,200 USD/ha in Acre (Brazil) to 5,000 USD/ha in Indonesia and 20,000 USD/ha in California.

* Available at: https://www.poder360.com.br/poder-governo/lula-gasta-mais-com-acoes-anti-incendios-mas-derrapa-no-combate/
** Our brief literature review covers the past five years, and even within this time frame, it draws on forest and fire data from several earlier years. We chose this period specifically to avoid discussing evidence that is 15 or 20 years out of date.
*** We use the terms losses and damages interchangeably, although this is not strictly accurate. Losses are irreversible, while damages are repairable. Available at: https://www.lossanddamagecollaboration.org/whatislossanddamage.

TABLE 1. Sample studies estimating several types of damage at the same time

Source: own ellaboration

Source	Area	Period	Categories of damages assessed and shares of total	Share of GDP
Hope *et al.* (2024)[25]	**Canada**	2013-2018	**Health (mortality and morbidity):** 75% **Timber:** 9% **Property, Asset and Infrastructure:** 6% **Suppression:** 10% (7% variable, 3% fixed costs) **Evacuation:** 1%	3.4%*
Kiely *et al.* (2021)[26**]	**Indonesia**	2004-2015	**Health impacts (smoke exposure, Disability Adjusted Life Years):** 26% **CO_2 emissions:** 40% **Productive losses (crops, plantations):** 33%	3.3%
Wang *et al.* (2020)[27]	**California**	2018	**Health costs:** 22% **Capital losses:** 19% **Indirect losses due to economic disruptions in 80 industry sectors:** 59%	1.5%
Campanharo *et al.* (2019)[28]	**Acre state, Brazil**	2008-2012	**Respiratory:** 3.6% **CO_2 emissions:** 64.3% **Production:** 7.5% **Fence:** 10.5% **Reestablishment:** 14.1%	0.5%
Barrett (2018)[29]	**U.S., review specific fire cases**	Several years between 2002 and 2016	SHORT TERM **Aid relief and Evacuation services:** 2% **Home and Property Loss:** 21% **Immediate Road & Landscape stabilization:** 3% **Federal Suppression Activities:** 8% **State/Local Suppression Activities:** 1% LONG TERM **Depreciated property values:** 8% **Degraded ecosystem services:** 34% **Energy & Infrastructure repairs:** 4% **Human casualties:** 1% **Long-term landscape rehabilitation:** 16% **Tax, business & natural resource loss:** 2% **Other:** 0.1%	N/A
Thomas *et al.* (2017)[30]	**U.S., review of estimates at several places**	Several years	DIRECT **Health** (Deaths, Morbidity, Psychological impacts) **Houses and other infrastructure, Environment** (Vegetation losses, Erosion, Watershed, Soil quality, Carbon emissions) **Timber and agriculture losses.** INDIRECT **Short term Business interruption** **Short term infrastructure provision disruptions** **Migration**	N/A

Notes:
* Own calculation based on 57.2 USD billion 2019 in the paper and 1.744 trillion USD 2019 for that year.
** Based on previous work in World Bank (2016) that did not include health impacts.

©Marizilda Crupp/Greenpeace

MORE COMPREHENSIVE ESTIMATES FOR BETTER POLICY DESIGN

Evaluating the costs of fire policies and comparing them to the costs avoided (benefits) through decreased areas burned is crucial for several reasons. First, it allows policymakers to identify the most cost-effective strategies, ensuring that limited resources are allocated in the most impactful way. Second, by understanding the trade-offs and economic impacts, decision-makers can prioritize interventions that provide the greatest return on investment, thus enhancing the overall efficiency of fire management practices. Moreover, integrating such analyses into policy design supports more informed, transparent, and equitable decisions, ultimately leading to better outcomes for both the environment and affected communities. This approach also helps in garnering public and political support by demonstrating the tangible benefits of proactive fire management measures. However, there are relatively few studies using benefit-cost analysis (BCA)* or cost-effectiveness analysis** to prioritize wildfire policies, and most focus on a specific area in developed countries.

For example, in a California watershed, benefits from fuel treatment were estimated to be 1.9 to 3.3 times higher than costs[31].

* Sometimes also referred to as cost-benefit analysis (CBA).
** In this case, instead of comparing the cost of a policy to the benefit (i.e., the decrease damages it yields), the comparison is made between the policy expenditures and its physical impact, for example, in terms of reducing the area burned.


©Acervo pessoal

ECUADOR

*I am **Domenica Dammer**, from the community of Mulauco (Ecuador). On September 4, 2024, a large fire burned the plot where we grow cereals and grains such as wheat, corn, barley and beans. Atukpamba is a permaculture center with over 30 years of experience.*

The fire occurred on a day when everything was extremely dry, after two months without rain, with very high solar radiation and strong winds. We suffered major material losses, including two barns, a cabin, mills, sieves, carts, seeders, grass choppers, and harvests. We received support from the surrounding community, both to prevent the fire from causing even greater damage and to help us recover afterward.

This year, we have dedicated ourselves to learning more strategies for land management to prevent such extensive damage and to share these lessons with our neighboring communities. We firmly believe that the world needs more people attuned to natural rhythms so that we can make this planet a better place to live.

Also, in the United States, wildfire mitigation activities — mainly mechanical thinning* — were analyzed for lands that serve as source areas for municipal water supplies in Denver, Colorado, during the 2011-2019 period. It was shown that the investments under the Forest to Faucets (F2F) partnership, under which payments are made to landowners for managing their forests in a way that protects and improves the quality of water resources, had a benefit-cost (B/C) ratio greater than 1 conditional on encountering wildfire in the 25-years period and including other co-benefits in addition to those of watershed protection, but B/C ratio are lower than 1 under alternative assumptions[32]. More recently, a meta-analysis** estimated a B/C ratio of 7.04 when considering thinning and burning alternatives in Western US[33]. Other policies, such as wildfire education actions to prevent ignition, show even higher returns, with benefits exceeding costs by an average of 35-fold[34].

Beyond the United States, early evacuation was identified as the only wildfire management policy with positive net economic benefits in Southeast Australia[35]. Moreover, a BCA was performed for an Earth observation mission to gather satellite data needed for wildfire monitoring (WildFireSat), showing that under pessimistic and conservative assumptions, mission costs typically exceed potential benefits by 1.16 to 1.59 times, while under more optimistic assumptions, benefits exceeded costs by a factor of 8.72 to 10.48[25].

Some cost-effectiveness estimates are available for Brazil. Expenditures from two programs implemented between 2012 and 2016 in Brazil were compared: the fire suppression and prevention program of the Chico Mendes Institute for Biodiversity Conservation (ICMBio) in public Federal Conservation Units (CU) and a private program promoting sustainable agriculture practices and wildfire management in private rural properties[36]. Their costs were compared to reductions in burned area instead of valuing the benefits in monetary terms.

The results showed that investments in fire management in CUs total USD 0.51/ha/year in the Amazon, and approximately 94% of the public investment in fire management in CUs was assigned to suppression instead of prevention activities. Burned areas within CUs were 64% lower but there was not always a clear difference between having or not having fire brigades. On private lands (data availability limits results to the state of Mato Grosso), average spending in fire suppression was much higher: USD 15.89/ha/year and 0.19/ha/year for prevention. With that investment, the area burned in PP decreased by 35% on the Amazon.***

Additionally, some recent studies in the region simply provide relevant evidence on wildfire management effectiveness in Brazil, with neither a valuation of benefits nor costs. Despite that, this type of study is also relevant for policy design since it estimates the concrete results of a policy. For example, it has been shown that emergency fire ban policies alone are insufficient to control the fire crisis in the Brazilian Amazon because above average fires occurred years later, highlighting the need for structural governance reforms and stronger enforcement[38].

In summary, fires have wide-ranging environmental, social, and economic impacts, many of which have been documented through physical and, to a lesser extent, monetary estimates in several Amazon countries. International comparisons highlight the

* Thinning reduces tree canopy density and removes smaller trees that can act as fire fuels.
** Note that meta-analysis is a method of synthesis of quantitative data by comparing multiple independent studies addressing the same topic.
*** In that same line, address of effective are fire brigades (Federal Brigades Program, FBP) that have an average cost of ~4.5 million USD in the period 2013–2017 to reduce fire by comparing before (2008–2012) and during (2013–2017) the implementation of the FBP in the Parque do Araguaia Indigenous Land. They find that FBP reduces the number of areas affected, but the recurrence of 4–5-year fire increased[37].

complexity of quantifying wildfire damage, with considerable variation in the types of impacts measured and the methodologies used. Despite this, the magnitude of losses — whether in terms of public health, emissions, or property — clearly justifies stronger and more cost-effective public policies.

While existing studies on benefit-cost and cost-effectiveness analyses remain limited and largely focused on developed countries, they provide valuable insights into improving wildfire policy design. Expanding this type of analysis in Amazon countries is essential to better target investments, evaluate trade-offs, and strengthen resilience to fire-related risks. Integrating economic valuation into fire management strategies can ultimately support more informed, efficient, and equitable policy decisions in the region.

©Dirección Nacional de Bomberos de Colombia

COLOMBIA

*I am **Clara Patricia Reina Gregorio**,*
a resident of kilometer 23 in the San Nicolás Reserve (Colombia). Last year, we experienced a vegetation fire that affected some of our crops, including cassava (mandioca), pineapple, and a few other vegetables.

During the incident, while I went to seek help, part of our chagras *(traditional cultivation plots) burned. Recognizing this need, and based on the knowledge we have gained, we are now organizing a community group made up of residents from the reserve and neighboring areas to be better prepared to respond to future incidents.*

We are very aware that fire is an important element in our territory, but there are also irresponsible people who sometimes misuse it.

chapter 6

FIRE AND HEALTH

Elizeu Chiodi Pereira[1,2,3], Dayane da Fonseca Barbosa[1,2],
Fernando Rodovalho[4], Thiago Nogueira[1,2,3],
Kelly Polido Kaneshiro Olympio[1,2,3]

[1]Departamento de Saúde Ambiental, Faculdade de Saúde Pública da Universidade de São Paulo (FSP/USP) - Brazil
[2]Laboratório de Análises da Exposição Humana a Contaminantes Ambientais (FSP/USP) - Brazil
[3]Expossoma e Saúde do Trabalhador (eXsat: The Human Exposome Research Group) - Brazil
[4]CoRAmazonia Project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

The World Health Organization warns that the climate emergency is also a public health emergency[1]. In the Amazon and worldwide, the effects of environmental degradation on health are becoming increasingly tangible. The Amazon Scientific Panel points out that the degradation of terrestrial and aquatic ecosystems directly affects people's well-being, with impacts ranging from an increase in infectious diseases to water and food insecurity, especially for the most vulnerable populations[2,1]. Recent studies indicate that the intensification of wildfires and degradation processes has been a key factor in the rise of air pollutant concentrations in the region, with adverse effects on public health[3,4].

During the critical wildfire season, hospitalizations for respiratory diseases in the Amazon can increase by up to 38%, with the most severe impacts seen among children and the elderly due to the immaturity or decline of their respiratory and immune systems[5,6,7]. Other vulnerable groups, such as individuals with preexisting health conditions, are also affected. This rise in hospitalizations is linked to worsening air quality caused by biomass burning, which releases large amounts of toxic chemical compounds and particulate matter (PM10, PM2.5, and PM<2.5). These pollutants, produced by the burning of vegetation cover, contain substances harmful to human health that, once inhaled, penetrate the lungs and enter the bloodstream. This exposure contributes to the aggravation of respiratory, circulatory, cardiovascular, neurological, and autoimmune diseases and increases the risk of developing various types of cancer[8,9,10,11,12].

Table 1 presents some classes of chemical compounds that may be part of the particulate matter generated during biomass burning and their associated health effects.

TABLE 1. Chemical compounds present in smoke produced by biomass burning and their main health effects.

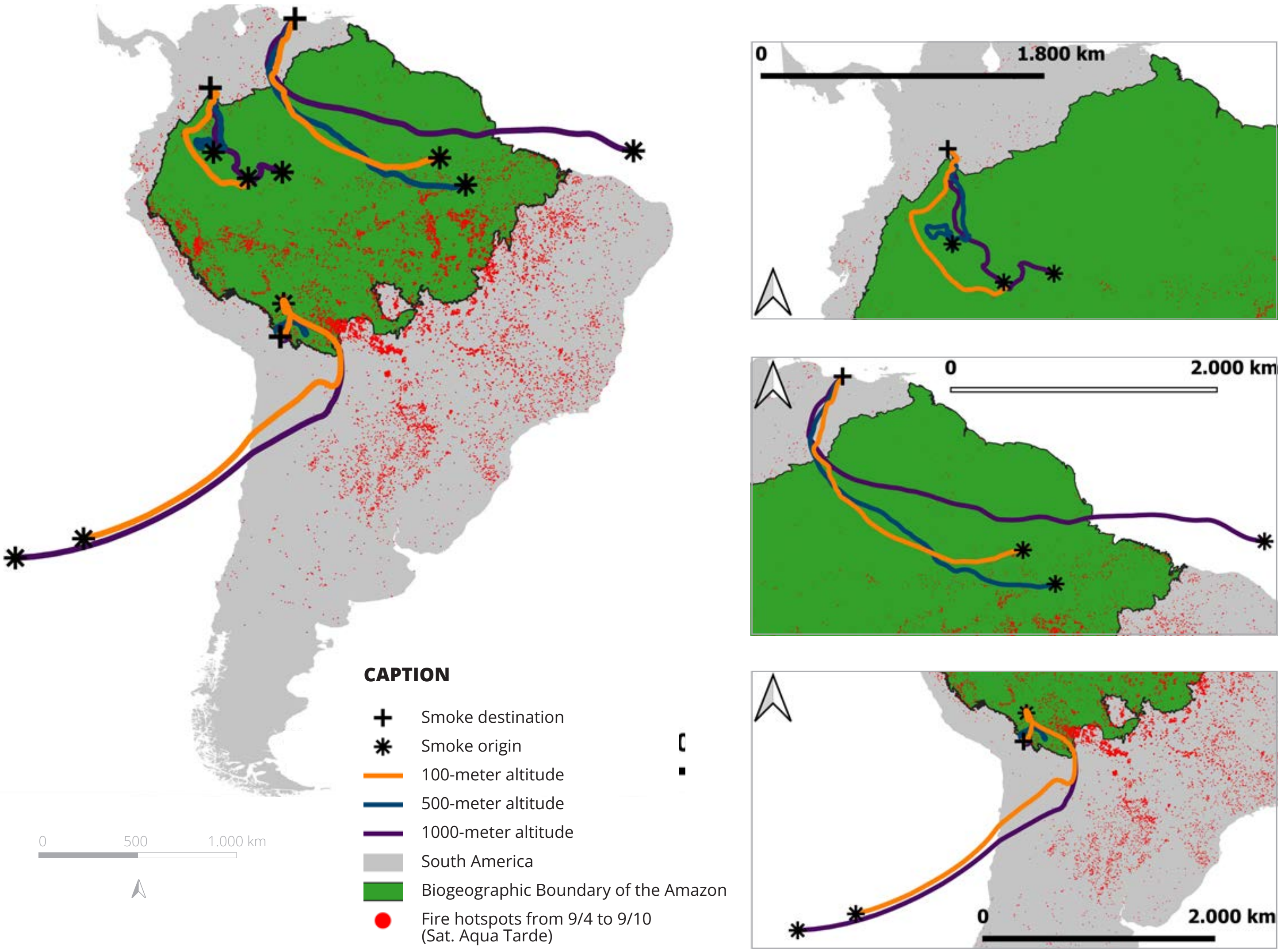
Source: References 8,9,10,11,12

COMPOUND	MAIN HEALTH EFFECTS
Particulate Matter ($PM_{2.5}$; PM_{10})	Respiratory, cardiovascular, and circulatory diseases; autoimmune disorders (e.g., lupus); cancer risk; fetal growth restriction
Black Carbon	Reduced lung function, especially in children
Carbon Monoxide (CO)	intoxication, headache, dizziness, cardiac risk, autoimmune diseases, and fetal growth restriction
Nitrogen Dioxide (NO_2)	Pulmonary inflammation and worsening of respiratory diseases
Volatile Organic Compounds (VOC)	Systemic toxic effects and increased cancer risk
Heavy Metals (mercury, lead, and others)	Neurotoxicity and renal and hepatic dysfunctions
Polycyclic Aromatic Hydrocarbons (PAH)	Inflammations and cancers affecting different body systems

As seen in the previous chapter, the alarming numbers of deaths, hospitalizations, developmental losses in children, and other public health effects caused by wildfires reveal a humanitarian crisis that transcends national borders, since these impacts are not confined to the regions where the fires occur. Pollutants released during such events can be transported by atmospheric currents and precipitate as contaminated rain, affecting air, water, and soil quality far beyond the Amazon itself[13,14].

This contamination affects aquifers, rivers, reservoirs, and crops, aggravating water, food, and health insecurity and threatening people's livelihoods.
It has been documented that pollutants generated by wildfires in African savannas were transported across the Atlantic to the Amazon and other brazilian biomes[15], reinforcing how these events can transcend borders and produce environmental, economic, and public health impacts on an intercontinental scale. Figure 1 below illustrates the backward trajectory of smoke plumes during wildfire events in South America.

FIGURE 1. Backward trajectories of air masses calculated using the HYSPLIT model, indicating the potential source regions of smoke transported to the receptor points of Bogotá, Caracas and La Paz*.



* Backward trajectories of air masses calculated using the HYSPLIT model (Hybrid Single-Particle Lagrangian Integrated Trajectory)16,17 indicate the probable source regions of pollutants that reached Bogotá (4.62° N, 74.06° W), Caracas (10.50° N, 66.91° W), and La Paz (16.48° S, 68.11° W). The 168-hour (7-day) simulations ended on September 10, 2024, at altitudes of 100, 500, and 1000 meters above ground level (AGL), to analyze the transport of smoke plumes following the peak of fire activity in South America (8,356 fire hotspots on September 3, 2024). The trajectories are overlaid with active fire data provided by the National Institute for Space Research (INPE). The simulation used meteorological data from the Global Forecast System (GFS) with a 0.25-degree resolution. Geographical boundaries of the Amazon biome were defined using data from the Amazon Georeferenced Socio-environmental Information Network (RAISG).

The impacts fall most heavily on communities that are already historically marginalized, such as riverine, indigenous, rural, and peripheral populations. Beyond facing greater exposure to pollution and smoke, these communities often contend with limited or inadequate access to healthcare, sanitation, and emergency response services, a common reality across large areas of the Amazon[18]. Social inequality, therefore, is not merely a backdrop but a factor that amplifies risks, constrains adaptation, and intensifies the health effects of wildfires, exposing populations unequally[19,20].

The public health crisis triggered by wildfires goes beyond air and water contamination or direct smoke exposure. The degradation of the amazonian ecosystem alters the microclimate, creating ideal conditions for the proliferation of disease vectors such as *Aedes* and *Anopheles* mosquitoes. As a result, endemic diseases like dengue, zika, and malaria intensify, and the risk of emerging zoonotic diseases increases. The growing proximity between humans and wildlife in degraded areas heightens the likelihood of contact with previously unknown pathogens[21].

In this sense, covid-19 served as a warning: environmental collapse can rapidly turn into a public health collapse at local, regional, or even global scales. With its vast biological diversity and the presence of largely unknown potential vectors, the Amazon ranks among the world's leading hotspots for the emergence of new pandemics. Preserving the forest's ecological balance is, therefore, a matter of global public health interest.

It is also essential to recognize and value those on the front lines of fighting wildfires — people who risk their health every day to protect both society and environment. Forest firefighters, fire brigades, professionals, and volunteers face extreme heat, intense physical strain, smoke inhalation, a high risk of burns, falling trees, and

©Mayangdi Inzaulgarat

encounters with venomous animals, among other threats, often in regions with little or no healthcare infrastructure. The severity of this exposure was recently acknowledged by the International Agency for Research on Cancer (IARC), which classified occupational exposure among these professionals as carcinogenic[22].

This vulnerability is further worsened by precarious working conditions: these professionals often operate without adequate protective equipment, medical supervision, or even formal employment contracts, a clear violation of decent work principles, which are embedded in the United Nations Sustainable Development Goals (SDG 8). Studies have already identified exposure to toxic compounds with the potential to cause physiological and DNA damage[23], as well as severe mental health impacts resulting from repeated exposure to danger and the lack of institutional support[24]. Caring for the health of those who care for the forest is not only an urgent necessity, it is an essential and overdue act of reciprocity.

Although health impacts of wildfires and climate crisis are increasingly evident, significant gaps persist in their monitoring. It is essential to expand research investigating human health exposure, including the use of biomarkers capable of detecting early health effects such as physiological changes and variations in individual susceptibility[25], thereby protecting populations from this exposure.

These tools can be used to monitor affected groups and communities, strengthening care and response strategies. A more precise characterization of these risks is essential to guide more effective, integrated and equitable public policies. As emphasized by the World Health Organization[1], health is a compelling argument for climate action, and it may be the key to transforming knowledge into action.


IBAMA
IBAMA

chapter 7

INTEGRATED FIRE MANAGEMENT

Fernando Rodovalho[1], Rachel Carmenta[2], Rodrigo Falleiro[3], Christian Berlinck[4]

[1]CoRAmazonia Project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
[2]Tyndall Centre for Climate Change Research and the School of Global Development, Norwich Research Park, University of East Anglia – United Kingdom
[3]Secretaria Nacional de Gestão Ambiental e Territorial do Ministério dos Povos Indígenas – Brazil
[4]Coordenação Geral de Políticas para o Manejo Integrado do Fogo, Ministério do Meio Ambiente e Mudança do Clima – Brazil

In previous chapters, we saw how the relationship with fire has changed over time, expanding from its original uses by traditional groups to being adopted by new actors who employed it for different purposes, moving away from careful, respectful, and sustainable practices. Fire evolved from being an environmental and cultural management tool used by indigenous peoples and traditional communities to becoming a widespread instrument for farmers and cattle ranchers of all scales in the Amazon, among other actors such as loggers and land grabbers[1].

The widespread use of fire across the amazonian landscape ultimately increases the occurrence of wildfires, leading to forest degradation, biodiversity loss, threats to human health, economic losses, and risks to traditional livelihoods. These interconnected processes undermine the region's ecological and community resilience and accelerate its approach toward the point of no return, as warned by scientific evidence[2,3].

In light of this situation, addressing the challenge requires consolidating fire management as an integral part of territorial governance, strengthening local capacities, including through coordination across multiple scales[4], integrating scientific and traditional knowledge, and promoting preventive strategies aligned with territorial dynamics[5]. Integrated Fire Management (IFM) thus emerges as an approach to rebalance the relationship between fire and environment, centered on planning, shared responsibility, and the appreciation of multiple dimensions and understandings of fire. It is structured around three interdependent pillars, represented by an equilateral triangle encompassing cultural, ecological, and fire-use aspects[6] (Figure 1).

FIRE ECOLOGY

Examines the positive and negative impacts of fire on ecosystems, including its regime (seasonality, frequency, intensity, location, objectives etc.) and its effects on sociobiodiversity. In tropical forests such as the Amazon, where most vegetation types are highly sensitive to fire, wildfires can lead to irreversible degradation processes, that is, to the collapse of the forest ecosystem. Ecological knowledge is essential for identifying thresholds, risk zones, preventive strategies, and for determining when the use of fire is viable or should be avoided[7,6,9,10].

FIRE CULTURE

Recognizes that the use of fire is deeply intertwined with social, economic, and cultural life of peoples, communities, and territories. These groups have developed and transmitted practices over generations, guided by ecological calendars and the careful observation of natural signs. However, they now face the climatic challenge of longer dry periods, reduced rainfall, and lower humidity, which make fire more likely to escape traditional controls. This dimension includes the role of fire in cultural expression, worldviews, territorial belonging, food security, medicine, protection and income generation[6,7,8].

INTEGRATED FIRE MANAGEMENT

FIRE USE

Recognized as a necessary tool in many contexts, especially in subsistence agriculture such as slash-and-burn practices, and in environmental conservation activities. Rather than enforcing blanket bans, it advocates for the planned and safe use of fire, with defined safety measures, appropriate burning windows, clear objectives, favorable weather conditions, technical training, and established responsibilities. It also encourages the use of alternatives to fire, such as agroforestry systems, whenever these transitions are built through participation and with respect for local knowledge[6,7,11].

©Rodrigo Falleiro

Building on the articulation of the three pillars of Integrated Fire Management (IFM) — fire culture, fire ecology, and fire use — practical forms of territorial action emerge. This approach gives rise to a continuous cycle of assessment, prevention, preparedness, response, and recovery, aimed at fostering resilient communities and landscapes, reducing wildfire risk, and protecting sensitive environments. It also seeks to restore ecosystems, strengthen local capacities, support emission reduction and biodiversity protection goals, enable the reintroduction and biocultural access to fire, and consolidate effective and participatory public governance. Table 1 describes this cycle of practical actions which, in an interconnected and continuous way, materializes the concept of IFM within territories[6,8,9,10,13].

FIGURE 1.

Source: References 6,8,9,10,13

INTEGRATED FIRE MANAGEMENT ACTION CYCLE

1 ASSESMENT AND PLANNING

ACTIVITIES

- Participatory assessment of social vulnerabilities, fire regimes, local knowledge, and fire-use practices, taking into account ecological, social, productive, and climatic aspects;
- Mapping of critical and priority areas for monitoring and protection, evacuation routes, and zoning with clearly defined objectives, targets, and limits for the use or exclusion of fire.;
- Co-creation of participatory Integrated Fire Management plans, including indicators, targets, and monitoring strategies;
- Identification of synergies between Integrated Fire Management (IFM) and other territorial policies (land use, climate, biodiversity, and environmental and territorial management);
- Revision of territorial plans based on lessons learned;
- Development and implementation of public policies to support the regulation of the balanced and biocultural use of fire;
- Development and implementation of integrated information systems to support data collection, management, and decision-making.

2 RISK MANAGEMENT, PREVENTION, AND REDUCTION

ACTIVITIES

- Continuous monitoring of climate, fuels, and soil moisture;
- Execution of prescribed burns with clearly defined objectives and areas, ensuring safety, suitable weather conditions, and prior communication with local stakeholders;
- Application of prescribed burns for conservation purposes in fire-adapted ecosystems, with proper planning and technical monitoring;
- Establishment of community fire calendars with broad communication among local stakeholders, promoting predictability and shared responsibility;
- Construction and maintenance of firebreaks and other practices to reduce fire spread and enhance control;
- Structuring a heterogeneous and pyro-dynamic landscape to reduce the continuous accumulation of fuels;
- Educational actions and awareness campaigns on fire risks and management;
- Encouragement of the gradual replacement of fire use with sustainable alternatives, whenever feasible and desired.

3

PREPAREDNESS AND TRAINING

ACTIVITIES

- Creation of the forest firefighter position and a corresponding career plan, along with incentives for the establishment, equipping, and strengthening of public, private, community, and volunteer firefighting brigades;
- Regular training in fire prevention, prescribed burning, wildfire suppression, safety measures, first aid, and the Incident Command System (ICS);
- Simulations and practical exercises to implement prevention and firefighting actions;
- Development, acquisition, distribution, use, and maintenance of personal protective equipment and appropriate tools for Integrated Fire Management (IFM) activities;
- Establishment of operational plans, command and communication protocols, and inter-institutional activation systems;
- Strengthening of local infrastructure: operational bases, warehouses, monitoring centers, and supply points.

4

RESPONSE

ACTIVITIES

- Coordinated wildfire suppression actions with pre-established safety measures, strategies, objectives, and protocols;
- Active protection of sensitive areas: communities, crops, reserves, and natural resources;
- Integrated and coordinated action among local forest brigades, public agencies, and civil society actors, thereby reducing response time for initial attack;
- Recording and analysis of wildfire data to improve Integrated Fire Management (IFM) plans and promote continuous learning.

5

RECOVERY AND RESTORATION

ACTIVITIES

- Post-fire assessment of ecological, social, economic, productive, and cultural impacts;
- Creation and management of community nurseries for native species;
- Promotion of active and passive restoration activities, prioritizing native species that are ecologically suited to local ecosystems and communities;
- Support for bioeconomy value chains in fire-affected areas, including non-timber forest products;
- Participatory monitoring of environmental and productive recovery.

The actions that structure IFM generally aim for fire management that is participatory and co-responsible, rooted in local territories and ways of life, with an emphasis on strengthening community-based fire management. This focus creates space for autonomy and local organization, generating co-benefits that reinforce territorial fire governance. By protecting essential resources for food sovereignty, income generation and bioeconomy, IFM seeks to enhance community resilience in face of climatic and economic instability, while strengthening collective rights to land, culture, and food security[14,15].

In this context, IFM contributes to climate justice by recognizing the diversity of knowledge systems, redistributing responsibilities, and addressing — as well as repairing — historical asymmetries in fire management. For example, it reconnects peoples to their ancestral fire management practices in places where traditions were interrupted by fire suppression regimes. IFM represents an ethical and political project of coexistence with fire, placing peoples and their territories at the very center of climate solutions[16,17] and guiding us toward new fire cultures[18].

Guided by local solutions coordinated at regional and national levels, and connected to a shared humanitarian agenda, IFM also stands out as a pathway to address global climate challenges. By coordinating multisectoral and territory-based actions, it contributes to the fulfillment of multilateral commitments through concrete and accessible practices. By reducing emissions, promoting territorial adaptation, valuing local knowledge, and integrating risk management into development strategies, IFM aligns with the core principles of international agreements such as the Paris Agreement[19], the Kunming-Montreal Global Biodiversity Framework[20], and the Sendai Framework[21].

As a solution deeply rooted in local territories, IFM translates global commitments into practical, attainable actions for peoples and communities, integrating environmental conservation with economic and cultural sustainability. Above all, it embodies a strategy that mobilizes a collective purpose: to protect life, sustain territories, and nurture a sustainable, just, and compassionate future.

©Dirección Nacional de Bomberos de Colombia

©Mayangdi Inzaulgarat


FORTLEV

chapter 8

RECOMMENDATIONS AND INSPIRATIONS

Fernando Rodovalho[1], Gabriel Franco Chaskelmann[2], Liana Oighenstein Anderson[3], Jarlene Gomes[4], Christian Niel Berlinck[5], David Sergio Torres Paredes[6], Daniel Segura Ramos[7], Carlos Pinto[8]

[1]CoRAmazonia Project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
[2]Brigada de Incêndio Florestal de Alter do Chão – Brazil
[3]Divisão de Observação da Terra e Geoinformática (DIOTG), Instituto Nacional de Pesquisas Espaciais (INPE) – Brazil
[4]Instituto de Pesquisa Ambiental da Amazônia (IPAM) – Brazil, Universidade de Brasília (UnB) – Brazil
[5]Coordenação Geral de Políticas para o Manejo Integrado do Fogo, Departamento de Políticas de Controle do Desmatamento e Incêndios, Ministério do Meio Ambiente e Mudança do Clima – Brazil
[6]Central Asháninka del Río Ene (CARE) – Peru
[7]Programa Amazonía Sin Fuego (PASF), Ministerio del Ambiente, Agua y Transición Ecológica de Ecuador (MAATE)
[8]Fundación Amigos de la Naturaleza (FAN) – Bolivia

Building territories adapted to fire and climate in the Amazon requires recognizing that fire has been and continues to be a part of reality, even though forest ecosystems are not naturally adapted to it. Therefore, its management must be strategic and, in the long term, should also consider transitioning toward fire-free territorial management techniques in sensitive environments and wherever most appropriate. The growing flammability of the Amazon, driven by climate extremes and changes in landscape configuration and land use, demands the active participation of all sectors of society — governments, communities, organizations, academia, and the private sector — in developing integrated solutions.

The purpose of this final chapter is to present practical recommendations to enhance the implementation of Integrated Fire Management across amazonian countries. Yet, it also serves as a call to action, grounded in real-world examples. Throughout this chapter, we highlight inspiring cases that demonstrate it is possible to turn recommendations into reality, provided they are supported by adequate investment, technical assistance, governance, and inclusive public policies that align conservation with sustainability.

IFM provides concrete pathways for prevention, adaptation, and response to wildfires, acknowledging the challenging conditions for fire suppression in amazonian vegetation and respecting the region's sociocultural and ecological diversity, from humid tropical forests, where fire is largely destructive, to open landscapes, where it plays a distinct ecological role. In light of the rapidly changing global climate and environment, landscapes demand adaptive strategies, including the potential for fire-free approaches in critical contexts.

The implementation of IFM takes into account the integrity of ecological and landscape processes, ensuring their continuous integration and management by rural communities, indigenous peoples and local populations, in coordination with specially protected areas, within a framework of adaptive biocultural landscapes and practices. Below, we present a series of successful examples and specific recommendations for the various social actors involved in fire governance across amazonian countries.

Photos ©Mayangdi Inzaulgarat

©Mayangdi Inzaulgarat

FOR GOVERNMENTS

Recognize and strengthen forest firefighters and brigade members, including volunteer and community brigades, as key actors in IFM, ensuring decent working conditions, social protection, continuous training, and established career pathways. In addition, it is essential to guarantee the integration of these professionals into public institutions and decision-making structures, valuing their technical expertise and territorial knowledge.

Integrate IFM into Nationally Determined Contributions (NDC), as well as into national and subnational plans for climate, land use and risk management. This includes ensuring dedicated institutional structures and budgets, along with the development of territorial plans that connect actors both horizontally (communities, producers, NGO) and vertically (federal, subnational, local), thereby promoting shared responsibility for implementation.

Strengthen multilevel and intercultural governance mechanisms for IFM, ensuring the effective participation of indigenous and traditional peoples, women and Youth, in decision-making spaces, while providing continuous training on fire management, legislation, and participatory tools.

Ensure that all IFM related actions are sustained over time, supported by long-term strategies for continuity and resilience beyond the critical fire seasons, recognizing that the best way to fight a wildfire is to prevent it from occurring.

Support community-based fire prevention and management through permanent and inclusive educational programs, co-creation of participatory assessments and community maps with clearly assigned responsibilities, and the definition of local risk indicators.

Promote, through public policies and fiscal incentives, the gradual and participatory replacement of fire use in rural areas, where applicable, with sustainable productive alternatives, while respecting cultural practices and local realities.

Strengthen fire monitoring, forecasting and early warning systems, as well as collective monitoring based on citizen engagement, combining geospatial and meteorological data with local practices of fire use and land management, community knowledge, and participation. Ensure open platforms for decision-making and interinstitutional response, built on the principle of shared responsibility.

Integrate scenario-based approaches into monitoring and forecasting, taking into account uncertainty, social tolerance to risk, and the increasing frequency of climate extremes, and apply these approaches to the development of public policies, training programs and emergency response planning.
Create sustainable financial

mechanisms and fiscal incentives to support the implementation of Integrated Fire Management (IFM) at all levels, recognizing the evident social, economic and environmental losses caused by wildfires.

Promote and encourage studies that strengthen the integration of scientific and traditional knowledge, ensuring broad dissemination of results to enhance the implementation of Integrated Fire Management (IFM).

Establish transboundary cooperation agreements with common protocols for wildfire prevention, early warning, and coordinated response.

Implement international agreements for the conservation of sociobiodiversity and climate, especially in the current context where climate change has intensified the occurrence, behavior and severity of wildfires. Reduced rainfall, longer dry spells, and rising temperatures reflect this global crisis, which demands joint action from all countries.

©Ricardo Stuckert

NATIONAL POLICY FOR INTEGRATED FIRE MANAGEMENT

BRAZIL

In 2024, Brazil established the National Policy for Integrated Fire Management (Law 19.944/2024), introducing an orderly, responsible, collaborative, and adaptive approach to fire management across the country. This law promotes shared responsibility among federal, state, and municipal governments and civil society, aligning biodiversity protection and the sustainable use of natural resources with the responsible use of fire. By valuing traditional knowledge, encouraging sustainable practices, and strengthening the autonomy of Indigenous peoples and local communities, this policy consolidates integrated fire management as a tool for caring for territories and their populations.

Its implementation takes place through a council that includes representatives from all levels of government and civil society — the National Committee on Integrated Fire Management — which fosters dialogue to build a common understanding for developing and implementing public policies for appropriate fire governance. Among the nationally established regulations, two stand out: the requirement for Integrated Fire Management Plans for managers of both public and private territories, and the mandatory adoption of preventive measures on rural properties.

The implementation of integrated fire management in Brazil has transformed fire governance within federal protected areas by combining ecological and sociocultural dimensions. The results achieved in the first years of implementation are promising for restoring appropriate fire regimes, with reductions in the number of events, burned area, operational costs, time devoted to firefighting, and conflicts with communities, ultimately strengthening the conservation of sociobiodiversity.

AGROECOLOGICAL FIELD SCHOOLS – PROGRAMA AMAZONÍA SIN FUEGO

ECUADOR

The use of fire to prepare agricultural areas is a traditional and cultural practice among small farmers, but it becomes a significant source of wildfires when not applied responsibly. To address this challenge in Ecuador, the Programa Amazonía sin Fuego, led by the National Environmental Authority, has been promoting sustainable alternatives to the use of fire in agriculture since 2017, particularly in eight provinces with a high incidence of wildfires.

Through the Farmers' Field Schools on Integrated Fire Management (ECA-MIF), the program promotes conservation agriculture practices such as no-till farming, crop rotation, and permanent soil cover. These practices have helped improve productivity, preserve soil, and reduce the occurrence of fires. In addition, the ECA-MIF have led to the creation of community brigades composed of trained farmers who strengthen local efforts in fire prevention and management, contributing to the country's environmental goals.

©Programa Amazônia sem Fogo

PERU

FOREST FIRE PREVENTION BACKPACK – SERVICIO NACIONAL DE ÁREAS NATURALES PROTEGIDAS POR EL ESTADO (SERNANP)

Developed by Peru's Servicio Nacional de Áreas Naturales Protegidas por el Estado (SERNANP), the Forest Fire Prevention Backpack has become a strategic tool for reducing the occurrence of wildfires in protected natural areas and their surrounding landscapes. Its goal is to raise awareness among rural communities (both indigenous and peasant), who, with the facilitation of park rangers, collaboratively build concepts and messages for wildfire prevention and integrated fire management.

Using a felt board and adhesive figures depicting images of the territory, the topic is presented to rural communities located in remote areas, where wildfires usually originate, strengthening their capacity to prevent and respond to fires safely and adaptively. This experience is now being replicated in other countries.

©SERNANP

©Adobe Stock

FOR CIVIL SOCIETY ORGANIZATIONS

Integrate actions related to Integrated Fire Management into civil society planning agendas to expand access to international financing, technical assistance, and scalable innovations for priority territories.

Strengthen the role of local associations, cooperatives, NGO, community forums, and other representative actors in connecting communities, governments, the private sector, and academia. Support the coordination of best practices, participatory monitoring, and ongoing capacity building that places community leadership and local autonomy at the center.

Strengthen the organizational and financial capacities of grassroots organizations, ensuring autonomy, continuity, and access to funds for Integrated Fire Management (IFM) activities.

Produce and disseminate multilingual and accessible educational materials that promote fire prevention and sustainable fire management, incorporating local narratives, visual formats, and cultural adaptations for indigenous peoples and local communities.

Document and share best practices and social technologies, promoting horizontal exchanges between territories and fostering intercultural learning processes.

Promote training and strengthening of different forest brigades (indigenous, community, and volunteer), alongside broader actions to enhance territorial fire governance, including local planning, coordination capacity, and emergency response.

Strengthen community monitoring and response capacity through alert networks, validation systems, and the use of low-cost, open-access technologies such as mobile applications, satellite imagery, and participatory mapping tools.

Support community projects for ecological and cultural restoration that value traditional knowledge and promote green jobs, income generation, and climate resilience.

FUNDO CASA SOCIOAMBIENTAL

BRAZIL

In response to the major wildfires of 2019 and 2020, which devastated territories across all brazilian biomes, the Fundo Casa Socioambiental identified the urgent need to support frontline communities. In 2020, it launched a strategy focused on community, volunteer, and Indigenous fire brigades.

Through six national calls for proposals, it supported 227 projects that benefited more than 100 thousand people, with an emphasis on brigade structuring, integrated fire management, training, and logistical and emergency support. With a strong presence in the Amazon and Cerrado, the fund has become one of Brazil's main mechanisms for rapid, accessible, and locally adapted financing. In July 2025, it organized the Brigadas em Rede *(Brigades in Network) meeting, bringing together more than 120 brigades to share experiences and strengthen their role in public policy.*

©Fundo Casa Socioambiental

©Instituto Boliviano de Investigación Forestal

COLLABORATIVE MECHANISMS FOR FOREST FIRE PREVENTION IN THE LOWLANDS OF BOLIVIA – IBIF

BOLIVIA

Developed by the Instituto Boliviano de Investigación Forestal (IBIF), in partnership with Tropenbos International and under the Fire-Resilient Landscapes Governance *component, this initiative built a dynamic, multisectoral network to prevent and respond to forest fires in the bolivian lowlands. Through municipal monitoring systems, early warning, and rapid response mechanisms, as well as local platforms connecting multiple stakeholders, it fostered collaboration among indigenous communities, the agricultural sector, local governments, and state authorities. This collective approach not only improves coordination and speeds up response but also strengthens communities as guardians of their territories, transforming forest fire prevention into a shared effort that protects lives, ecosystems, and livelihoods.*

AMA PLATFORM – RAISG – REGIONAL

Developed by the Amazon Network of Georeferenced Socio-Environmental Information (RAISG), the AMA Platform — named after the Guarani word for rain — offers an integrated system to explore and understand the Amazon through maps, visualizations, and data under a unified regional perspective. Built through the collaboration of eight civil society organizations, with shared protocols and accessible language, the platform empowers communities, public managers, and civil society to strengthen territorial governance, promote adaptive and integrated fire management, and mobilize coordinated, evidence-based actions across the region

©RAISG

PRIVATE COMPANIES

- Integrate IFM into corporate sustainability policies, particularly for companies operating in territories threatened by forest fires or whose activities are associated with fire risk and environmental degradation.

- Support and fund forest fire prevention campaigns, as well as promote environmental education and awareness among employees, supply chains and local communities.

- Support the structuring and training of community and volunteer brigades, and invest in programs for prevention, monitoring, and rapid response to forest fires to strengthen territorial preparedness within the framework of IFM.

- Collaborate with local governments and civil society organizations to strengthen interinstitutionally coordinated actions within the framework of IFM.

- Promote research, development, and innovation in fire monitoring and response technologies, as well as in alternatives to the use of fire, in coordination with academia and technical institutions, sharing these technological solutions with grassroots organizations and civil society.

- Adopt and promote sustainable production practices, including gradual replacement of fire use in production chains where applicable, and seek fiscal incentives aligned with the objectives of IFM.

- Implement fire prevention and control measures on rural properties integrated into local and regional Integrated Fire Management Plans, such as: managing the accumulation of combustible materials, creating fuel breaks and firebreaks, training staff and/or coordinating with neighboring brigades, acquiring firefighting equipment, and participating in local communication networks.

©Thomás Tanaka

FOR COMMUNITY-BASED ORGANIZATIONS

Map, document, and share territorial knowledge and experiences related to the use and management of fire, reinforcing cultural identity, local autonomy, and inspiring other communities.

Develop and implement community-based fire management protocols that combine traditional knowledge with institutional dialogue, and establish rapid response, accountability, safe evacuation, and inter-institutional coordination strategies for wildfire emergencies.

Value and strengthen ancestral and cultural practices related to fire, complementing them with technical procedures and innovation based on dialogue, while taking into account increasing climate risks and the need for adaptation strategies.

Explore sustainable alternatives to the use of fire, such as agroforestry systems, through public policies and tax incentives, promoting a gradual replacement when possible and desired, based on dialogue with local knowledge and the co-creation of solutions adapted to local ways of life.

Promote the continuous training of community forest brigades and the development of youth and local leadership, ensuring the intergenerational continuity of territorial fire management and strengthening community institutions.

Use accessible technologies for territorial monitoring and navigation, and establish culturally adapted visual alert systems to communicate daily fire risk levels, fostering collective preparedness and local response.

Actively participate in dialogue and decision-making spaces, including councils, networks, and forums with public authorities, civil society organizations, researchers, and other communities, to influence territorial governance and actions for integrated fire management.

Implement community programs and projects with resources to support wildfire prevention, monitoring, and rapid response through interinstitutional partnerships.

Promote the equitable participation of men, women, and all generations in the implementation of integrated fire management actions, strengthening social cohesion and inclusive governance.

CENTRAL ASHÁNINKA DEL RÍO ENE - CARE

PERU

Central Asháninka del Rio Ene implemented the PAAMARI strategy in 2024 — paamari means "fire" in the Asháninka language — to strengthen integrated fire management in 45 indigenous communities. The initiative created Community Forest Monitoring Committees and founded the CARE School, which offered seven training modules on prevention, monitoring, responsible fire use, drone operation, and territorial governance.

By integrating traditional knowledge with technical tools — such as satellite imagery, the Fire Weather Index (FWI), burning calendars, and daily alerts — the strategy reduced the number of fires from 25 to 9 and decreased the burned area by 81.4% compared to 2023. In 2025, new community brigades were formed, composed of community members trained for first response to wildfires and territorial defense.

©Central Asháninka del Rio Ene

©Instituto Boliviano de Investigación Forestal

FOREST MONITORING AND WILDFIRES: AN EMPOWERMENT INITIATIVE OF THE GWARAYÚ INDIGENOUS PEOPLE AND YOUTH

BOLIVIA

The Gwarayú people, in Santa Cruz (Bolivia), represented by the Central Organization of the Native People of Guarayos, hold collective rights over the Guarayos Original Communal Land, which encompasses 1.35 million titled hectares. Within this territory, communities, women's organizations, and community forest groups coexist, managing around 50 forest management plans that are essential for livelihoods, territorial defense, and forest conservation — now threatened by illegal settlements, deforestation, and fires.

With support from the Instituto Boliviano de Investigación Forestal (IBIF), the Guarayos Indigenous Forestry Association, and indigenous youth organized as the Technical Youth Team, territorial control, monitoring, and technical assistance actions have been strengthened. Through the Forest Technical Unit and the Territorial Monitoring Center, the communities conduct verification, reporting, and risk response following established community protocols, enabling timely coordination with public institutions.

FILHAS DA MÃE DO FOGO

BRAZIL

In 2024, the Filhas da Mãe do Fogo *("Daughters of the Fire Mother") initiative supported the creation of three pioneering brigades composed exclusively of women in the Marajó region, strengthening the role of afro-descendant (*quilombola*) and riverside women in fire prevention, management and response. Rooted in the AWA Agroextractivist Cooperative and community training programs, the initiative expanded women's leadership in protecting traditional territories, reducing wildfire risks, improving household safety, and valuing ancestral knowledge. In Jocojó, women mobilized to form their own brigade in response to the growing number of fire incidents, joining a broader movement that reached 17 municipalities. The brigades played a decisive role in 2024, containing fires near communities and productive areas, and leading educational workshops on responsible fire use with local families.*

©Observatório do Marajó

FOR ACADEMIA

Co-develop research with communities, recognizing traditional knowledge as a legitimate and complementary system of understanding, and establish long-term partnerships with territories as allies in strengthening local solutions for integrated fire management.

Develop intercultural and interscientific research that integrates traditional knowledge and technologies with scientific approaches to better understand the effects of climate change on rainfall, wind, and temperature patterns.

Promote the inclusion of professionals and research lines from disciplines such as agriculture, sociology, anthropology, telecommunications, meteorology, and climatology, among others, broadening the scope beyond forest, biological, anthropological and geographical sciences.

Foster scientific research structured around the core pillars of IFM: culture, ecology, and fire use, while also prioritizing studies focused on the analysis and development of public policies and governance frameworks at national, subnational, and local levels.

Produce useful and accessible data for fire management at local and regional scales, supporting participatory planning and decision-making.

Assess the social and environmental impacts of fire and the effectiveness of related public policies, generating evidence to guide more effective actions and decisions.

Investigate the impacts of exposure to fire and smoke on human health, especially among vulnerable populations, and advance research on broader socio-environmental effects, including biodiversity, water, food security, and gender, aligned with the Sustainable Development Goals.

Implement a continuous monitoring program focused on landscape ecology, metapopulations, and metacommunities within a heterogeneous landscape, in order to improve territorial management and guide effective decisions and actions.

Ensure that research results are returned to communities through culturally, visually, and community-adapted knowledge translation methods, and create inclusive academic pathways for indigenous and rural youth. In addition, research funding agencies should adapt their frameworks to support these efforts and promote the strategic local use of knowledge and the development of local leadership.

ASSESSING SMOKE EXPOSURE IN THE AMAZON – USP

BRAZIL

Launched in 2022, this initiative, developed by the Faculdade de Saúde Pública da Universidade de São Paulo and the eXsat Research Group (The Human Exposome Research Group), investigates the impacts of wildfire smoke exposure on forest firefighters and amazonian communities. Through the collection of biological (blood, urine, saliva) and environmental samples in the region known as the Arch of Fire, the project evaluates biomarkers of exposure and health effects, identifying metabolites and proteins that may indicate biological risks. By addressing a historical gap in biomonitoring data for these populations in Brazil, this project enhances public health knowledge. Funded by the São Paulo Research Foundation (FAPESP — Grants: 2023/04212-4; 2023/04803-2; 2023/04877-6; and 2024/17990-8), the study provides scientific evidence to support health and safety policies, helping protect both those who fight forest fires and those who live in the most affected areas.

É FOGO! – EDUCATIONAL GUIDES FOR RAISING AWARENESS ABOUT FIRE IN THE AMAZON AND THE PANTANAL

The É Fogo! *activity guides were created to raise community awareness about the causes and impacts of wildfires in the Amazon and the Pantanal through accessible and practical educational tools. With five adaptable methodologies — oral storytelling, theater, monitoring, film, and social mapping — the guides connect scientific and traditional knowledge, encouraging communities to engage in fire prevention and risk reduction. Used by more than ten thousand people and 70 institutions, these materials have strengthened environmental education and awareness, increased risk perception, and empowered local groups to act collectively in face of the climate crisis.*

CROSS-CUTTING AXIS
NETWORK ENGAGING ALL STAKEHOLDERS

Beyond specific responsibilities of each actor, effective implementation of Integrated Fire Management (IFM) in the Amazon depends on consolidating networks, collaborative platforms, and permanent spaces for intercultural dialogue. Together, these elements strengthen multisectoral governance and enable the continuous exchange of experiences and knowledge among territories.

Foster multisectoral amazonian networks — local, national, and regional — that bring together governments, communities, researchers, and civil society organizations to coordinate actions based on mutual trust.

Formalize shared governance arrangements with clearly defined responsibilities, continuous learning cycles, and sustainable financing mechanisms (such as territorial funds or REDD+ mechanisms adapted to IFM).

Establish open platforms for monitoring and learning, with simple and accessible tools to generate, share, and use territorial data.

Recognize and support community-based initiatives for communication and exchange between territories, such as fairs, gatherings, technical visits, local radio stations, and videos.

Create permanent intercultural training spaces that integrate traditional and scientific practices into policy and project design.

Ensure visibility, continuity, and funding for existing best practices, valuing those implementing them at the grassroots level and encouraging their adaptation and replication across different contexts.

Design and implement international, national, and regional IFM programs and projects that guide local actions and promote complementarity across different scales.

©Dirección Nacional de Bomberos de Colombia

PROGRAMA DE BOMBEROS INDÍGENAS DE RIOSUCIO, CALDAS

COLOMBIA

The Indigenous Firefighters Program of Riosucio, Caldas, is an innovative strategy developed by the Programa de Bomberos Indígenas de Riosucio, Caldas to prevent and combat forest fires in indigenous and rural territories. By combining the ancestral knowledge of local communities with modern firefighting techniques, the program trained indigenous firefighters and established local substations with the support of the government and partners. This initiative strengthened community response capacity, significantly reduced the number of fires, and promoted the protection of territories, biodiversity, and local economies based on agriculture, fishing, and livestock.

REDE DE BRIGADAS DO BAIXO TAPAJÓS

BRAZIL

In coordination with local and federal environmental agencies, the Rede de Brigadas do Baixo Tapajós brings together volunteer and community brigades under an integrated strategy of Integrated Fire Management (IFM) activities. Operating across more than one million hectares, the initiative combines crop field mapping, satellite-based fire monitoring, climate education, and an Emergency Response Fund. By merging traditional knowledge with cutting-edge technology and coordinated action, the network has strengthened local autonomy, reduced response times, and protected lives, forests, and traditional livelihoods in one of the most complex and vulnerable regions of the Amazon.

©Brigada de Alter

CHALLENGES

Position Integrated Fire Management as a central tool for climate change mitigation and adaptation, making environments and territories more fire-adapted and aligned with the principles of nature-based solutions.

Promote inclusive and coordinated governance that engages governments, the private sector, communities, and academia, ensuring recognition of traditional knowledge and the active participation of women, youth, and older people.

Advance the development and implementation of Integrated Fire Management Plans as participatory tools for territorial governance, integrated with local land-use regulations and aligned with fire-use authorizations, cultural practices, and prevention measures on rural properties.

Ensure continuous and long-term financial support for IFM actions at all levels, while engaging international partners to promote collaborative and sustainable financing strategies.

Strengthen technical, institutional, and community capacities, shifting from reactive to integrated strategies, and aligning policies with local contexts and future scenarios.

Standardize qualifications and promote unified IFM training programs to ensure quality, consistency, and capacity across the entire Amazon region.

Invest in the production of knowledge and the integration of technological tools for monitoring, forecasting, and planning to support territorial decision-making.

Invest in local and municipal actions, as well as in voluntary and community brigades, to reduce unwanted ignitions and shorten response times.

Implement governance structures at national level, articulated with subnational, regional, and local frameworks, and grounded in principles of shared responsibility and landscape-scale management.


PREVFOGO
IBAMA
PREVFOGO
IBAMA
PREVFOGO
IBAMA
PREVFOGO
IBAMA
PREVFOGO
IBAMA
©Augusto Dauster

©Taller Ramif

EPILOGUE

AMAZONIAN COOPERATION FOR INTEGRATED FIRE MANAGEMENT

Carlos Salinas[1], Fernando Rodovalho[2], Cristian Guerrero[2], Arnaldo Carneiro[3]

[1]Amazon Cooperation Treaty Organization (ACTO)
[2]CoRAmazonia Project, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
[3]Amazon Cooperation Treaty Organization (ACTO) / Amazon Regional Observatory (ARO)

Wildfires know no political or administrative boundaries. Their impacts cross national borders, affecting ecosystems, communities, and climate on a regional scale. Therefore, addressing this challenge requires more than isolated efforts: it demands cooperation, coordination, and shared commitment. With this understanding, in 2023, the Member States of the Amazon Cooperation Treaty Organization (ACTO) established the *Memorandum of Understanding on Cooperation and Mutual Assistance for Integrated Fire Management*[1] to develop a regional cooperation system for Integrated Fire Management (IFM) in the Amazon region. This agreement acknowledges the transboundary nature of wildfires and lays the foundation for technical cooperation, exchange of experiences, coordinated actions and mutual support.

This vision was further strengthened in the Belém Declaration[2], signed by the presidents of the amazonian countries during the Amazon Summit in August 2023. In the declaration, they reaffirmed their commitment to developing joint policies and coordinated actions for the prevention and management of fire, emphasizing the use of technology, the promotion of sustainable alternatives to fire use in rural areas, and the strengthening of technical, institutional, and community capacities.

I AMAZON NETWORK FOR INTEGRATED FIRE MANAGEMENT (RAMIF)

It was in this context that, at the end of 2023, the Amazon Network for Integrated Fire Management (RAMIF) was established. RAMIF has since consolidated itself as a technical and political platform for cooperation based on equality, solidarity and mutual benefit. The network's actions range from developing mechanisms for mutual support and assistance among countries to combat wildfires, to strengthening technical and institutional capacities, and promoting the exchange and dissemination of good practices in Integrated Fire Management (IFM). In addition, the network has advanced integrated communication strategies to give visibility to local initiatives and to strengthen the recognition of those working directly in the territories. More than an institutional arrangement, RAMIF represents a collective commitment to keeping the forest standing and to honoring the peoples who keep it alive.

To guide its work, RAMIF approved, in June 2024 in Lima (Peru), a Biennial Work Plan structured around key fields of action and strategic initiatives, as outlined below.

	Fields of action	Strategic actions
1	Cooperation and mutual assistance	**1.1** Timely response and mutual assistance
		1.2 Fire management (techniques and cultural practices)
		1.3 Monitoring and early warning
2	Strengthening capacities	**2.1** Training and awareness raising
		2.2 Research and innovation
		2.3 Experience exchange and knowledge management
3	Communication for social change	**3.1** Communication for both social and behavior change
		3.2 Political and normative influence and engagement with change agents
4	Strategic planning and institutional strengthening	**4.1** Coordination, cooperation and financing
		4.2 RAMIF management

2 AMAZON REGIONAL OBSERVATORY

Launched in 2021, the Amazon Regional Observatory (ARO) is an initiative of the Amazon Cooperation Treaty Organization (ACTO), designed to serve as a reference hub for essential information to support the integrated and sustainable management of the Amazon. The ARO can play a key role in ACTO's integration efforts. By bringing together national data from Member Countries, the observatory offers a shared and comprehensive view of amazonian realities that transcend national borders, strengthening cooperation and evidence-based decision-making across the region.

As an observatory, the ARO is responsible for systematizing information related to critical events occurring in the Amazon region which, if they reach a tipping point, could trigger a new ecological dynamic in the area. Its relevance lies in its capacity to compile, integrate, process, and disseminate scientific information among institutions, government authorities, universities, academia, and civil society across the Amazon countries.

3 OTHER GLOBAL AND REGIONAL COOPERATION INITIATIVES

International cooperation around Integrated Fire Management in support of the Amazon region has been strengthened through global, regional, and bilateral initiatives that promote knowledge and experience exchange, as well as capacity building to address the growing challenges posed by wildfires. The Global Fire Management Hub, led by the FAO, operates as a global platform for technical coordination, promoting training, knowledge sharing, and policy support for integrated fire management at different levels. The Expert Group on Forest Fires of Latin America and the Caribbean (GEFF-LAC), driven by the European Union, fosters the exchange of experiences and the development of regional capacities, consolidating a network of specialists focused on solutions tailored to local realities.

Within the Amazon region, cooperation projects such as CoRAmazonia, developed through German cooperation in partnership with ACTO, and the FiRe Project (FAO, Germany, and Switzerland), combine efforts by promoting innovation, technical training, exchange of experiences, and the strengthening of institutional and community capacities in Integrated Fire Management (IFM). These efforts are complemented by initiatives such as the European Union's Amazonia+ Program, regional projects from the Inter-American Development Bank (IDB), among others. Together, these actions converge toward a common agenda aimed at reducing wildfire risks, protecting biodiversity, and contributing to global climate commitments, underscoring the strategic role of international cooperation in enhancing the region's socio-environmental resilience.


©Mayangdi Inzaulgarat


STIHL

REFERENCES

CHAPTER 1

1. Aliaga-Rossel, E., Martins, M. B., Barrera, S., Benítez, Á., Cano, C. A., dos Santos, T. C. M., et al. Situación, tendencias y dinámica de la diversidad biológica y las contribuciones de la naturaleza para las personas. In: Corvalán, M. E. (ed.) *Evaluación Rápida de la Diversidad Biológica y Servicios Ecosistémicos en la Región Amazónica.* OTCA, Proyecto OTCA/BIOMAZ, GIZ-Brasil, BMZ, Instituto Humboldt. Brasília (2023).
2. Levis, C., Costa, F. R., Bongers, F., Peña-Claros, M., Clement, C. R., Junqueira, A. B., et al. Persistent effects of pre-Columbian plant domestication on amazonian forest composition. *Science* 355, 925–931 (2017). https://doi.org/10.1126/science.aal0157
3. Science Panel for the Amazon (SPA). *Amazon Assessment Report 2021.* Nobre, C., Encalada, A., Anderson, E., Roca Alcázar, F. H., Bustamante, M., Mena, C., et al. (eds.) United Nations Sustainable Development Solutions Network, New York (2021). https://doi.org/10.55161/RWSX6527
4. Intergovernmental Panel on Climate Change (IPCC). Summary for policymakers. In: Pörtner, H.-O., Roberts, D. C., Poloczanska, E. S., Mintenbeck, K., Tignor, M., Alegría, A., et al. (eds.) *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the IPCC.* Cambridge Univ. Press, Cambridge, UK and New York, NY, USA, 3–33 (2022). https://doi.org/10.1017/9781009325844.001
5. Lovejoy, T. E. & Nobre, C. Amazon tipping point. *Sci. Adv.* 4, eaat2340 (2018). https://doi.org/10.1126/sciadv.aat2340
6. Nobre, C. A., Sampaio, G., Borma, L. S., Castilla-Rubio, J. C., Silva, J. S. & Cardoso, M. Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm. *Proc. Natl. Acad. Sci. U.S.A.* 113, 10759–10768 (2016). https://doi.org/10.1073/pnas.1605516113
7. Flores, B. M., Montoya, E., Sakschewski, B., et al. Critical transitions in the Amazon forest system. *Nature* 626, 555–564 (2024). https://doi.org/10.1038/s41586-023-06970-0
8. Marengo, J. A., Cunha, A. P., Espinoza, J.-C., Fu, R., Schöngart, J., Jimenez, J. C., et al. The drought of Amazonia in 2023–2024. *Am. J. Clim. Change* 13, 567–597 (2024). https://doi.org/10.4236/ajcc.2024.133026
9. Phillips, O. L., Aragão, L. E., Lewis, S. L., Fisher, J. B., Lloyd, J., López-González, G., et al. Drought sensitivity of the Amazon rainforest. *Science* 323, 1344–1347 (2009). https://doi.org/10.1126/science.1164033
10. Malhi, Y., Roberts, J. T., Betts, R. A., Killeen, T. J., Li, W. & Nobre, C. A. Climate change, deforestation, and the fate of the Amazon. *Science* 319, 169–172 (2008). https://doi.org/10.1126/science.1146961
11. Carmenta, R., Cammelli, F., Dressler, W., Verbicaro, C. & Zaehringer, J. G. Between a rock and a hard place: The burdens of uncontrolled fire for smallholders across the tropics. *World Dev.* 145, 105521 (2021). https://doi.org/10.1016/j.worlddev.2021.105521

CHAPTER 2

1. Pausas, J. G. & Keeley, J. E. A burning story: the role of fire in the history of life. *BioScience* 59, 593–601 (2009). https://doi.org/10.1525/bio.2009.59.7.10
2. Maezumi, S. Y., Fletcher, M. S., Safford, H. & Roberts, P. Fighting with fire: historical ecology and community-based approaches to fire management, stewardship, and ecosystem resilience. *One Earth* 7, 936–941 (2024).
3. Glaser, B., Haumaier, L., Guggenberger, G. & Zech, W. The "Terra Preta" phenomenon: a model for sustainable agriculture in the humid tropics. *Naturwissenschaften* 88, 37–41 (2001).
4. McMichael, C. H. et al. Predicting pre-Columbian anthropogenic soils in Amazonia. *Proc. R. Soc. B* 281, 20132475 (2014).
5. Levis, C. et al. How people domesticated amazonian forests. *Front. Ecol. Evol.* 5, 171 (2018). https://doi.org/10.3389/fevo.2017.00171
6. Meggers, B. J. Archeological evidence for the impact of mega-Niño events on Amazonia during the past two millennia. *Clim. Change* 28, 321–338 (1994). https://doi.org/10.1007/BF01104077
7. Cochrane, M. Fire science for rainforests. *Nature* 421, 913–919 (2003). https://doi.org/10.1038/nature01437
8. Santos, F. L. M. et al. Prescribed burning reduces large, high-intensity wildfires and emissions in the Brazilian savanna. *Fire* 4, 56 (2021). https://doi.org/10.3390/fire4030056
9. Flores, B. M. & Levis, C. Human-food feedback in tropical forests. *Science* 372, 1146–1147 (2021).
10. Mistry, J., Bilbao, B. A. & Berardi, A. Community owned solutions for fire management in tropical ecosystems: case studies from Indigenous communities of South America. *Philos. Trans. R. Soc. B* 371, 20150174 (2016).
11. Pivello, V. R. The use of fire in the Cerrado and amazonian rainforests of Brazil: past and present. *Fire Ecol.* 7, 24–39 (2011).
12. Bilbao, B., Mistry, J., Millán, A. & Berardi, A. Sharing multiple perspectives on burning: towards a participatory and intercultural fire management policy in Venezuela, Brazil, and Guyana. *Fire* 2, 39 (2019). https://doi.org/10.3390/fire2030039
13. Moura, L. C. et al. The legacy of colonial fire management policies on traditional livelihoods and ecological sustainability in savannas: impacts, consequences, new directions. *J. Environ. Manage.* 232, 600–606 (2019). https://doi.org/10.1016/j.jenvman.2018.11.057
14. UNESCO. Indigenous peoples' traditional knowledge of fire: observing, understanding, and coping with climate change and the vulnerabilities of socio-environmental systems – case studies from the Guiana Shield (Guyana, Suriname, Venezuela). UNESCO, Paris (2024).
15. Bilbao, B. A., Ferrero, B. G., Falleiro, R. M., Moura, L. C. & Fagundes, G. M. Traditional fire uses by Indigenous Peoples and local communities in South America. In: Fidelis, A. & Pivello, V. R. (eds) *Fire in the South American Ecosystems.* Ecological Studies 250. Springer, Cham (2025). https://doi.org/10.1007/978-3-031-89372-8_3
16. Bilbao, B. A., Leal, A. V. & Méndez, C. L. Indigenous use of fire and forest loss in Canaima National Park, Venezuela: assessment of and tools for alternative strategies of fire management in Pemón indigenous lands. *Hum. Ecol.* 38, 663–673 (2010). https://doi.org/10.1007/s10745-010-9344-0
17. FAO. Community-based fire management: a review. Forestry Paper 166. Food and Agriculture Organization of the United Nations, Rome (2011).
18. Myers, R. Living with fire: sustaining ecosystems & livelihoods through integrated fire management. The Nature Conservancy, Global Fire Partnership (2006).
19. Pasiecznik, N. & Goldammer, J. G. (eds) Towards fire-smart landscapes. *Tropical Forest Issues* 61. Tropenbos International, Ede (2022).

20. Simmons, C. S., Walker, R. T., Wood, C. H., Arima, E. & Cochrane, M. A. Wildfires in Amazonia: a pilot study examining the role of farming systems, social capital, and fire contagion. *J. Lat. Am. Geogr.* 3, 81–95 (2004). https://doi.org/10.1353/lag.200
21. Bowman, M. S., Amacher, G. S. & Merry, F. D. Fire use and prevention by traditional households in the Brazilian Amazon. *Ecol. Econ.* 7 (2008). https://doi.org/10.1016/j.ecolecon.2007.12.003
22. Silva, R. D. O., Barioni, L. G. & Moran, D. Fire, deforestation, and livestock: when the smoke clears. *Land Use Policy* 100, 104949 (2021). https://doi.org/10.1016/j.landusepol.2020.104949
23. Becker, B. K. Geopolítica da Amazônia. *Estud. Avançados* 19, 71–86 (2005).
24. Feanside, P. M. Deforestation in Brazilian Amazonia: history, rates, and consequences. *Conserv. Biol.* 19, 680–688 (2005). https://doi.org/10.1111/j.1523-1739.2005.00697.x
25. Prates, R. C. & Bacha, C. J. C. Os processos de desenvolvimento e desmatamento da Amazônia. *Econ. Soc.* 43 (2011). https://doi.org/10.1590/S0104-06182011000300006
26. Carmenta, R. Between a rock and a hard place: the burden of environmental regulations for smallholders in the Brazilian Amazon. *For. Policy Econ.* 128, 102452 (2021). https://doi.org/10.1016/j.forpol.2021.102452
27. Moutinho, P. & Azevedo-Ramos, C. Untitled public forestlands threaten Amazon conservation. *Nat. Commun.* 14, 1152 (2023).
28. Lapola, D. M. et al. The drivers and impacts of Amazon forest degradation. *Science* 379, eabp8622 (2023). https://doi.org/10.1126/science.abp8622
29. Berenguer, E. et al. Drivers and ecological impacts of deforestation and forest degradation in the Amazon. In: Nobre, C. et al. (eds) *Amazon Assessment Report 2021.* United Nations Sustainable Development Solutions Network, New York (2021). https://doi.org/10.55161/AIZJ1133
30. Alencar, A., Brando, P. M., Asner, G. P. & Putz, F. E. Landscape fragmentation, severe drought, and the new Amazon forest fire regime. *Ecol. Appl.* 25, 1493–1505 (2015). https://doi.org/10.1890/14-1528.1
31. Fonseca, M. G. et al. Effects of climate and land-use change on fire regimes in the Amazon. *Nat. Commun.* 14, 345 (2023). https://doi.org/10.1038/s41467-022-35647-z
32. Nepstad, D. et al. Amazon drought and its implications for forest flammability and tree growth: a basin-wide analysis. *Glob. Change Biol.* 10, 704–717 (2004). https://doi.org/10.1111/j.1529-8817.2003.00772.x
33. de Faria, B. L. et al. Climate change and deforestation increase the vulnerability of amazonian forests to post-fire grass invasion. *Glob. Ecol. Biogeogr.* 30, 2368–2381 (2021).

CHAPTER 3

1. MapBiomas Amazônia. Coleção 6 da série anual de Mapas de Cobertura e Uso da Terra. (2025). Available at: https://amazonia.mapbiomas.org/pt/
2. MapBiomas Bolívia. Coleção 2 da série anual de Mapas de Cobertura e Uso da Terra da Bolívia. (2025). Available at: https://bolivia.mapbiomas.org/en/
3. MapBiomas Brasil. Coleção 9 da série anual de Mapas de Cobertura e Uso da Terra do Brasil. (2025). Available at: https://brasil.mapbiomas.org/
4. MapBiomas Colômbia. Coleção 2 da série anual de Mapas de Cobertura e Uso da Terra da Colômbia. (2025). Available at: https://colombia.mapbiomas.org/
5. MapBiomas Equador. Coleção 2 da série anual de Mapas de Cobertura e Uso da Terra do Equador. (2025). Available at: https://ecuador.mapbiomas.org/
6. MapBiomas Peru. Coleção 3 da série anual de Mapas de Cobertura e Uso da Terra do Peru. (2025). Available at: https://peru.mapbiomas.org/
7. MapBiomas Venezuela. Coleção 2 da série anual de Mapas de Cobertura e Uso da Terra da Venezuela. (2025). Available at: https://venezuela.mapbiomas.org/en/
8. Shlisky, A., Alencar, A., Manta, M. & Curran, L. M. Overview: Global fire regime conditions, threats, and opportunities for fire management in the tropics. In: Cochrane, M. A. (ed.) *Tropical Fire Ecology* 65–83 (Springer, 2009).
9. Pivello, V. R. et al. Understanding Brazil's catastrophic fires: causes, consequences and policy needed to prevent future tragedies. *Perspect. Ecol. Conserv.* 19, 233–255 (2021).
10. Meggers, B. J. Archeological evidence for the impact of mega-Niño events on Amazonia during the past two millennia. *Clim. Change* 28, 321–338 (1994).
11. Bilbao, B., Mistry, J., Millán, A. & Berardi, A. Sharing multiple perspectives on burning. *Fire* 2, 39 (2019).
12. Giglio, L., Csiszar, I. & Justice, C. O. Global distribution and seasonality of active fires with MODIS. *J. Geophys. Res. Biogeosci.* 111, G02016 (2006).
13. Lima, A., Silva, T. S. F. & Aragão, L. E. O. C. Land use/cover changes determine the spatial relationship between fire and deforestation in the Brazilian Amazon. *Appl. Geogr.* 34, 239–246 (2012).
14. Alencar, A. A., Brando, P. M., Asner, G. P. & Putz, F. E. Landscape fragmentation, severe drought, and the new Amazon forest fire regime. *Ecol. Appl.* 25, 1493–1505 (2015).
15. Alencar, A. A. C. et al. Long-term Landsat-based monthly burned area dataset. *Remote Sens.* 14, 2510 (2022).
16. Cochrane, M. A. Fire science for rainforests. *Nature* 421, 913–919 (2003).
17. Barlow, J., Berenguer, E., Carmenta, R. & França, F. Clarifying Amazonia's burning crisis. *Glob. Change Biol.* 26, 319–321 (2020).
18. Projeto MapBiomas. Coleção 10 da série anual de Mapas de Cobertura e Uso da Terra do Brasil. (2025). Available at: https://brasil.mapbiomas.org/
19. Brando, P. M. et al. Droughts, wildfires, and forest carbon cycling: a pantropical synthesis. *Annu. Rev. Earth Planet. Sci.* 47, 555–581 (2019).
20. Silvério, D. V. et al. Intensification of fire regimes and forest loss in the Território Indígena do Xingu. *Environ. Res. Lett.* 17, 045012 (2022).
21. Lapola, D. M. et al. The drivers and impacts of Amazon forest degradation. *Science* 379, eabp8622 (2023).
22. Alencar, A., Nepstad, D. & Diaz, M. C. V. Forest understory fire in the Brazilian Amazon. *Earth Interact.* 10, 1–17 (2006).
23. Aragão, L. E. O. C. et al. Drought-related fires counteract the decline of Amazon deforestation carbon emissions. *Nat. Commun.* 9, 536 (2018).
24. Vara-Vela, A. L. et al. A predictive framework for Amazon forest fire smoke dispersion. *Bull. Am. Meteorol. Soc.* 102, E1700–E1713 (2021).
25. Nepstad, D. et al. Amazon drought and implications for forest flammability and tree growth. *Glob. Change Biol.* 10, 704–717 (2004).
26. Marengo, J. A. et al. Long-term variability, extremes and changes in temperature and hydrometeorology in the Amazon. *Acta Amaz.* 54, e54es22098 (2024).
27. Cochrane, M. A. et al. Positive feedbacks in the fire dynamic of closed-canopy tropical forests. *Science* 284, 1832–1835 (1999).

28. Brando, P. M. et al. Abrupt increases in amazonian tree mortality due to drought–fire interactions. *Proc. Natl. Acad.* Sci. U.S.A. 111, 6347–6352 (2014).
29. Berenguer, E. et al. Tracking the impacts of El Niño drought and fire in human-modified amazonian forests. Proc. Natl. Acad. Sci. U.S.A. 118, e2019377118 (2021).
30. Giglio, L. Global estimation of burned area using MODIS active fire observations. Atmos. Chem. Phys. 6, 957–974 (2006).
31. Pessôa, A. C. M. et al. Intercomparison of burned area products and implications for carbon emission estimates in the Amazon. Remote Sens. 12, 3864 (2020).
32. Science Panel for the Amazon (SPA). Amazon Assessment Report 2021 – Annex I: The multiple viewpoints for the Amazon. (UN SDSN, 2021).
33. RAISG. Amazon Geo-Referenced Socio-Environmental Information Network. RAISG limits 2024 [cartographic data]. (2024).
34. Carvalho, N. S. et al. Spatio-temporal variation in dry season determines the amazonian fire calendar. *Environ. Res. Lett.* 16, 125009 (2021).
35. Fundación Tierra. *Incendios forestales 2024: Tras las huellas del fuego.* (2024).
36. Pacheco, P. El contexto de la deforestación y degradación de los bosques en Bolivia: causas, agentes e instituciones. (CIFOR, 2012).
37. WWF. *Uncovering sub-regional drivers of deforestation in the Amazon.* (2024).
38. Maillard, O. et al. Forest cover fragmentation, drought and forest fires in Santa Cruz, Bolivia. *Forests* 11, 910 (2020).
39. He, Y. et al. Enact reforms to protect Bolivia's forests from fire. *Science* 387, 255 (2025).
40. Pismel, G. O. et al. Wildfire governance in a tri-national frontier of southwestern Amazonia. *Int. J. Disaster Risk Reduct.* 86, 103529 (2023).
41. Singh, M. et al. Fire dynamics of the Bolivian Amazon. *Land* 11, 1436 (2022).
42. BRASIL. Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal. (2004).
43. Haddad, E. A. et al. Economic drivers of deforestation in the Brazilian Legal Amazon. *Nat. Sustain.* 7, 1141–1148 (2024).
44. Morton, D. C. et al. Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. *Proc. Natl. Acad. Sci. U.S.A.* 103, 14637–14641 (2006).
45. Morton, D. C. et al. Agricultural intensification increases deforestation fire activity in Amazonia. *Glob. Change Biol.* 14, 2262–2275 (2008).
46. Brito, B. et al. Stimulus for land grabbing and deforestation in the Brazilian Amazon. *Environ. Res. Lett.* 14, 064018 (2019).
47. Armenteras, D., Schneider, L. & Dávalos, L. M. Fires in protected areas reveal unforeseen costs of Colombian peace. *Nat. Ecol. Evol.* 3, 20–23 (2019).
48. Armenteras, D. et al. Curb land grabbing to save the Amazon. *Nat. Ecol. Evol.* 3, 1497 (2019).
49. Peek, P. Urban poverty, migration and land reform in Ecuador. *ILO Working Paper* (1979).
50. Messina, J. P. & Cochrane, M. A. The forests are bleeding: land-use change and a new fire regime in the Ecuadorian Amazon. *J. Lat. Am. Geogr.* 6, 85–100 (2007).
51. Wasserstrom, R. & Southgate, D. D. Deforestation, agrarian reform and oil development in Ecuador, 1964–1994. *Natural Resources* 4, 31 (2013).
52. Dezécache, C. et al. Gold-rush in a forested El Dorado: deforestation leakages and need for regional cooperation. *Environ. Res. Lett.* 12, 034013 (2017).
53. Torres-Padilla, J. *Informe: Incendios forestales y deforestación en la Amazonia peruana.* (2025).
54. Finer, M. et al. Future of oil and gas development in the western Amazon. *Environ. Res. Lett.* 10, 024003 (2015).
55. Finer, M. & Mamani, N. Deforestación 2020 en la Amazonía Peruana (MAAP n.º 124). (2020).
56. Uriarte, M. et al. Depopulation of rural landscapes exacerbates fire activity in the western Amazon. Proc. Natl. Acad. Sci. U.S.A. 109, 21546–21550 (2012).
57. Valdivia Blume, C. Expansión de la frontera agropecuaria y deforestación en la Amazonía peruana. (2024)
58. Giljum, S. et al. Uncovering global drivers of forest loss due to mining. *Nat. Commun*. 13, 116 (2022).
59. Pacheco, P., Aguado, I. & Mollicone, D. Drivers of forest fires in the Venezuelan Amazon. *Reg. Environ. Change* 14, 1041–1053 (2014).

CHAPTER 4

1. Jolly, W. M. et al. Climate-induced variations in global wildfire danger from 1979 to 2013. *Nat Commun* 6, 7537 (2015). https://doi.org/10.1038/ncomms8537
2. Jones, M. W. et al. Global and Regional Trends and Drivers of Fire Under Climate Change. *Reviews of Geophysics* 60, e2020RG000726 (2022). https://doi.org/10.1029/2020RG000726
3. Libonati, R. et al. Drought–heatwave nexus in Brazil and related impacts on health and fires: A comprehensive review. *Annals of the New York Academy of Sciences* 1517, 44–62 (2022b). https://doi.org/10.1111/nyas.14764
4. Libonati, R. et al. Twenty-first century droughts have not increasingly exacerbated fire season severity in the Brazilian Amazon. *Sci Rep* 11, 4400 (2021). https://doi.org/10.1038/s41598-021-83724-7
5. Berenguer, E. et al. Drivers and ecological impacts of deforestation and forest degradation in the Amazon. *Acta Amaz.* 54, e54es22342 (2024). https://doi.org/10.1590/1809-4392202301113
6. Oliveras Menor, I. et al. Integrated fire management as an adaptation and mitigation strategy to altered fire regimes. *Commun Earth Environ* 6, 202 (2025). https://doi.org/10.1038/s43247-025-01553-3
7. Flores, B. M. et al. Critical transitions in the Amazon forest system. *Nature* 626, 555–564 (2024). https://doi.org/10.1038/s41586-024-07288-0
8. Lovejoy, T. E. & Nobre, C. Amazon Tipping Point. *Sci. Adv.* 4, eaat2340 (2018). https://doi.org/10.1126/sciadv.aat2340
9. NASA Goddard Institute for Space Studies. GISS Surface Temperature Analysis (GISTEMP). https://data.giss.nasa.gov/ (2024).
10. Sherwood, S. C. & Huber, M. An adaptability limit to climate change due to heat stress. *Proc. Natl. Acad. Sci. U.S.A.* 107, 9552–9555 (2010). https://doi.org/10.1073/pnas.0913352107
11. Geirinhas, J. L., Trigo, R. M., Libonati, R., Coelho, C. A. S. & Palmeira, A. C. Climatic and synoptic characterization of heat waves in Brazil. *Intl J Climatol* 38, 1760–1776 (2018). https://doi.org/10.1002/joc.5294
12. Miranda, V. F. V. V. et al. Heat stress in South America over the last four decades: a bioclimatic analysis. *Theor Appl Climatol* 155, 911–928 (2024). https://doi.org/10.1007/s00704-023-04847-3
13. Monteiro Dos Santos, D. et al. Twenty-first-century demographic and social inequalities of heat-related deaths in Brazilian urban areas. *PLoS ONE* 19, e0295766 (2024). https://doi.org/10.1371/journal.pone.0295766
14. Marengo, J. A. et al. Climatological patterns of heatwaves during

winter and spring 2023 and trends for the period 1979–2023 in central South America. *Front. Clim.* 7, 1529082 (2025). https://doi.org/10.3389/fclim.2025.1529082

15. Jiménez-Muñoz, J. C., Sobrino, J. A., Mattar, C. & Malhi, Y. Spatial and temporal patterns of the recent warming of the Amazon forest. *JGR Atmospheres* 118, 5204–5215 (2013). https://doi.org/10.1002/jgrd.50456
16. Jiménez, J. C. et al. Vegetation Warming and Greenness Decline across Amazonia during the Extreme Drought of 2023. *Remote Sensing* 16, 2519 (2024). https://doi.org/10.3390/rs16102519
17. Marengo, J. A. et al. The Drought of Amazonia in 2023-2024. *AJCC* 13, 567–597 (2024). https://doi.org/10.4236/ajcc.2024.134028
18. de Lima, L. S. et al. Severe droughts reduce river navigability and isolate communities in the Brazilian Amazon. *Commun Earth Environ* 5, 370 (2024). https://doi.org/10.1038/s43247-024-01585-w
19. Maciel, D. A. et al. Sentinel-1 data reveals unprecedented reduction of open water extent due to 2023-2024 drought in the central Amazon basin. *Environ. Res. Lett.* 19, 124034 (2024). https://doi.org/10.1088/1748-9326/ad813b
20. Libonati, R. et al. Assessing the role of compound drought and heatwave events on unprecedented 2020 wildfires in the Pantanal. *Environ. Res. Lett.* 17, 015005 (2022a). https://doi.org/10.1088/1748-9326/ac449c
21. Libonati, R. et al. Drought–heatwave nexus in Brazil and related impacts on health and fires: A comprehensive review. *Ann. N. Y. Acad. Sci.* 1517, 44–62 (2022b). https://doi.org/10.1111/nyas.14764
22. Geirinhas, J. L. et al. Recent increasing frequency of compound summer drought and heatwaves in Southeast Brazil. *Environ. Res. Lett.* 16, 034036 (2021). https://doi.org/10.1088/1748-9326/abde36
23. Zscheischler, J. et al. Compound weather and climate events: a review. *Nat Rev Earth Environ* 1, 333–347 (2020). https://doi.org/10.1038/s43017-020-0060-z
24. Geirinhas, J. L., Russo, A. C., Libonati, R. et al. Combined large-scale tropical and subtropical forcing on the severe 2019–2022 drought in South America. *npj Clim Atmos Sci* 6, 185 (2023). https://doi.org/10.1038/s41612-023-00510-3
25. Mukherjee, S., Mishra, A. K., Ashfaq, M. & Kao, S.-C. Relative effect of anthropogenic warming and natural climate variability to changes in Compound drought and heatwaves. *Journal of Hydrology* 605, 127396 (2022). https://doi.org/10.1016/j.jhydrol.2021.127396
26. Costa, D. F., Gomes, H. B., Silva, M. C. L. & Zhou, L. The most extreme heat waves in Amazonia happened under extreme dryness. *Clim Dyn* 59, 281–295 (2022). https://doi.org/10.1007/s00382-022-06182-9
27. Drumond, A. et al. The role of the Amazon Basin moisture in the atmospheric branch of the hydrological cycle: a Lagrangian analysis. *Hydrol. Earth Syst. Sci.* 18, 2577–2598 (2014). https://doi.org/10.5194/hess-18-2577-2014
28. Espinoza, J.-C. et al. The new record of drought and warmth in the Amazon in 2023 related to regional and global climatic features. *Sci Rep* 14, 8107 (2024). https://doi.org/10.1038/s41598-024-54140-y
29. Cochrane, M. A. & Barber, C. P. Climate change, human land use and future fires in the Amazon. *Global Change Biology* 15, 601–612 (2009). https://doi.org/10.1111/j.1365-2486.2008.01786.x
30. Libonati, R. et al. Drought–heatwave nexus in Brazil and related impacts on health and fires: A comprehensive review. *Ann. N. Y. Acad. Sci.* 1517, 44–62 (2022b). https://doi.org/10.1111/nyas.14764
31. Zscheischler, J. et al. Compound weather and climate events in 2024. *Nat Rev Earth Environ* 6, 240–242 (2025). https://doi.org/10.1038/s43017-025-00777-9
32. Clarke, B. et al. Climate change, not El Niño, main driver of extreme drought in highly vulnerable Amazon River Basin. (2024). https://doi.org/10.25561/108761
33. Panisset, J. S. et al. Contrasting patterns of the extreme drought episodes of 2005, 2010 and 2015 in the Amazon Basin. *Intl J Climatol* 38, 1096–1104 (2018). https://doi.org/10.1002/joc.5224
34. Nepstad, D. et al. Amazon drought and its implications for forest flammability and tree growth: a basin wide analysis. *Global Change Biology* 10, 704–717 (2004). https://doi.org/10.1111/j.1365-2486.2003.00786.x
35. Bowman, D. M. J. S. et al. Fire in the Earth System. *Science* 324, 481–484 (2009). https://doi.org/10.1126/science.1163886
36. Vitolo, C. et al. ERA5-based global meteorological wildfire danger maps. *Sci Data* 7, 216 (2020). https://doi.org/10.1038/s41597-020-0544-y
37. O'Neill, B. C. et al. The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6. *Geosci. Model Dev.* 9, 3461–3482 (2016). https://doi.org/10.5194/gmd-9-3461-2016
38. IPCC. *Climate Change 2022 – Impacts, Adaptation and Vulnerability*. Cambridge University Press (2022). https://doi.org/10.1017/9781009325844
39. Coppola, E. et al. Climate hazard indices projections based on CORDEX-CORE, CMIP5 and CMIP6 ensemble. *Clim Dyn* 57, 1293–1383 (2021). https://doi.org/10.1007/s00382-021-05640-z
40. Schwingshackl, C., Sillmann, J., Vicedo Cabrera, A. M., Sandstad, M. & Aunan, K. Heat Stress Indicators in CMIP6: Estimating Future Trends and Exceedances of Impact Relevant Thresholds. *Earth's Future* 9, e2020EF001885 (2021). https://doi.org/10.1029/2020EF001885
41. Almazroui, M. et al. Assessment of CMIP6 Performance and Projected Temperature and Precipitation Changes Over South America. *Earth Syst Environ* 5, 155–183 (2021). https://doi.org/10.1007/s41748-021-00237-9
42. Quilcaille, Y. & Batibeniz, F. Fire weather index data under historical and SSP projections in CMIP6 from 1850 to 2100. Preprint at https://doi.org/10.3929/ETHZ-B-000583391 (2022).
43. Quilcaille, Y., Batibeniz, F., Ribeiro, A. F. S., Padrón, R. S. & Seneviratne, S. I. Fire weather index data under historical and shared socioeconomic pathway projections in the 6th phase of the Coupled Model Intercomparison Project from 1850 to 2100. *Earth Syst. Sci. Data* 15, 2153–2177 (2023). https://doi.org/10.5194/essd-15-2153-2023

CHAPTER 5

1. Fidelis, A. *Is fire always the "bad guy"?* Flora 268, 151611 (2020).
2. Bilbao, B. A., Ferrero, B. G., Falleiro, R. M., Moura, L. C. & Fagundes, G. M. Traditional Fire Uses by Indigenous Peoples and Local Communities in South America. In *Fire in the South American Ecosystems* 39–81 (Springer, Cham, 2025).
3. de Mendonça, M. J. C. et al. The economic cost of the use of fire in the Amazon. Ecol. Econ. 49, 89–105 (2004).
4. Johnston, F. H., Williamson, G., Borchers-Arriagada, N., Henderson, S. B. & Bowman, D. M. Climate change, landscape fires, and human health: a global perspective. *Annu. Rev. Public Health* 45, 295–314 (2024).
5. To, P., Eboreime, E. & Agyapong, V. I. O. The Impact of Wildfires on Mental Health: A Scoping Review. *Behav. Sci.* 11, 126 (2021).
6. Brando, P. M. et al. Fire-induced tree mortality in a neotropical forest: the roles of bark traits, tree size, wood density and fire behavior. *Glob. Change Biol*. 18, 630–641 (2012).
7. Cochrane, M. A. et al. Positive feedbacks in the fire dynamic of closed canopy tropical forests. *Science* 284, 1832–1835 (1999).

8. Silvério, D. V. et al. Testing the Amazon savannization hypothesis: fire effects on invasion of a neotropical forest by native cerrado and exotic pasture grasses. *Phil. Trans. R. Soc. B* 368, 20120427 (2013).
9. Armenteras, D. et al. Fire-induced loss of the world's most biodiverse forests in Latin America. *Sci. Adv.* 7, eabd3357 (2021).
10. Foley, J. A. et al. Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. *Environ. Res. Lett*. 2, 045015 (2007).
11. Pereira, A. R., Torres, F. T. P. & Berlinck, C. N. Ecological implications of the direct effects of fire on neotropical vertebrates. *Sci. Total Environ*. 979, 179437 (2025).
12. Pfeifer, M. et al. Creation of forest edges has a global impact on forest vertebrates. *Nature* 551, 187–191 (2017).
13. Maillard, O., Herzog, S. K., Soria-Auza, R. W. & Vides-Almonacid, R. Impact of fires on Key Biodiversity Areas (KBAs) and priority bird species for conservation in Bolivia. *Fire* 5, 4 (2022).
14. Ledezma-Vargas, R. & Nina, R. E. Impacto de los incendios en la estructura y composición de la vegetación del Bosque Seco Chiquitano. Informe Técnico. Fundación para la Conservación del Bosque Chiquitano, Museo de Historia Natural Noel Kempff Mercado (2021).
15. Silva, C. V. et al. Estimating the multi-decadal carbon deficit of burned amazonian forests. *Environ. Res. Lett*. 15, 114023 (2020).
16. Andreae, M. O. et al. Transport of biomass burning smoke to the upper troposphere by deep convection in the equatorial region. Geophys. *Res. Lett*. 28, 951–954 (2001).
17. Barros, B., Oliveira, M. & Morais, S. Continent-based systematic review of the short-term health impacts of wildfire emissions. J. Toxicol. *Environ. Health B* 26, 387–415 (2023).
18. Nawaz, M. O. & Henze, D. K. Premature deaths in Brazil associated with long-term exposure to PM2.5 from Amazon fires between 2016 and 2019. *GeoHealth* 4, e2020GH000268 (2020).
19. Butt, E. W. et al. Large air quality and public health impacts due to amazonian deforestation fires in 2019. *GeoHealth* 5, e2021GH000429 (2021).
20. Sant'Anna, A. A. & Rocha, R. Health impacts of deforestation-related fires in the Brazilian Amazon. Instituto de Estudos para Políticas de Saúde (2020).
21. Carneiro, J., Cole, M. A. & Strobl, E. Foetal Exposure to Air Pollution and Students' Cognitive Performance: Evidence from Agricultural Fires in Brazil. *Oxf. Bull. Econ. Stat*. 86, 156–186 (2024).
22. Butt, E. W. et al. Large air quality and human health impacts due to Amazon forest and vegetation fires. *Environ. Res. Commun*. 2, 095001 (2020).
23. Oliveira, A. S. et al. Economic losses to sustainable timber production by fire in the Brazilian Amazon. *Geogr. J*. 185, 55–67 (2019).
24. Canavire-Bacarreza, G., Puerta-Cuartas, A. & Ramos, A. On the effects of wildfires on poverty in Bolivia. *J. Dev. Econ*. 175, 103494 (2025).
25. Hope, E. S., McKenney, D. W., Johnston, L. M. & Johnston, J. M. A cost-benefit analysis of WildFireSat, a wildfire monitoring satellite mission for Canada. PLoS One 19, e0302699 (2024).
26. Wang, D. et al. Economic footprint of California wildfires in 2018. *Nat. Sustain*. 4, 252–260 (2020).
27. Kiely, L. et al. Assessing costs of Indonesian fires and the benefits of restoring peatland. *Nat. Commun*. 12, 1–11 (2021).
28. Campanharo, W. A., Lopes, A. P., Anderson, L. O., da Silva, T. F. M. R. & Aragão, L. E. O. C. Translating Fire Impacts in Southwestern Amazonia into Economic Costs. *Remote Sens*. 11, 764 (2019).
29. Barrett, K. The full community costs of wildfire. Headwater Economics (2018). https://headwaterseconomics.org/wp-content/uploads/full-wildfire-costs-report.pdf
30. Thomas, D. S., Butry, D. T., Gilbert, S. W., Webb, D. H. & Fung, J. F. The costs and losses of wildfires: a literature review. NIST Special Publication 1215 (2017).
31. Buckley, M. et al. Mokelumne watershed avoided cost analysis: why Sierra fuel treatments make economic sense. Sierra Nevada Conservancy, The Nature Conservancy & USDA Forest Service (2014).
32. Jones, K. W., Gannon, B., Timberlake, T., Chamberlain, J. L. & Wolk, B. Societal benefits from wildfire mitigation activities through payments for watershed services: Insights from Colorado. *For. Policy Econ*. 135, 102661 (2022).
33. Hjerpe, E. E., Colavito, M. M., Waltz, A. E. & Meador, A. S. Return on investments in restoration and fuel treatments in frequent-fire forests of the American west: A meta-analysis. *Ecol. Econ*. 223, 108244 (2024).
34. Prestemon, J. P., Butry, D. T., Abt, K. L. & Sutphen, R. Net benefits of wildfire prevention education efforts. *For. Sci.* 56, 181–192 (2010).
35. Venn, T. J. & Quiggin, J. Early evacuation is the best bushfire risk mitigation strategy for south-eastern Australia. *Aust. J. Agric. Resour. Econ*. 61, 481–497 (2017).
36. Oliveira, A. S. et al. Costs and effectiveness of public and private fire management programs in the Brazilian Amazon and Cerrado. *For. Policy Econ*. 127, 102447 (2021).
37. Machado, M. S. et al. Emergency policies are not enough to resolve Amazonia's fire crises. *Commun. Earth Environ*. 5, 204 (2024).
38. World Bank Group. *The cost of fire: an economic analysis of Indonesia's 2015 fire crisis*. Indonesia sustainable landscapes knowledge note no. 1 (2016).

CHAPTER 6

1. World Health Organization (WHO). *COP29 special report on climate change and health: Health is the argument for climate action*. Geneva: WHO (2024).
2. Armenteras, D. et al. Human well-being and health impacts of the degradation of terrestrial and aquatic ecosystems. In: *Amazon Assessment Report 2021* (eds Nobre, C. et al.) United Nations Sustainable Development Solutions Network, New York (2021).
3. Butt, E. W., Conibear, L., Knote, C. & Spracklen, D. V. Large air quality and public health impacts due to amazonian deforestation fires in 2019. *GeoHealth* 5, e2021GH000429 (2021).
4. Bolaño-Diaz, S., Camargo-Caicedo, Y., Tovar Bernal, F. & Bolaño-Ortiz, T. R. The effect of forest fire events on air quality: A case study of Northern Colombia. *Fire* 5, 191 (2022).
5. Ribeiro, M. R. et al. Amazon wildfires and respiratory health: Impacts during the forest fire season from 2009 to 2019. *Int. J. Environ. Res. Public Health* 21, 675 (2024).
6. Machado-Silva, F. et al. Drought and fires influence the respiratory diseases hospitalizations in the Amazon. *Ecol. Indic.* 109, 105817 (2020).
7. Requia, W. J. et al. Health impacts of wildfire-related air pollution in Brazil: A nationwide study of more than 2 million hospital admissions between 2008 and 2018. *Nat. Commun.* 12, 6555 (2021).
8. Ignotti, E. et al. Impact on human health of particulate matter emitted from burnings in the Brazilian Amazon region. *Rev. Saúde Pública* 44, 121–130 (2010).
9. Campanharo, W. A., Morello, T., Christofoletti, M. A. M. & Anderson, L. O. Hospitalization due to fire-induced pollution in the Brazilian Legal Amazon from 2005 to 2018. *Remote Sens.* 14, 69 (2022).

10. Blaskievicz, P. H. et al. Atmospheric pollution exposure increases disease activity of systemic lupus erythematosus. *Int. J. Environ. Res. Public Health* 17, 1984 (2020).
11. Cândido da Silva, A. M., Moi, G. P., Mattos, I. E. & Hacon, S. S. Low birth weight at term and the presence of fine particulate matter and carbon monoxide in the Brazilian Amazon. *BMC Pregnancy Childbirth* 14, 309 (2014).
12. Sisenando, H. A. et al. Micronucleus frequency in children exposed to biomass burning in the Brazilian Legal Amazon region: A control case study. *BMC Oral Health* 12, 6 (2012).
13. Gioda, A. et al. Assessing over decadal biomass burning influence on particulate matter composition in subequatorial Amazon. *Atmos. Pollut. Res.* 14, 101675 (2023).
14. Andreae, M. O. et al. Smoking rain clouds over the Amazon. *Science* 303, 1337–1342 (2004).
15. Holanda, B. A. et al. African biomass burning affects aerosol cycling over the Amazon. *Commun. Earth Environ.* 4, 154 (2023).
16. Stein, A. F. et al. NOAA's HYSPLIT atmospheric transport and dispersion modeling system. *Bull. Am. Meteorol. Soc.* 96, 2059–2077 (2015).
17. Rolph, G., Stein, A. & Stunder, B. Real-time Environmental Applications and Display System: READY. *Environ. Model. Softw.* 95, 210–228 (2017).
18. Rocha, R. & Sant'Anna, A. A. Winds of fire and smoke: Air pollution and health in the Brazilian Amazon. *World Dev.* 151, 105722 (2022).
19. Carvalho, L. V. B. et al. Exposição ocupacional a substâncias químicas, fatores socioeconômicos e Saúde do Trabalhador: uma visão integrada. *Saúde Debate* 41, 313–326 (2017).
20. Palmeiro-Silva, Y. K. et al. Identifying gaps on health impacts, exposures, and vulnerabilities to climate change on human health and wellbeing in South America: A scoping review. *Lancet Reg. Health Am.* 26, 100580 (2023).
21. Allen, T. et al. Global hotspots and correlates of emerging zoonotic diseases. *Nat. Commun.* 8, 1124 (2017).
22. International Agency for Research on Cancer (IARC). *Occupational exposure as a firefighter*. IARC Monographs, Vol. 132. Lyon: WHO/IARC (2023).
23. Oliveira, M. et al. Firefighters exposure to fire emissions: Impact on biomarkers of exposure to PAHs and genotoxic/oxidative effects. *J. Hazard. Mater.* 383, 121179 (2020).
24. Held, M. B. et al. Environmental health of wildland firefighters: A scoping review. *Fire Ecol.* 20, 16 (2024).
25. Amorim, L. C. A. Os biomarcadores e sua aplicação na avaliação da exposição aos agentes químicos ambientais. *Rev. Bras. Epidemiol.* 6, 158–166 (2003).

CHAPTER 7

1. Carmenta, R., Cammelli, F., Dressler, W., Verbicaro, C. & Zaehringer, J. G. Between a rock and a hard place: The burdens of uncontrolled fire for smallholders across the tropics. *World Development* 145, 105521 (2021).
2. Lovejoy, T. E. & Nobre, C. Amazon tipping point. *Sci. Adv.* 4, eaat2340 (2018).
3. Flores, B. M., Montoya, E., Sakschewski, B. *et al.* Critical transitions in the Amazon forest system. *Nature* 626, 555–564 (2024).
4. Londres, M., Salk, C., Andersson, K. P., Tengö, M., Brondizio, E. S., Lopes, G. R. *et al.* Place-based solutions for global social-ecological dilemmas: An analysis of locally grounded, diversified, and cross-scalar initiatives in the Amazon. *Glob. Environ. Change* 82, 102718 (2023).
5. Nóbrega Spínola, J., Soares da Silva, M. J., Assis da Silva, J. R., Barlow, J., Ferreira, J. & Leverkus, A. B. A shared perspective on managing amazonian sustainable-use reserves in an era of megafires. *J. Appl. Ecol.* 57, (2020).
6. Myers, R. *Living with Fire: Sustaining ecosystems & livelihoods through Integrated Fire Management*. The Nature Conservancy, Global Fire Partnership (2006).
7. FAO. *Community-based fire management: A review*. Forestry Paper 166. Food and Agriculture Organization of the United Nations, Rome (2011).
8. Pasiecznik, N. & Goldammer, J. G. (eds). *Towards fire-smart landscapes*. Tropical Forest Issues 61. Tropenbos International, Ede, the Netherlands (2022).
9. UNEP. *Spreading like wildfire: The rising threat of extraordinary landscape fires*. United Nations Environment Programme (2022).
10. Oliveras Menor, I., Prat-Guitart, N., Spadoni, G. L. *et al.* Integrated fire management as an adaptation and mitigation strategy to altered fire regimes. *Commun. Earth Environ.* 6, 202 (2025).
11. FAO. *Integrated Fire Management Voluntary Guidelines – Principles and strategic actions. Second edition*. Forestry Working Paper 41. Food and Agriculture Organization of the United Nations, Rome (2024).
12. Maffi, L. What is biocultural diversity? In *Biocultural diversity conservation* 3–11 (Routledge, 2012).
13. Brasil. Lei nº 14.944, de 31 de julho de 2024 – Política Nacional de Manejo Integrado do Fogo. Diário Oficial da União, Brasília (2024).
14. Ericksen, P. J. What is the vulnerability of a food system to global environmental change? *Ecol. Soc.* 13, 2 (2008).
15. Rosenfeld, T., Pokorny, B., Marcovitch, J. & Poschen, P. BIOECONOMY based on non-timber forest products for development and forest conservation. *For. Policy Econ.* 163, 103228 (2024).
16. Schlosberg, D. & Collins, L. B. From environmental to climate justice: climate change and the discourse of environmental justice. *WIREs Clim. Change* 5, 359–374 (2014).
17. Sultana, F. Critical climate justice. *Geogr. J.* 188, 118–124 (2022).
18. Ottolini, I., Salesa, D., del Romero Renau, L. & Salvador, N. Kindling Change: Shaping a New Fire Culture in Mediterranean socioenvironmental systems from the roots. *Hum. Geogr.* 18, 1 (2024).
19. UNFCCC. *Paris Agreement*. United Nations Framework Convention on Climate Change (2015).
20. CBD. *Kunming-Montreal Global Biodiversity Framework*. Secretariat of the Convention on Biological Diversity (2022).
21. UNDRR. *Sendai Framework for Disaster Risk Reduction 2015–2030*. United Nations Office for Disaster Risk Reduction (2015).

EPILOGUE

1. OTCA – Organização do Tratado de Cooperação Amazônica. Memorando de Entendimento entre os Países Membros da OTCA para a Cooperação em Manejo Integrado do Fogo na Região Amazônica. (OTCA, 2021); available at: https://otca.org/memorando-fogo/
2. OTCA – Organização do Tratado de Cooperação Amazônica. Declaração de Belém: Cúpula dos Países Amazônicos. (OTCA, 2023); available at: https://otca.org/declaracao-de-belem/

FRONTIERS OF FIRE

AN OVERVIEW
OF FIRE IN THE
AMAZON REGION

ISBN: 978-85-61873-50-9

EXECUTION

ACTO Amazon Cooperation Treaty Organization

AMAZON REGIONAL OBSERVATORY

german cooperation DEUTSCHE ZUSAMMENARBEIT

Implemented by giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

CoRAmazonia Amazon Regional Cooperation

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Embassy of Switzerland in Peru

International Cooperation - SDC
Regional Hub Lima

ACTO Amazon Cooperation Treaty Organization

STRATEGIC PARTNERS

INPE

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

MINISTÉRIO DO MEIO AMBIENTE E MUDANÇA DO CLIMA

GOVERNO FEDERAL BRASIL UNIÃO E RECONSTRUÇÃO

USP

UFRJ UNIVERSIDADE FEDERAL DO RIO DE JANEIRO

LASA

IPAM Amazônia 30 anos

AMAZONIA VIVA

GFDRR

Administered by THE WORLD BANK IBRD · IDA | WORLD BANK GROUP