
IRRECOVERABLE CARBON
THE PLACES WE MUST PROTECT TO AVERT CLIMATE CATASTROPHE
CONSERVATION INTERNATIONAL

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CONSERVATION INTERNATIONAL

Foreword

The last year has been dominated by shortages — a shortage of coronavirus vaccines; a shortage of water in arid regions; and in the wake of new climate research, a shortage of optimism.

In September, the Intergovernmental Panel on Climate Change (IPCC) released their Sixth Assessment Report, which offered a troubling prognosis: the climate crisis has already arrived, and by the time my two-year-old daughter is in college, Earth will have already exceeded the 1.5°C threshold established by the Paris Agreement. But truthfully, many of us didn't need a 4,000-page report to tell us what we could already see with our own eyes, hear with our ears, and smell with our noses. Wildfire, storms, and floods have devastated places we love and call home — and according to the IPCC, extreme weather will only become more common.

But the Panel's report also offered reasons for hope. Nature is resilient. We still have a window to make an immense difference. And if we can cut global emissions, our climate will stabilize within a few decades. Those models, however, are built upon a key assumption: that the health of our carbon-storing biosphere does not deteriorate any further. Unfortunately, nature is under assault around the world. More than any other report I've read, the IPCC assessment made clear that must take immediate, targeted action to protect what remains, and restore what's been lost.

At Conservation International, we're focused on research that not only enhances our understanding of the world, but also offers actionable data for policymakers and field professionals. In this report, you'll find a comprehensive atlas of the world's irrecoverable carbon reserves: ecosystems that, if destroyed, could quietly bust our carbon budget. Though many of these areas are at risk of degradation by agriculture, mining, and other commercial activities, the good news is they're also highly concentrated — and that gives us a fighting chance of meeting our climate targets. With irrecoverable carbon, we have a rare opportunity to make a global difference with relatively small-scale efforts: preserving an additional 5.4 percent of the Earth's surface would safeguard 75 percent of the world's reserves. If we lose these areas, however, we have no hope of recovering.

No doubt, the challenge ahead of us is daunting: halving emissions each decade, preventing the loss of carbon stored in natural reservoirs, and protecting 30 percent of the Earth's land and ocean by 2030. But we aren't alone in this fight. Indigenous peoples, ambitious governments, enlightened corporations, and other nonprofits are rallying around the idea that protecting nature is crucial to life on Earth. As we look to meet ambitious goals with finite resources, the future of conservation will be defined by precision, and this research will fundamentally reshape how humanity prioritizes areas for protection and restoration.

These findings are a gift, and I hope you're as energized by them as I am.

With gratitude,

Dr. M. Sanjayan

Chief Executive Officer
Conservation International

“We have growing evidence that the final battleground — whether we fail or succeed in delivering the Paris Climate Agreement of holding the 1.5 degrees Celsius global warming line — is not only whether we are able to get off fossil fuels, it is also whether we are able to safeguard carbon stores in nature. Here, we provide the first global assessment of the ecosystems that hold our future in their hands.”

Johan Rockström

Chief Scientist at Conservation International & Director of the Potsdam Institute for Climate Impact Research

PHOTO: M. AXELSSON/AZOTE

“Here are the places in nature that we cannot afford to lose if we’re going to stabilize our climate. They are mangroves, wetlands, peat lands, and páramos, old-growth forests, and other special landscapes that hold enormous amounts of climate-altering greenhouse gases collected over hundreds of years or more. It would be devastating for the planet to lose the carbon stored in these ecosystems. This report is an important guide as we work to protect climate-critical places and make targeted investment in nature’s most important, irreplaceable ecosystems.”

Carlos Manuel Rodriguez

CEO and Chairperson of the
Global Environment Facility

PHOTO: GLOBAL ENVIRONMENT FACILITY

“At least a third of Earth’s irrecoverable carbon is managed by Indigenous peoples and local communities. This paper presents the way for new collaboration and approaches as equal partners to better protect these vital landscapes to continue providing their critical carbon storage and sequestration functions well into the next century and beyond.”

Hindou Oumarou Ibrahim

President of the Association for Indigenous Women and Peoples of Chad and Conservation International Board Member

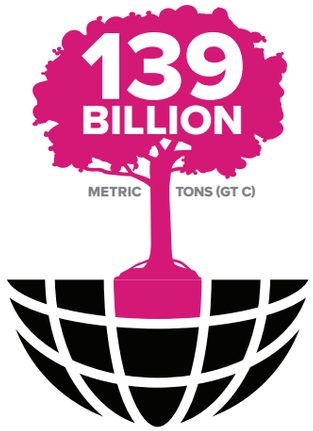
PHOTO: © CONSERVATION INTERNATIONAL

Key Messages

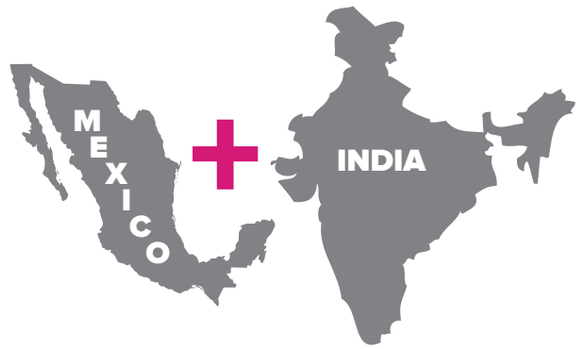
- "Irrecoverable carbon" refers to the vast stores of carbon in nature that are vulnerable to release from human activity and, if lost, could not be restored by 2050 — when the world must reach net-zero emissions to avoid the worst impacts of climate change.

- There are high concentrations of irrecoverable carbon in the Amazon (31.5 Gt), the Congo Basin (8.1 Gt), and New Guinea (7.3 Gt). Other important irrecoverable carbon reserves are located in the Pacific Northwest of North America, the Valdivian forests of Chile, the mangroves and swamp forests of Guyana, the peatlands of Northern Scotland, Niger Delta's mangroves, Cambodia's Tonle Sap Lake, the Scandinavian and Siberian boreal forests, and the eucalyptus forest of Southeast Australia, among others.

- If deforestation continues at current rates, at least 10% of global irrecoverable carbon stocks could be gone by 2050. However, the spatial distribution, types and pace of future risks cannot simply be extrapolated from historical trends. Deforestation frontiers can shift due to unpredictable market or political forces, and climate change can threaten previously "secure" areas. Proactive monitoring and management is needed to ensure that Earth's irrecoverable carbon is safeguarded over the coming decades.



We mapped irrecoverable carbon globally and found that Earth's ecosystems contain
139 billion metric tons (Gt C), equivalent to 15 years' worth of fossil fuel emissions.



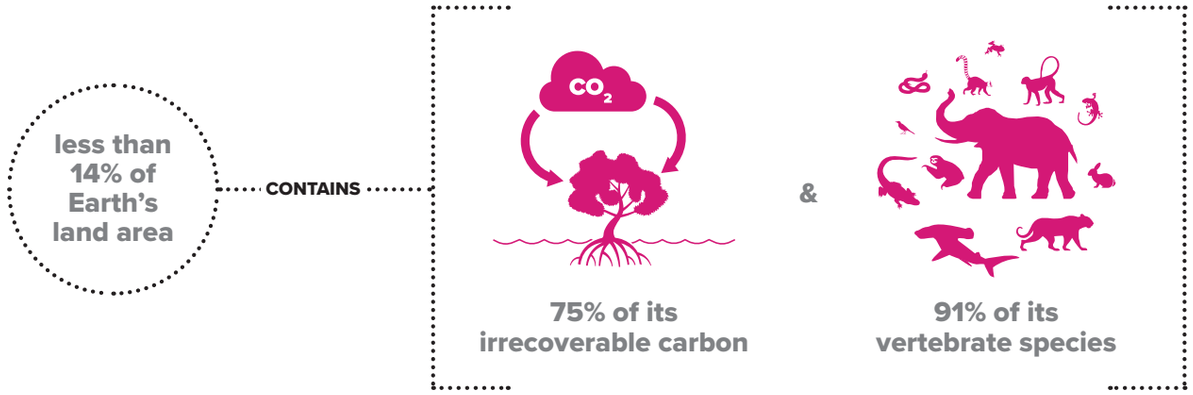
Globally,
half of the world's irrecoverable carbon is found on just 3.3% of its land area
(4.9 million km2), roughly equivalent to the combined land mass of India and Mexico.

More than one-third of irrecoverable carbon (47 Gt) is found within Indigenous and local communities' lands and 23% (32 Gt) is within protected areas.
More than half of irrecoverable carbon (52% or 72 Gt) lies outside of protected areas or Indigenous and local communities' management and stewardship.

- While protected area designations do not guarantee conservation outcomes, well-managed, legally protected areas reduce tropical deforestation and its associated carbon emissions. Similarly, lands managed by Indigenous peoples and local communities have significantly lower deforestation rates and can secure carbon stocks over time.

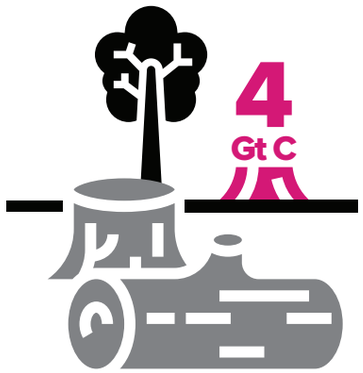
- Globally, half of the world's irrecoverable carbon is found on just 3.3% of its land area (4.9 million km^2), roughly equivalent to the combined land mass of India and Mexico. This means that mobilizing resources to protect a relatively small amount of land — which holds a disproportionately large amount of irrecoverable carbon — can have significant returns for the climate, biodiversity and human well-being. Rapid gains could be achieved by first focusing on the areas with the highest concentrations of irrecoverable carbon per hectare: peatlands, mangroves, tropical wetlands and tropical forests.

- As countries come together to negotiate a new Global Biodiversity Framework, many governments have called for 30% of land to be protected by 2030. Focusing at least a portion of this global effort to expanding land conservation in areas that are essential for climate stability is a win-win strategy.

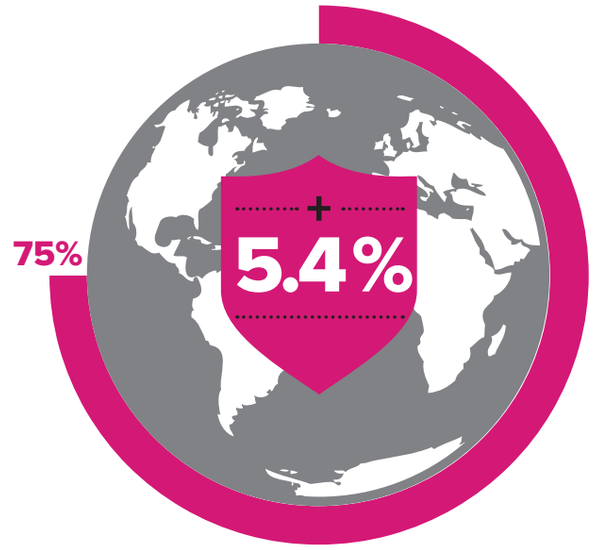


Like irrecoverable carbon, much of Earth's biodiversity is highly concentrated. Overlaying irrecoverable carbon with biodiversity data reveals 'doubly irreplaceable' areas, mainly in the tropics.

Less than 14% of Earth's land area contains 75% of its irrecoverable carbon and provides habitats for 91% of its vertebrate species.



Over the past decade,
at least 4 Gt of irrecoverable carbon have been lost due to land-use change.
This is equivalent to roughly 5% of fossil fuel emissions over that time period. These places are vulnerable and we are losing these invaluable areas at a rapid rate.



The world could proactively secure
75% of irrecoverable carbon by protecting an additional 5.4% of land (about 8 million km2)
beyond what is currently protected. This additional area is roughly equivalent to the size of Australia.

Earth's Irrecoverable Carbon

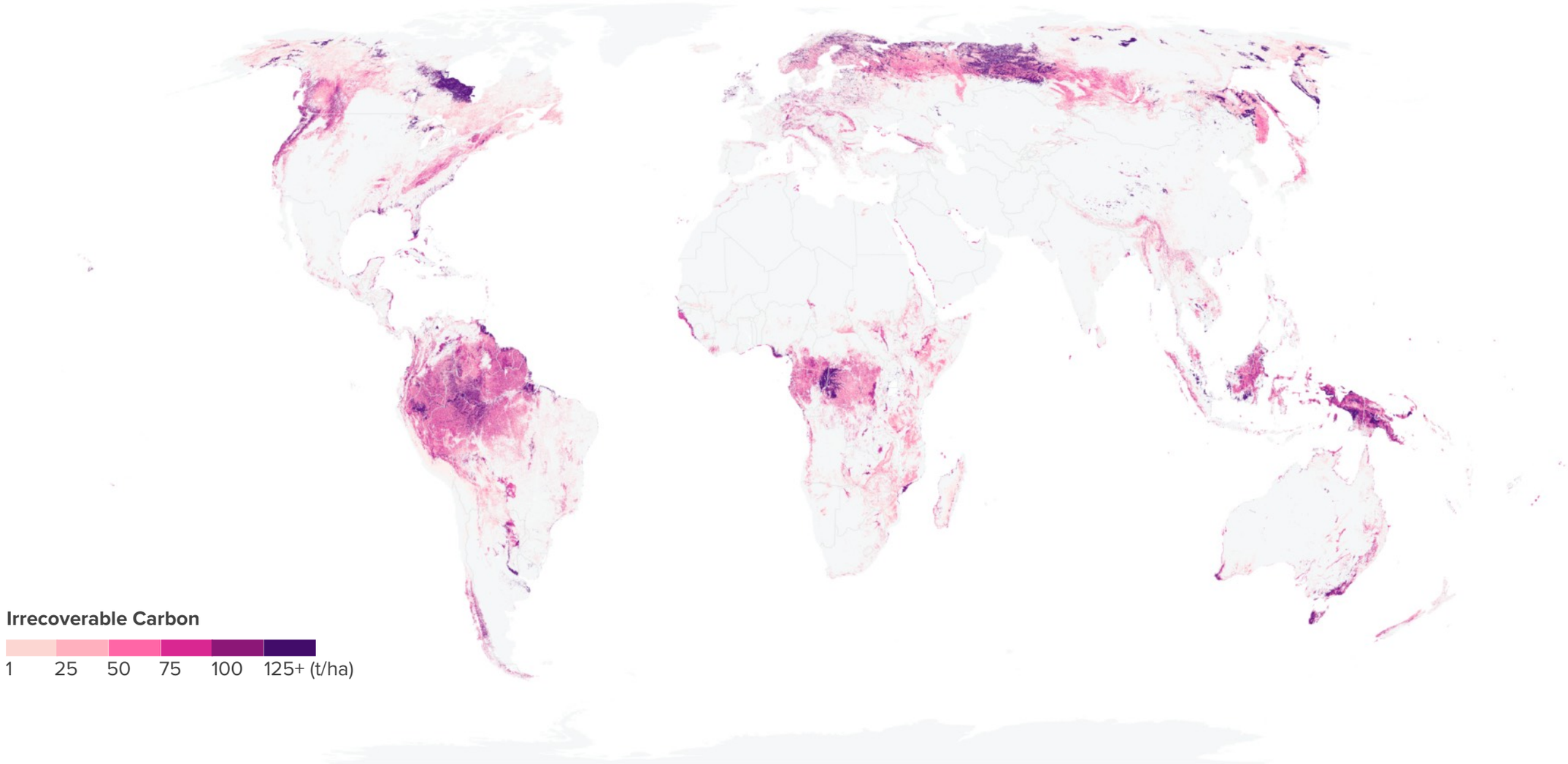


Figure 1: Irrecoverable Carbon in Earth's ecosystems.
This map shows dense stores of ecosystem carbon which, if lost, could not be recovered by mid-century. From Noon et al. 2021. *Mapping the irrecoverable carbon in Earth's ecosystems*. Nature Sustainability.

An interactive version of the map is available at https://irrecoverable.resilienceatlas.org/

To avert climate catastrophe, there are ecosystems that we cannot afford to destroy, because they store vast amounts of carbon. Nature has absorbed more than half of anthropogenic emissions to date, preventing at least 0.4° C of warming. To stay within the 1.5° C limit, there are some natural places that we simply cannot afford to lose.

Our team of scientists examined all ecosystems on Earth — from forests to grasslands to mangroves to tidal marshes — to identify this "irrecoverable carbon." If lost, these carbon stores could not be restored by 2050, the year by which we need to reach net-zero emissions to avoid the worst impacts of climate change. But protecting these ecosystems is largely within our control.

139 billion metric tons. That's the amount of irrecoverable carbon we estimate is stored in Earth's ecosystems. It's equivalent to about 15 years of fossil fuel emissions. To get this figure, we used the latest remote sensing technology and combined data from various sources—including global maps of carbon stored in vegetation and soil, as well as measurements of carbon sequestration rates from more than 13,000 forest plots—into a global scale and high-resolution data set.

While not all of these places are immediately threatened, many are being destroyed or may become threatened in the years ahead. The fact that they're "irrecoverable" means that we must 1) identify where they are and 2) proactively protect them before it's too late.

Science Summary

The concept of irrecoverable carbon is intended to differentiate among the billions of metric tons of carbon stored in the biosphere[1] based on three criteria relevant for conservation efforts. We assess ecosystem carbon stocks according to: (a) how they can be influenced by direct and local human action ("manageability"), (b) the magnitude of carbon lost upon disturbance ("vulnerability"), and (c) the recoverability of carbon stocks following loss ("recoverability"). Applying the three criteria across all terrestrial, coastal, and freshwater ecosystems reveals that some places contain irrecoverable carbon, or manageable carbon stocks that, if lost, represent a permanent debit from the remaining carbon budget,[2] or the amount of carbon humans can emit while still keeping global warming within safe levels (1.5 to 2 ºC above pre-Industrial levels).[3] Effective strategies to reduce the risk of catastrophic climate change will need to locate large irrecoverable carbon reserves that are at risk due to anthropogenic action and prioritize their conservation and sustainable management, alongside efforts to phase out fossil fuel emissions and restore degraded ecosystems.

We look at three dimensions of ecosystem carbon stocks to narrow down the most important lands to conserve for the climate.

Manageability at the local scale

Can people directly affect the ecosystem's carbon stock?

Magnitude of vulnerable carbon

How much of the ecosystem's carbon would be released to the atmosphere if the ecosystem were converted to another land-use?

Recoverability of ecosystem carbon, if lost:

If lost, how much of the ecosystem's carbon could we get back?*

*30 years considered was considered the key timeframe to consider given the need to reach net-zero emissions by mid-century

Irrecoverable carbon = Vulnerable carbon – Recoverable carbon*

**defined as sequestration in 30 years*

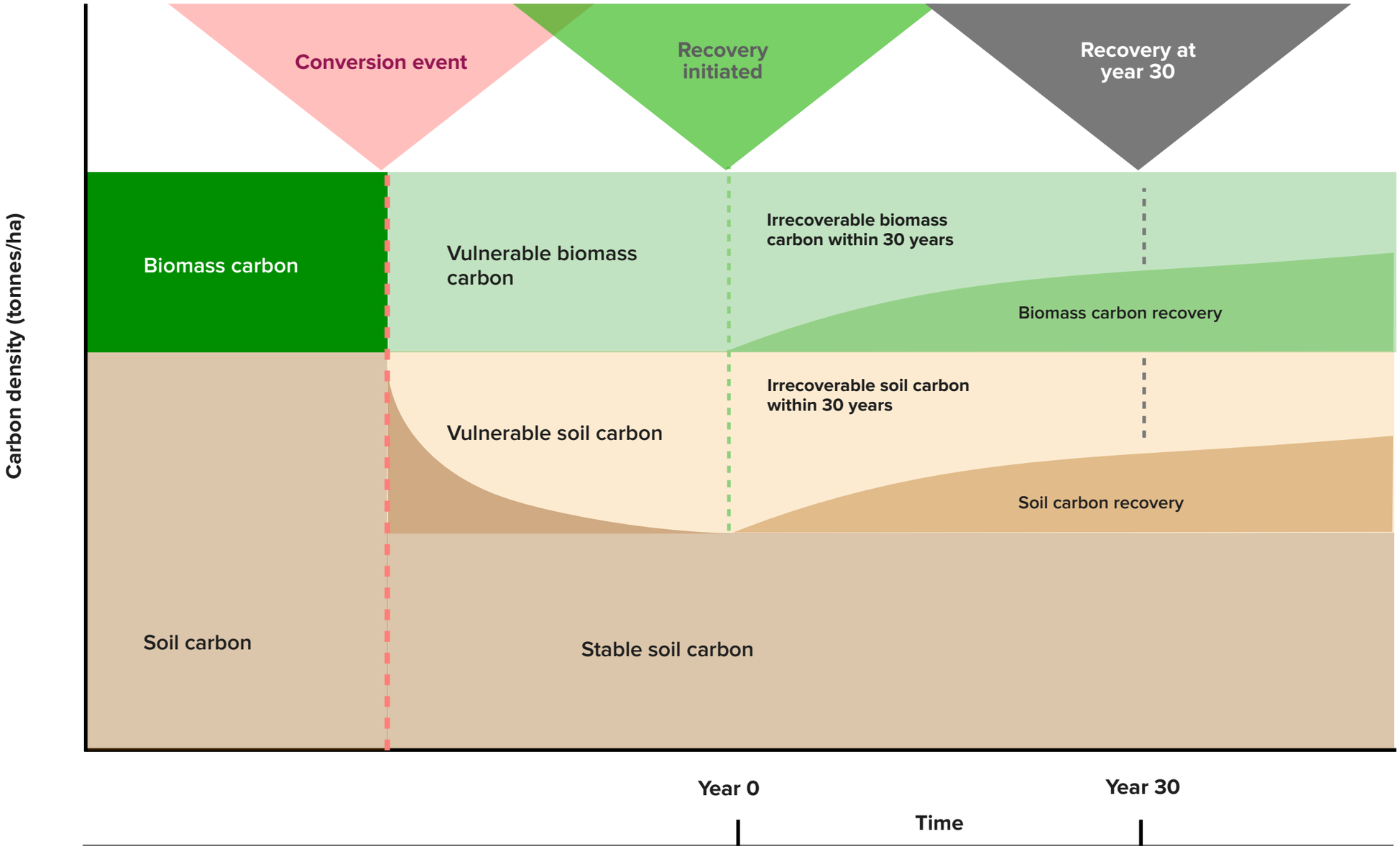
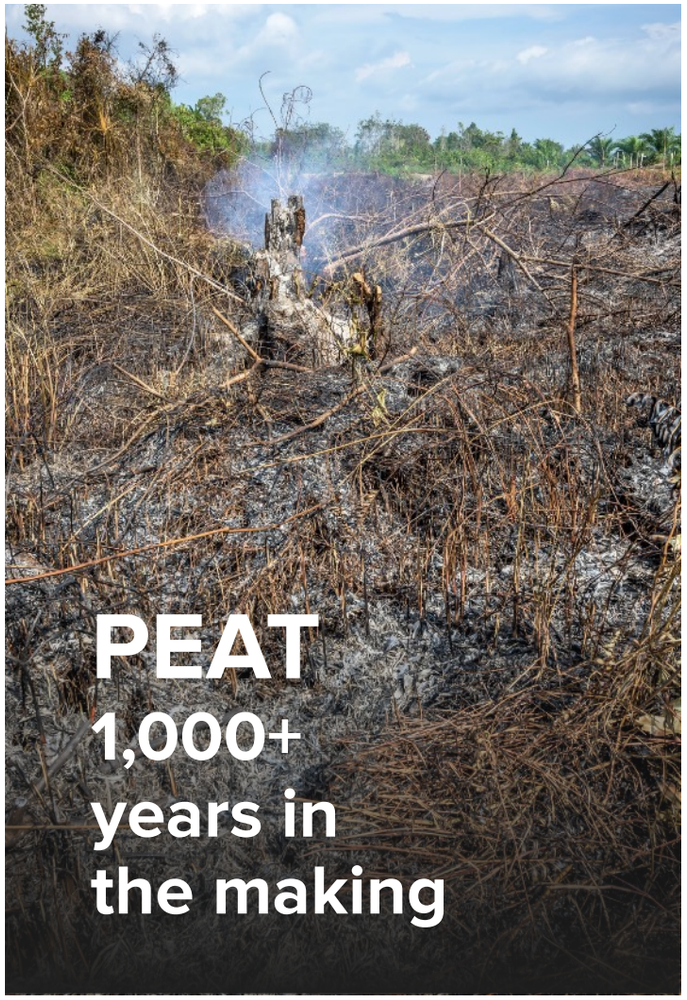


Figure 2: Illustration of vulnerable and irrecoverable carbon in a hypothetical terrestrial ecosystem
This illustration shows the steps we followed for each pixel of our map. Figure adapted from Goldstein et al. 2020. *Protecting the irrecoverable carbon in Earth's ecosystems*. Nature Climate Change.



Though the time it takes to sequester and store carbon in ecosystems is shorter than the time it takes to fossilize carbon as coal or oil, some ecosystems such as peatlands, mangroves and old-growth forests contain carbon that has been sequestered over decades or even centuries. Whether 300 million years in the making or 40, the atmosphere doesn't care. Any 'lost' carbon, whether burned as fossil fuels or emitted due to land conversion, that could not be re-sequestered within one human generation represents a permanent risk to humanity. Just as many fossil fuels will need to remain in the ground to avert climate catastrophe, certain ecosystems must be top priorities to protect this generation, since any loss will affect the climate of future ones.

PHOTO: © VISIONSOFAMERICA/JOE SOHM **PHOTO:** © CONSERVATION INTERNATIONAL/PHOTO BY TORY READ **PHOTO:** © CONSERVATION INTERNATIONAL/PHOTO BY RUSSELL A. MITTERMEIER

WHAT ARE IRRECOVERABLE CARBON RESERVES?

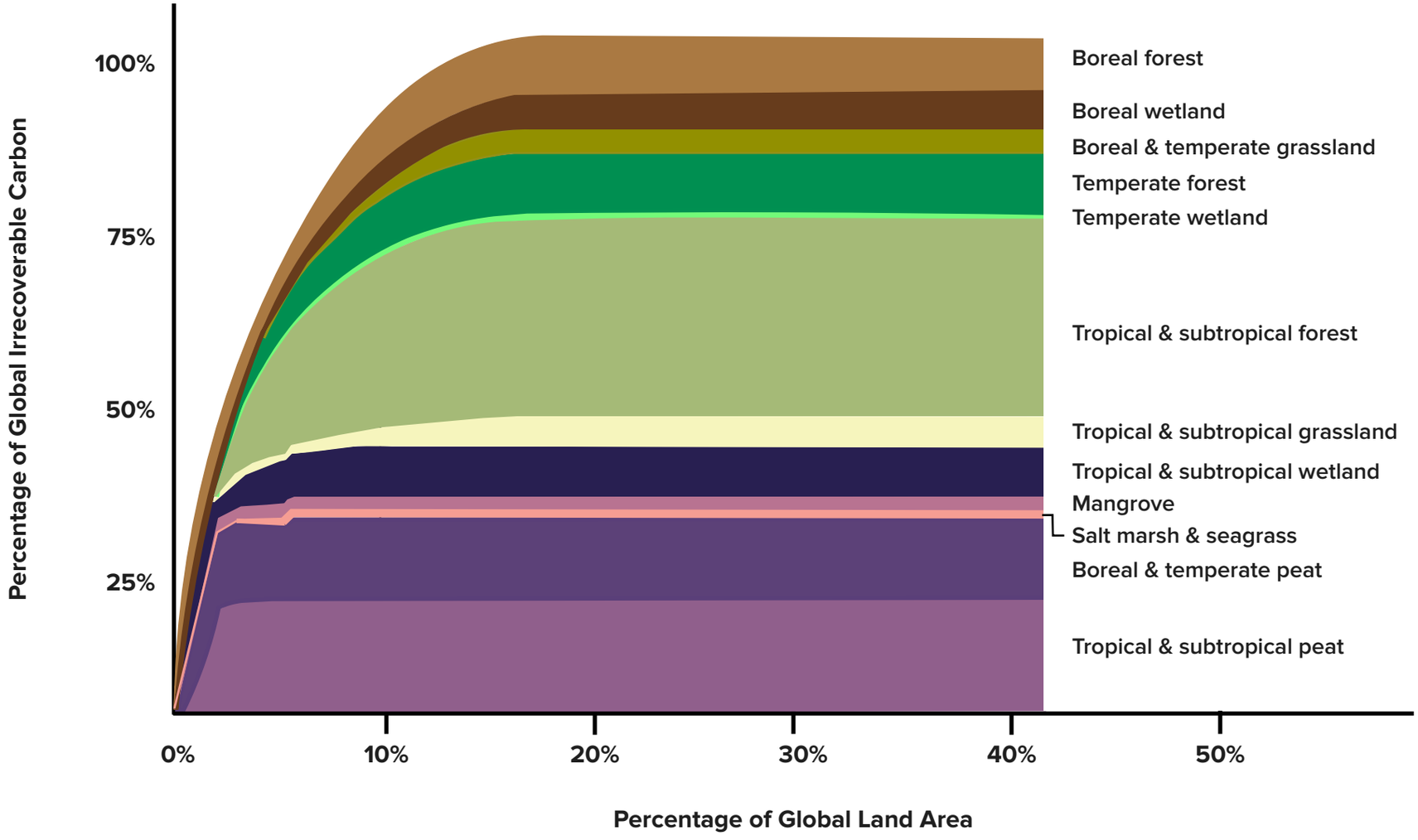
Photo: © Pete Oxford/iLCP

What are Irrecoverable Carbon Reserves?

We seek to design and establish the next generation of protected areas as “Irrecoverable Carbon Reserves.” While these areas may be called different things in different languages or contexts, and will be governed in diverse ways, the idea is the same: area-based conservation to secure the places with the most irrecoverable carbon.

Why do we need them?

Though these areas are critical to the long-term security of Earth’s climate, there has been limited concerted global effort to protect them. This is a missed opportunity. Globally, half of the world’s irrecoverable carbon is found on just 3.3% of its land area (4.9 million km^2), roughly equivalent to the combined land areas of India and Mexico. This means that efforts to secure irrecoverable carbon from current and future risks could make rapid gains by first focusing on the areas with the highest concentrations of irrecoverable carbon per hectare: peatlands, mangroves, tropical wetlands and tropical forests. The world could proactively secure 75% of our irrecoverable carbon by conserving just 5.4% of additional land (about 800 M hectares) beyond the land currently in protected areas. This additional area is about equivalent to the size of Australia.



50%

of the irrecoverable carbon is in 3.3% of the earth’s land area

75%

is in 7.5% of land area

Figure 3: The majority of Earth’s irrecoverable carbon is concentrated in a relatively small land area
Figure adapted from Noon et al. 2021. *Mapping the irrecoverable carbon in Earth’s ecosystems*. Nature Sustainability.

Why now?

Expanding the protection of irrecoverable carbon lands globally is both a scientific imperative and a timely political opportunity. As countries are coming together in 2021 to negotiate a new Global Biodiversity Framework, many governments have called for 30% of land to be protected and conserved by 2030 (roughly double the amount in currently recognized protected areas). However, few countries are connecting their efforts on area-based conservation to their efforts on climate change. Focusing at least a portion of the global effort to expand land conservation in places essential for climate stability is a win-win strategy.

30 x 30

Four foundational principles of Irrecoverable Carbon Reserves

Irrecoverable Carbon Reserves are areas that are newly conserved or managed according to four foundational principles:

Inclusive

With more than one-third of Irrecoverable Carbon and 80% of the world's biodiversity under Indigenous and local community* guardianship, conservation areas must align with Indigenous and local community visions and self-determination, especially as they are often among the most effective stewards of nature. In the past, Indigenous peoples and local communities have often been left out of key decisions on how their lands should be managed. We will partner with Indigenous peoples and local communities in expanding conservation of irrecoverable carbon and supporting their efforts to effectively manage their lands.

Climate Resilient

Working with a coalition of like-minded organizations, we will co-design Irrecoverable Carbon Reserves, the next generation of conservation areas, and future-proof them for both climate and biodiversity shifts using our new spatial science on irrecoverable carbon and on species' likely movements under climate change. This will ensure that the lands we protect are in the right place to secure the most irrecoverable carbon and help the most species adapt. Rigorous science and proactive management will be essential in the coming decades as risks such as fire, temperature changes, and species migration threaten areas previously considered "secure."

Sustainably financed

Real, lasting protection comes with sustainably financed conservation areas. Despite providing 5:1 benefits per dollar spent,[4] current protected areas have only a third of the funding they need for effective management, leading to loss of carbon and biodiversity; we can change this paradigm by ensuring smart, sustainable financing of Irrecoverable Carbon Reserves.

Tech enabled

Technology can help us establish area-based conservation in the right places for carbon and biodiversity protection under climate change, monitor and rapidly respond to threats, and inform management decisions. However, most protected areas are stuck in the 2010s when it comes to tech-enabled monitoring and management. Irrecoverable Carbon Reserves will bridge this gap through rapid assessments, company partnerships and on-site trainings, seeking out the latest technological advancements in areas such as remote monitoring, advanced sensors, artificial intelligence and ubiquitous Internet access.

*Local communities are not formally defined under international law and include communities that do not self-identify as Indigenous but who share similar characteristics of social, cultural, and economic conditions that distinguish them from other sections of the national community. Local communities often have long-standing, culturally constitutive relations to lands and resources. (Definition adapted from Rights & Resources Institute.)

Examples of the principles

Inclusive

In northwestern Bolivia, the Municipal Government of Ixiamas spent two years engaging more than 800 stakeholders from three Indigenous groups and communities on the future of their region. The result of this process was the creation in 2019 of a new 1.5-million-hectare municipal protected area called Bajo Madidi. It is the largest subnational protected area in the country. In 2021, the creation of the Guanay protected area added an additional 110,000 hectares to this accomplishment. This corner of the Amazon is a mix of intact tropical forest, savanna, and wetlands that hold 187 Mt of irrecoverable carbon and 20 endangered or threatened species, including black-faced spider monkeys, giant otters and giant anteaters. Beyond protecting a huge amount of land, Bajo Madidi also connects 2.9 million hectares of titled Indigenous lands with 6 million hectares of protected areas, thus building a mosaic of more than 10 million hectares of lands with conservation and management objectives.

Stakeholder meetings led to the creation of Bajo Madidi Municipal Conservation and Management Area in Bolivia.
Photo: Eduardo Forno

Grinnell Glacier in Glacier National Park, Montana in 2013. The park's glaciers are projected to be gone by 2030, altering the hydrology of the park and requiring new management strategies.
Photo: Allie Goldstein

Climate Resilient

The United States' National Park Service recently issued new guidance for the management of national parks in the face of climate change. This is a major change for an organization that previously took a "hands-off" approach to land management, with a goal of letting nature thrive within protected parks without human interference. Now, scientists are realizing that nature won't be able to thrive without our help. In places such as Glacier National Park and Joshua Tree National Park, climate change impacts (rising temperatures and fire, respectively) are threatening the park's very namesakes. A new approach called "Resist, Accept, Direct" now guides natural resource managers to proactively manage ecosystems for future changes — a major paradigm shift.[5]

For example, in Acadia National Park in Maine, some native tree species such as red spruce are struggling to survive as the climate warms and invasive species gain foothold. Nine of the 10 most common tree species are projected to lose habitat over the next 80 years. Park managers are now considering hand-planting tree species adapted to more southern climates within Acadia. In Glacier National Park, park managers are making proactive management decisions to "keep options open" for vulnerable species. For example, after 10 out of 17 lakes on the west side of the park were compromised by invasive fish species, they built a creek barrier to protect the strongest remaining bull trout population, on Quartz Lake.[6]

Sustainably financed

The Kayapó maintain legal control over an area of 10.6 million hectares (around 26 million acres) of primary tropical forest and savanna in the southeastern Amazon region of Brazil. They number approximately 7,000 people scattered across 46 villages in five territories. The land lies in the crosshairs of Brazil's "arc of deforestation," with a frontier characterized by violent land conflicts. In 2011, the Kayapó Fund was created as the first trust fund to focus on long-term financing for conservation of the Amazon by Indigenous people. With fundraising and technical assistance from Conservation International's Global Conservation Fund and financial backing from the Amazon Fund, managed by the Brazilian Development Bank, the Kayapó Fund started operations with an initial donation of US$ 8 million. The grants target monitoring and protection of Kayapó land, the development of sustainable economic activities and the reinforcement and capacity-building of Kayapó organizations. For example, a territorial monitoring and surveillance program has been developed through supply of boats and radios, equipment maintenance, border patrol training and use of aerial survey data. These expeditions have successfully removed gold miners and scouted some vulnerable sectors of illegal fishing, deforestation and illegal logging. Some of the funds are also used to establish sustainable businesses that rely on non-timber forest products such as nuts, copaiba oils, fruit and honey. The conservation leadership of the Kayapó people and the Kayapó Fund show how large areas of irrecoverable carbon can be sustainably financed in a way that is aligned with the interests of Indigenous peoples and local communities. Similar models have been replicated in many regions of the globe, and new financial mechanisms and climate financing frameworks are being developed to support the ongoing management and protection of irrecoverable carbon.

Kayapó children playing in a river.
Photo: Cristina Mittermeier

Eddy Mendoza and Andres Cano test Firecast OnSight, a mobile application for real-time fire alerts, in Madagascar.
Photo: Karyn Tabor

Tech enabled

Firecast is a forest and fire monitoring and alert system for the tropics that uses satellite observations to track fires and forest disturbances, delivering near-real-time updates to conservation managers through email alerts or mobile messaging. In Indonesia, park officials use the active fire alerts for targeted patrolling of nearly 8,000 square kilometers in Gunung Leuser National Park. In Baly Bay, Madagascar, Durrell Wildlife Conservation Trust engaged local villages in a friendly competition around fire detection using Firecast: They challenged communities to use the GPS coordinates of detected fires to respond rapidly to burns within a protected area, with the winning village receiving money for a development project. Firecast and other technologies that combine near-real-time satellite-based monitoring with mechanisms to delivery essential information directly to the people who need it, when they need it can be transformative in monitoring for threats to high-carbon areas and making the management of conservation areas more efficient and affordable.

THE PLACES WE CANNOT AFFORD TO LOSE

Photo: © Conservation International/photo by John Martin

The Places We Cannot Afford to Lose

We now know where irrecoverable carbon can be found — and can protect it. Below are some of the geographic priorities for irrecoverable carbon.

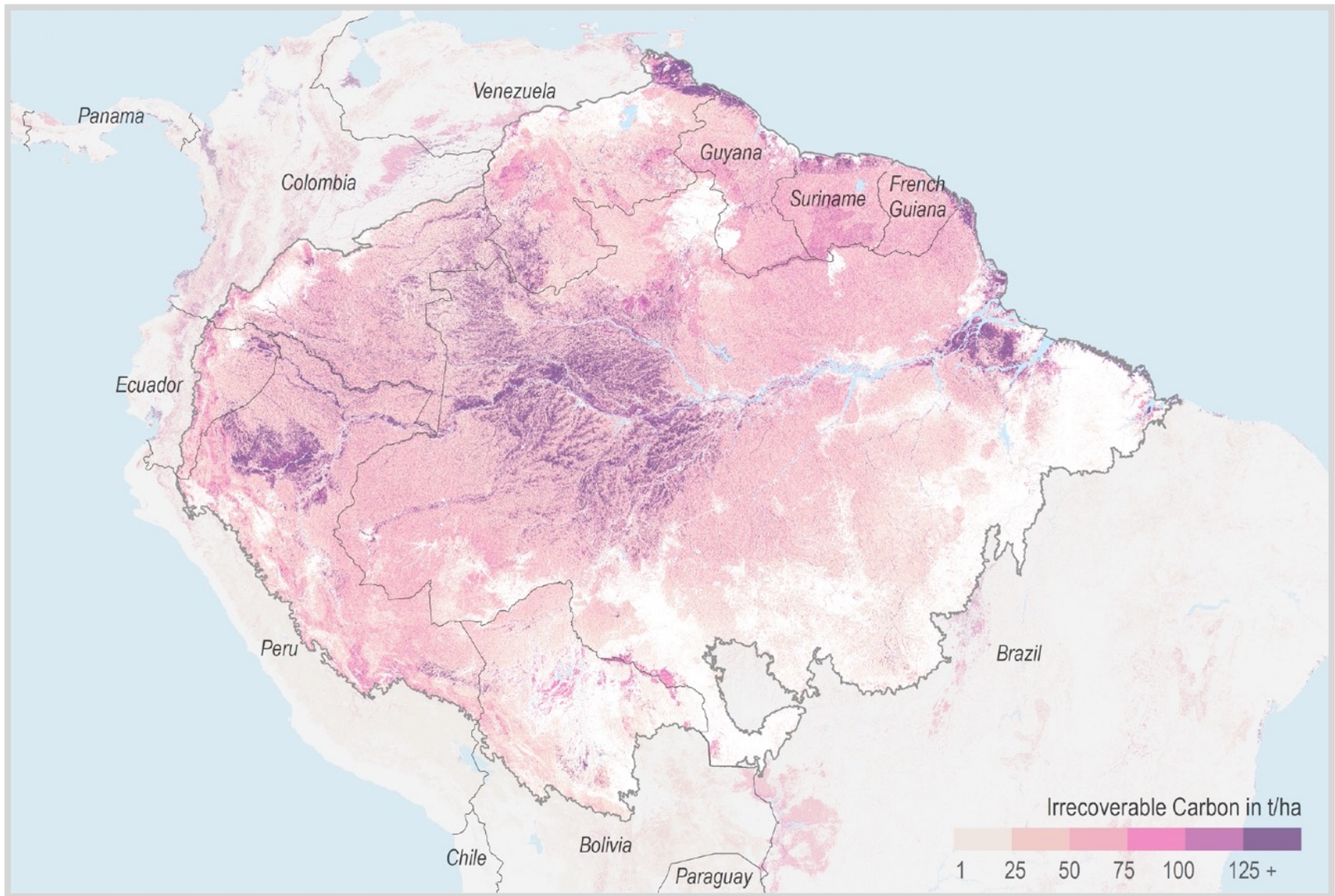


Figure 4: Irrecoverable carbon in Amazonia

Amazonia

31.5 billion metric tons of irrecoverable carbon (23% of global total)

The Amazon rainforest is home to 30 million people—as many people as Tokyo, Mexico City and New York City combined. It also contains 10 percent of all known species and contains 20 percent of the world's fresh water. Though this entire basin is essential for irrecoverable carbon, a few areas stand out: The Igapó — seasonally flooded forests along the banks of the Amazon River — contain among the largest concentrations of carbon in Amazonia. Farther west, the aguajal forests of northern Peru are dominated by the aguaje palm, which Indigenous peoples call the “tree of life” because it provides fruit and timber while also purifying water. The mangroves and swamp forests stretching from the Atlantic coasts of southeastern Venezuela, Guyana, Suriname and French Guiana are among the most carbon-rich ecosystems in the world.

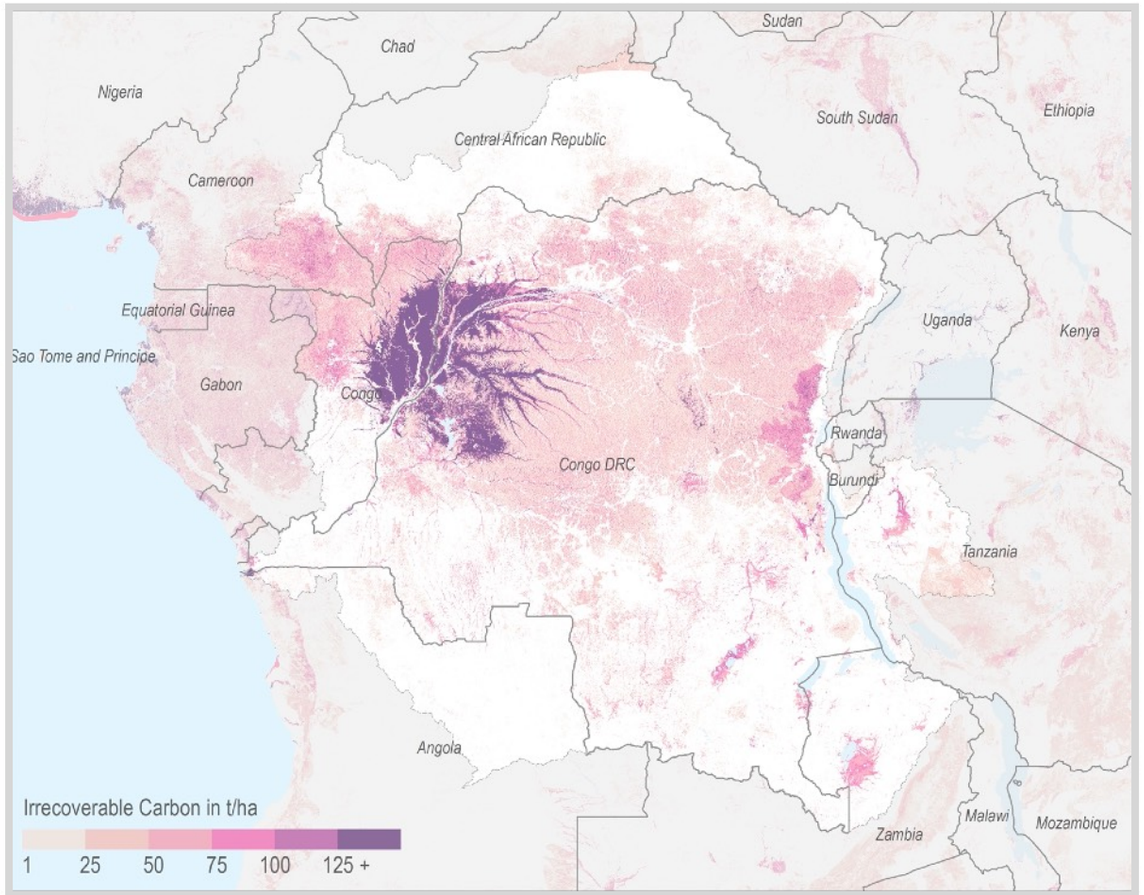


Figure 5: Irrecoverable carbon in the Congo Basin

Congo Basin

8.1 billion metric tons of irrecoverable carbon (6% of global total)

In peatland ecosystems, most of the carbon is below your feet, where waterlogged conditions slow the decomposition of plants, creating rich soil carbon that can build up over hundreds or even thousands of years. In 2017, a research team exploring the Congo basin of Central Africa found that the peat-covered area was 16 times larger than had been previously known, containing about 30 percent of the world's tropical peatland carbon. The Congo Basin is also designated as a High Biodiversity Wilderness Area, home to 9,750 plant, 698 bird, 275 mammal, and 142 reptile species.

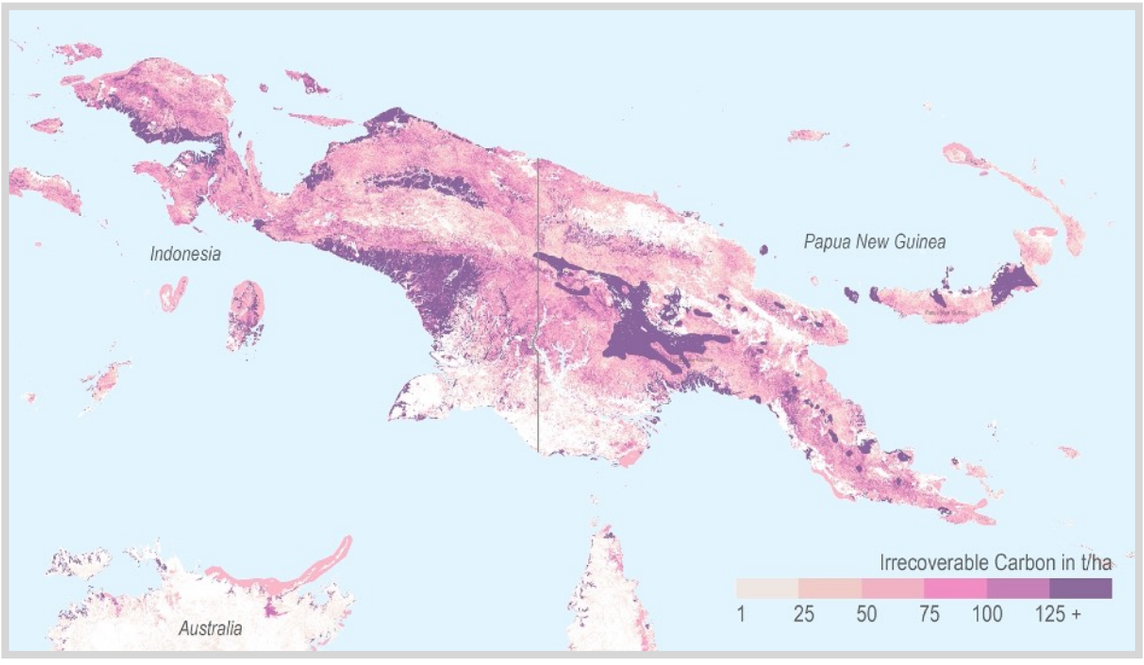


Figure 6: Irrecoverable carbon in New Guinea

New Guinea

7.3 billion metric tons of irrecoverable carbon (5% of global total)

New Guinea is the world's second-largest island, consisting of Papua New Guinea in the east and the Indonesian provinces of Papua and West Papua in the west. The island is basically coast-to-coast irrecoverable carbon, including some of the most expansive carbon-rich mangroves, largest intact tropical peatlands and rich rainforests. New Guinea is designated as a High Biodiversity Wilderness Area, home to 17,000 plant species, 60% of which are endemic, plus 650 birds, half of which are endemic. As unsustainable palm oil plantations have razed peatlands and forests on other Indonesian islands, West Papua is embarking on a different development path. In 2019, it declared itself the world's first "Sustainable Development Province," putting sustainability at the center of its economic activity.

Other important irrecoverable carbon places

North America

- **Hudson Bay, Canada**: On the southwest shores of Canada's Hudson Bay, northern peatlands, known as “muskeg,” store over 4 billion metric tons of irrecoverable carbon and are home to wildlife including caribou and wolverines. Mining development in the area threatens this unique ecosystem, and some First Nations and environmental groups have raised the alarm.
- **Pacific Northwest of North America**: This unique ecosystem on the northwest coast of North America combines all the trappings of a rainforest — mist, daily rainfall, hanging vegetation — with temperate species. The old-growth forest that once stretched from Oregon to southeast Alaska is now mostly confined to protected areas such as Olympic National Park.
- **Swamp forests of southern Florida**: This unique wetland ecosystem includes mangroves, cypress swamps and pinelands, storing massive concentrations of carbon both above ground in the trees but also below ground in waterlogged soils. Everglades National Park protects a portion of it.

South America

- **Valdivian Forests:** Nestled between the Pacific Ocean and the Andes Mountains in Chile, the Valdivian Forest is a biodiversity hotspot, home to unique species such as Darwin’s frog, mountain catfish, chinchilla and many lizards. It also contains nearly 1 billion metric tons of irrecoverable carbon.
- **Guianan Mangroves and Swamp Forests:** Stretching across the Atlantic coasts of Venezuela, Guyana, Suriname and French Guiana, these mangroves and swamp forests are among the most carbon-rich in the world.
- **Igapó forests, Western Brazil:** The Igapó forests are seasonally flooded forests along the banks of the Amazon River that contain the largest concentrations of carbon in Amazonia. They attract many aquatic species and are primarily threatened by dam development that is changing the very hydrology that enables these forests to accumulate their carbon stores.
- **Aguajales, Northern Peru:** The carbon-rich Aguajales of the Loreto and Ucayali regions of northern Peru cover around 4 million hectares in the Peruvian Amazon and are dominated by a palm species called aguaje, which Indigenous peoples call the "tree of life" because it provides fruit and timber while also purifying water.

Europe

- **Peatlands of Northern Scotland:** Northern peatlands or bogs are a signature piece of the Scottish landscape and heritage, covering around 2 million hectares. "Blanket bogs" are found in only a few parts of the world where cool, wet, oceanic climates create conditions for bog mosses and other plants to break down very slowly, storing carbon over thousands of years. The bogs also support breeding grounds for birds.

Other important irrecoverable carbon places

Africa

- **Niger Delta Mangroves:** The largest continuous mangrove area in Africa is in the Niger Delta. These living carbon reserves are at odds with exploitation of Nigeria's "dead" carbon reserves—the 1.4 million barrels of oil that Nigeria exports per day. In addition to deforestation due to oil development itself (rigs, camps, roads, etc.) spills frequently course their way into the mangroves.
- **Okavango Basin, Botswana:** This massive inland wetland of northwest Botswana consists of marshlands and seasonally flooded plains, one of the few major interior delta ecosystems that does not flow into a sea. It is a bright spot of carbon storage in an otherwise dry, low-carbon country. The Okavango is also home to some of the world's most endangered large mammals such as cheetahs, white and black rhinos, and lions.
- **Bangweulu wetlands, Zambia**: Its name means "where the water meets the sky", Bangweulu is an Important Bird Area and Ramsar Wetland of International Importance, boasting over 400 species of birds, including the iconic Shoebill Stork. These freshwater wetlands offer essential fish stocks for the surrounding communities, who own and sustainably protect these natural resources through public-private and community partnerships.
- **Zambezi Delta, Mozambique**: The delta where the Zambezi River meets the Indian Ocean contains wildlife and natural assets that are experiencing pressures from mining, encroachment from human settlements, illegal timber trade and wildlife trafficking due to instability introduced from prolonged unrest in Mozambique since Independence. Underfunded law enforcement continues to complicate conservation in the Zambezi Delta protected area network, which stores vast carbon reserves.

Asia

- **Cambodia's Tonle Sap:** As a seasonally flooded lake, the Tonle Sap Lake swells to more than four times its size during the monsoon season, supporting a $2 billion fish industry and providing two-thirds of the protein consumed in the country. The flooded forest ecosystem surrounding the lake also stores an inordinate amount of carbon due to the water-logged environment, which slows decomposition rates.
- **Sundarbans Mangroves:** The mangrove area in the delta of the Ganges, Brahmaputra and Meghna Rivers in the Bay of Bengal (southern India and Bangladesh) is one of the largest remaining mangrove areas in the world. The ecosystem is vulnerable to climate change risks such as floods, cyclones and sea-level rise as well as human exploitation. People rely on intact mangroves as nurseries for fish and crab, but also cut them down for firewood.
- **Malaysian forests and peat swamps**: Both peninsular Malaysia and the Malaysian states of Sarawak and Sabah on the island of Borneo contain areas of primary forest and peat swamps with high concentrations of irrecoverable carbon.
- **Borneo**: The island of Borneo consists of the Malaysian states of Sabah and Sarawak, the Indonesia province of Kalimantan, and the tiny nation of Brunei. Borneo's lowland and montane rainforests, mangroves, and tropical peatlands make up one of the most highly concentrated areas of irrecoverable carbon in the world.
- **Scandinavian and Siberian taiga**: This huge swath of boreal forests and peatlands stretches across Russia, Finland, Sweden and Norway—the largest ecoregion in Europe. The area holds 16% of Earth's irrecoverable carbon, averaging more than 50 metric tons per hectare, and is also home to charismatic mammals such as lynx, brown bear, wolverine and elk.
- **East Russian taiga**: This area in the southeast corner of Russia (also known as the Okhotsk-Manchurian Taiga ecoregion) is dominated by mountains and holds nearly 2% of Earth's irrecoverable carbon as well as the last major Siberian tiger range.

Australia

- **Eucalyptus forest of Southeast Australia:** The most carbon-dense forest in the world in terms of aboveground biomass. The megafires that whipped through Australia in 2019-2020 destroyed parts of this subtropical ecosystem, which are particularly vulnerable because of their dry conditions and oil-rich foliage.

Photos: © WWF Mozambique/flickr, © Conservation International/photo by Koulang Chey, © Giles Watson/flickr

IRRECOVERABLE CARBON + IRREPLACEABLE BIODIVERSITY

Photo: © Jon McCormack

Irrecoverable Carbon and Irreplaceable Biodiversity

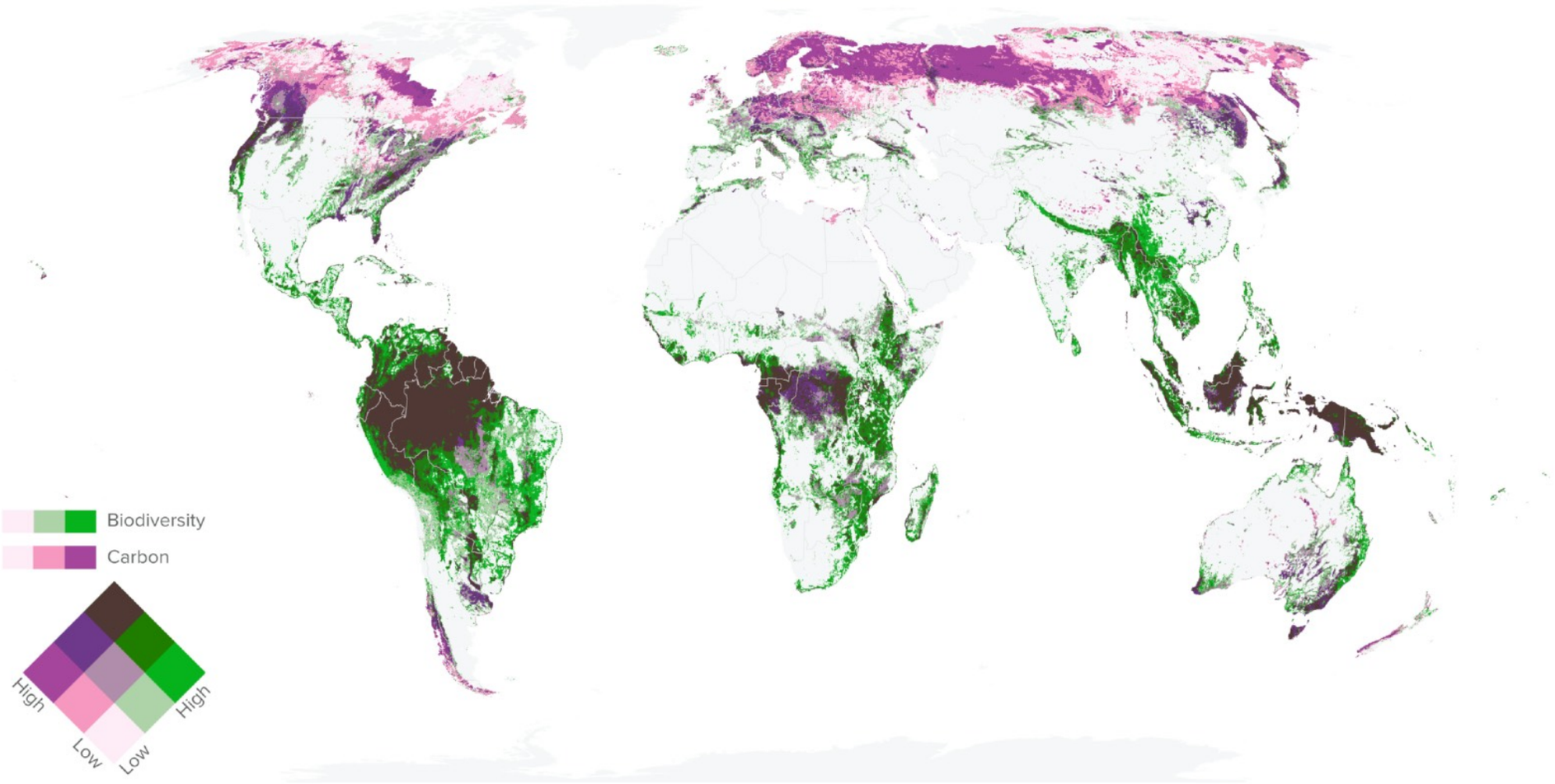


Figure 7: Irrecoverable carbon and irreplaceable biodiversity overlap strongly in the tropics

Irrecoverable carbon data is from Noon et al. 2021. Mapping the irrecoverable carbon in Earth's ecosystems. *Nature Sustainability*. Biodiversity data is adapted from expert range maps compiled by BirdLife International and IUCN Red List that have been filtered for intact habitat based on up-to-date satellite data. The summed range size rarity data used here shows the global importance for all terrestrial vertebrate species (birds, amphibians, reptiles, mammals) that are present in a given location, with the ability to subset for endangered and threatened species.

In biodiversity conservation, the concept of "irreplaceability" already drives priority setting. Once a species goes extinct, it's gone. Tools such as Biodiversity Hotspots and the International Union for the Conservation of Nature's Red List of Threatened Species show us the places we must protect to avoid extinctions. Like irrecoverable carbon, much of Earth's biodiversity is highly concentrated. The areas of high irrecoverable carbon and high biodiversity shown in Figure 7 cover less than 14% of Earth's land but include 75% of its irrecoverable carbon and habitat for 91% of its species.

Here, we combined the habitat ranges of tens of thousands of birds, mammals, amphibians and reptiles with our map of irrecoverable carbon to see if we could find places that are "doubly irreplaceable" for climate and biodiversity. The key areas of overlap lie in the tropics — the Amazon Basin, the Congo Basin and insular Southeast Asia — though there are also some doubly irreplaceable areas elsewhere, including the Pacific Northwest of North America and southeast Australia.

The coincidence of high carbon and high biodiversity is, in fact, not an accident in many cases. Seed-dispersing animals often play a key role in planting trees. And forests with more diverse species often store more carbon, in part because different species respond differently to disturbances such as fires or pests, making the forest as a whole more resilient.

CURRENT PROTECTION STATUS OF EARTH'S IRRECOVERABLE CARBON

The Kayapó maintain legal control over an area of 10.6 million hectares (around 26 million acres) of primary tropical forest and savanna in the southeastern Amazon region of Brazil. See p. 18."

Photo: © Cristina Mittermeier / iLPC

Current Conservation Status of Earth's Irrecoverable Carbon

Assessing how much irrecoverable carbon falls within state-designated protected areas or Indigenous peoples and local community (IPLC) lands provides an estimate of the magnitude of the irrecoverable carbon under some level of direct protection, stewardship or management (Fig. 8). When we overlaid our irrecoverable carbon map with the most recent global data on protected areas (from Protected Planet[7]) and Indigenous and community lands (from a "Territories of Life" report by the World Conservation Monitoring Center[8]), we found that a little less than half (48%) of Earth's irrecoverable carbon is within these areas.

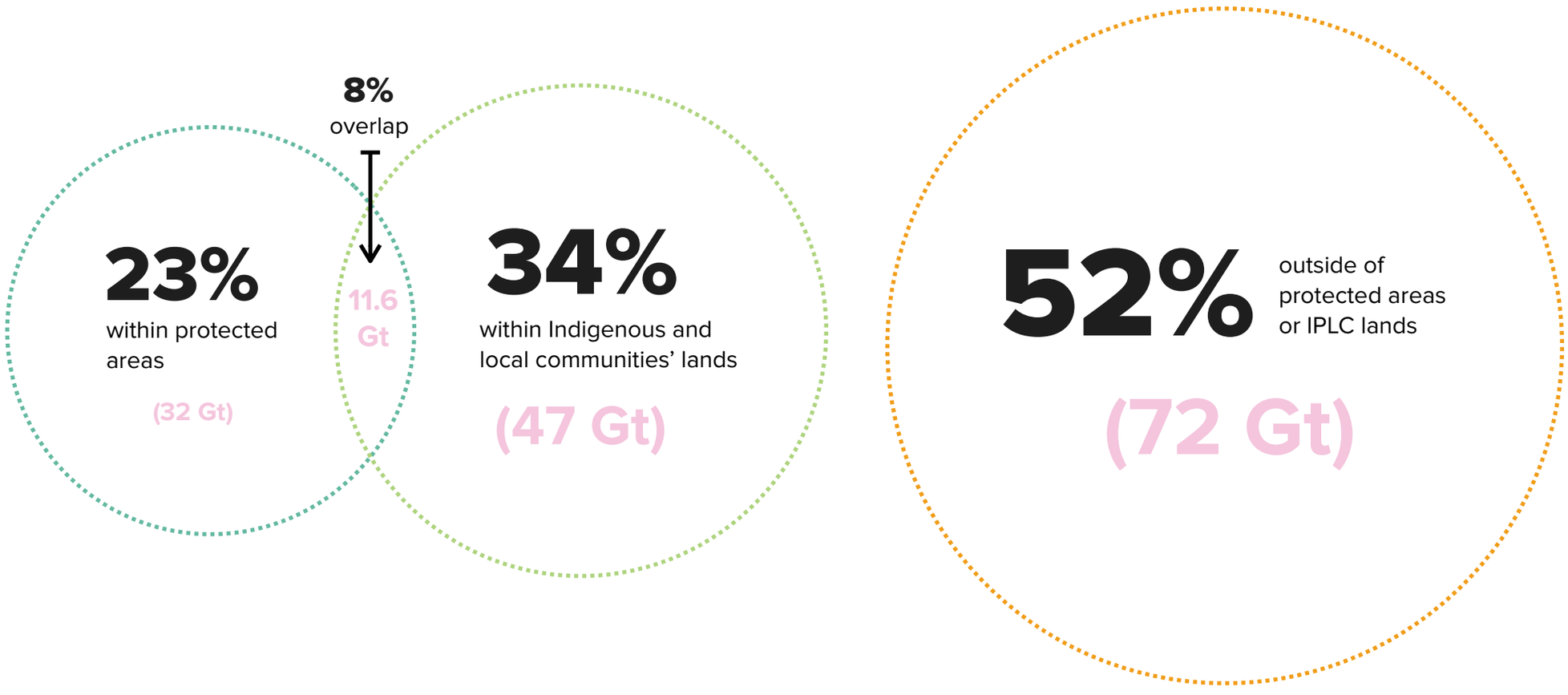


Figure 8: Portion of Irrecoverable Carbon in protected areas and IPLC lands
Note: Circles are for illustrative purposes and are not sized to scale.

Protected areas

While protected area designations do not guarantee conservation outcomes or long-term permanence[9], legally protected areas have been found to reduce tropical deforestation[10] and its associated carbon emissions.[11] More than a third (11.3 Gt) of irrecoverable carbon within protected areas is in Brazil, while Venezuela, Canada, Australia, Indonesia, the United States, Peru, the Republic of Congo and the Democratic Republic of Congo each protect between 1 and 2 Gt.

The proportion and patterns of irrecoverable carbon within protected areas differs by country, with implications for national strategies to secure irrecoverable carbon, especially as risks to irrecoverable carbon shift over time. For example, Guyana has historically low deforestation rates but only five protected areas covering less than 10% of its territory. The recent discovery of offshore oil in 2015 has ushered in a new era of development, especially along the country's northeastern border, where its densest irrecoverable carbon lies in coastal mangroves (Fig. 9). Meanwhile, nearly a quarter of Gabon's irrecoverable carbon is within protected areas. In Cambodia, the most concentrated area of irrecoverable carbon rings the forested lands around the seasonally flooded Tonle Sap Lake in the center of the country. Though much of this land is within protected areas, it faces pressures from rice paddy development as well as extreme heat and drought that have exacerbated forest fires. Overall, 42% of Cambodia's irrecoverable carbon is within protected areas, though a new regulation makes more than 127,000 hectares of previously protected land potentially up for sale or rent. (See PADDD, next page.)

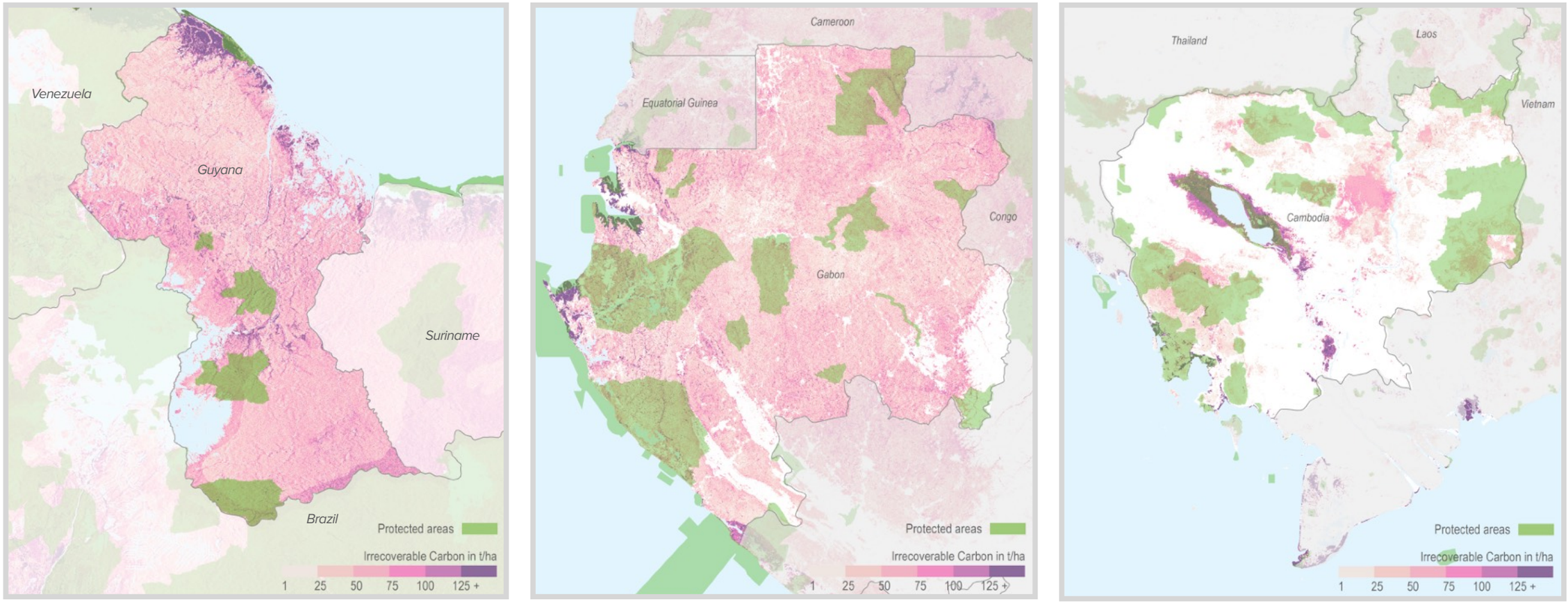


Figure 9: Irrecoverable carbon in protected areas in Guyana, Gabon, and Cambodia
Note: Guyana's map also includes data on Indigenous lands from Indigenous Affairs, 2010.

PADDD in irrecoverable carbon lands

Even as countries look to expand the global protected area network, many current areas are under threat. We think of protected areas as permanent fixtures of the landscape, but research has revealed that governments often relax restrictions, shrink boundaries or eliminate protections altogether. Protected area downgrading, downsizing and degazettement (PADDD) events are processes through which protected areas can lose some or all of their legal protections. PADDD has occurred in at least 75 countries, affecting an area about the size of Mexico; this area contains over 3 billion metric tons of irrecoverable carbon. Not all PADDD events put protected areas and irrecoverable carbon at risk, such as legal changes that transfer land rights to IPLCs or allow sustainable use of resources.[12] However, most PADDD events globally have authorized new or expanded industrial-scale development or extractive activities – like mining, industrial agriculture, and large-scale infrastructure – which threaten ecosystems and their irrecoverable carbon. Oil drilling and associated infrastructure has also been authorized in protected areas, which not only degrades ecosystems, but also directly contributes to CO_2 emissions.

Figure 10 shows two examples of PADDD. The boundaries of Yasuní National Park in Ecuador have changed several times. The park is larger today than its original size, but legal protections have been loosened to allow for oil drilling and associated infrastructure, like roads, pipelines and helipads.[13] Part of the park was upgraded to designate the Tagaeri-Taromenane Intangible Zone, prohibiting industrial extraction to on the lands of Indigenous peoples in voluntary isolation. However, recent satellite imagery shows the encroachment of an oil road near the Intangible Zone.

In Rondônia, Brazil and in some surrounding areas, several previously protected areas were downsized or completely degazetted. These PADDD events authorized hydropower dams or rural settlements. Research revealed that PADDD was more likely to occur in protected areas with higher deforestation rates.[14] Bargaining between development and conservation interests — loss of protections in one place, accompanied by gains in protections elsewhere — has also been detected in the Brazilian Amazon. These findings underscore the importance of continued enforcement and management to prevent deforestation — and loss of irrecoverable carbon — in the first place. Transparency and participatory decision-making, monitoring, sustainable financing and local support are also key to ensuring lasting protections.

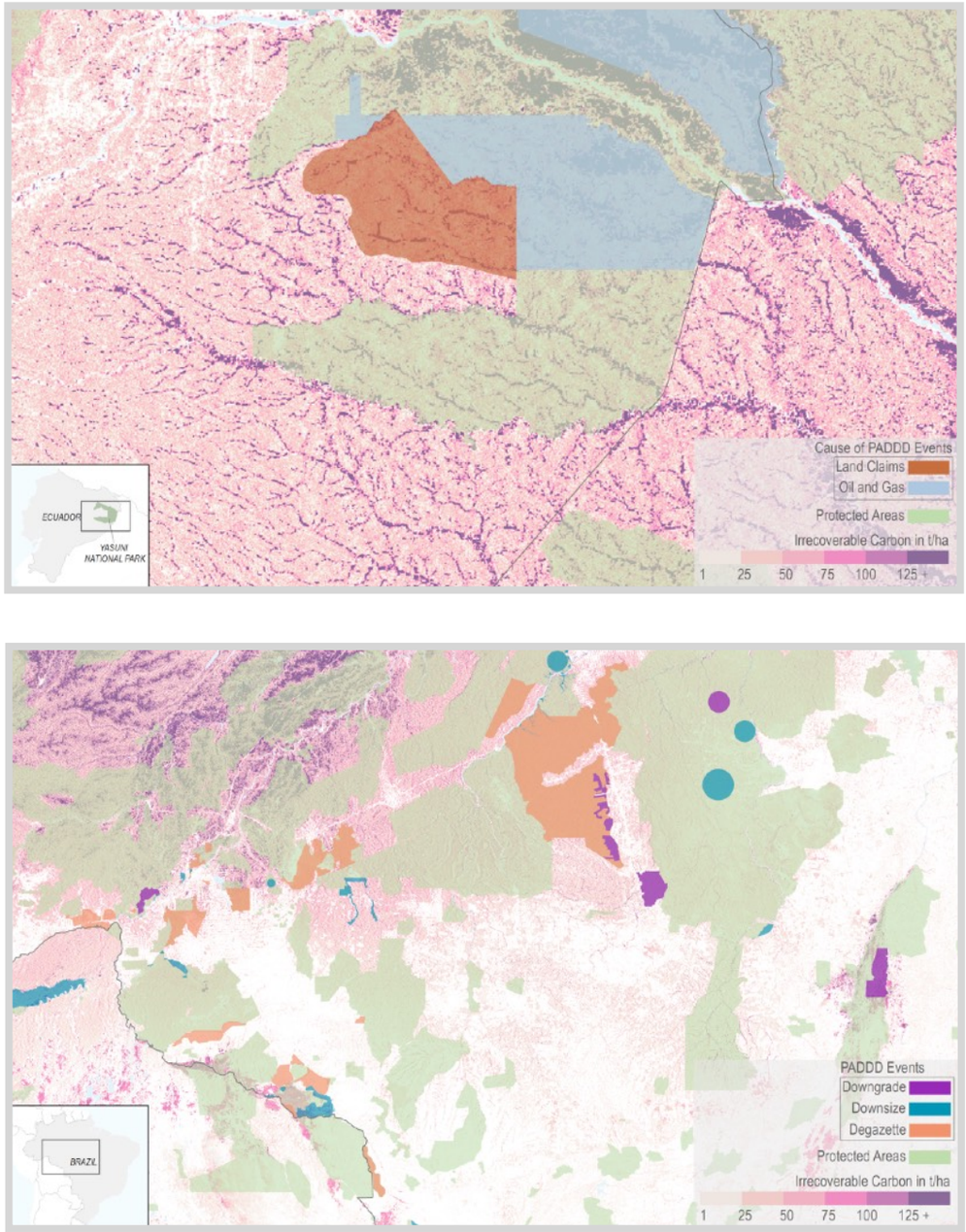


Figure 10: PADDD events in Ecuador (top) and Brazil (bottom) affect areas with irrecoverable carbon

Indigenous and community lands

Globally, 132 countries containing mapped IPLC lands cover nearly 32% of Earth's terrestrial surface,[15] and 114 of these countries contain irrecoverable carbon. Given that many IPLC lands have not been mapped, our finding that a third of Earth's irrecoverable carbon is within IPLC lands is likely an underestimate. IPLCs' role in sustainable management and conservation of irrecoverable carbon is therefore of particular importance.

Similar to protected areas, IPLC status does not always guarantee conservation outcomes; however, IPLCs often manage the land in a way consistent with maintaining irrecoverable carbon. In fact, a recent study of Indigenous lands in the Amazon and Panama found that these lands secured similar or even larger carbon stocks than comparable protected areas over the same timeframe.[16] IPLCs have an inextricable link to their lands so their traditional knowledge, ways of life and livelihood systems are essential for the continued stewardship of these lands. This means securing IPLCs' engagement and collaboration is key to conserving carbon and irrecoverable carbon. However, mining, industrial agriculture, and other activities continue to degrade IPLCs' lands, especially where IPLCs' tenure over those lands lack legal recognition.

Studies of Amazonian countries (where nearly a quarter of IPLC-managed irrecoverable carbon is found) show that IPLC lands with secure tenure have significantly lower deforestation than in lands without it.[17] This indicates that land rights are crucial to protect both the rights of IPLCs and the high-carbon ecosystems they use and steward. IPLCs are diverse groups facing diverse sets of threats, so policies and investments related to the protection of land rights and or carbon ecosystems should be context-specific in a way that respects the self-determination and visions of IPLCs. Free and prior informed consent (FPIC) must always be obtained from the IPLCs for decisions connected to their lands and rights.

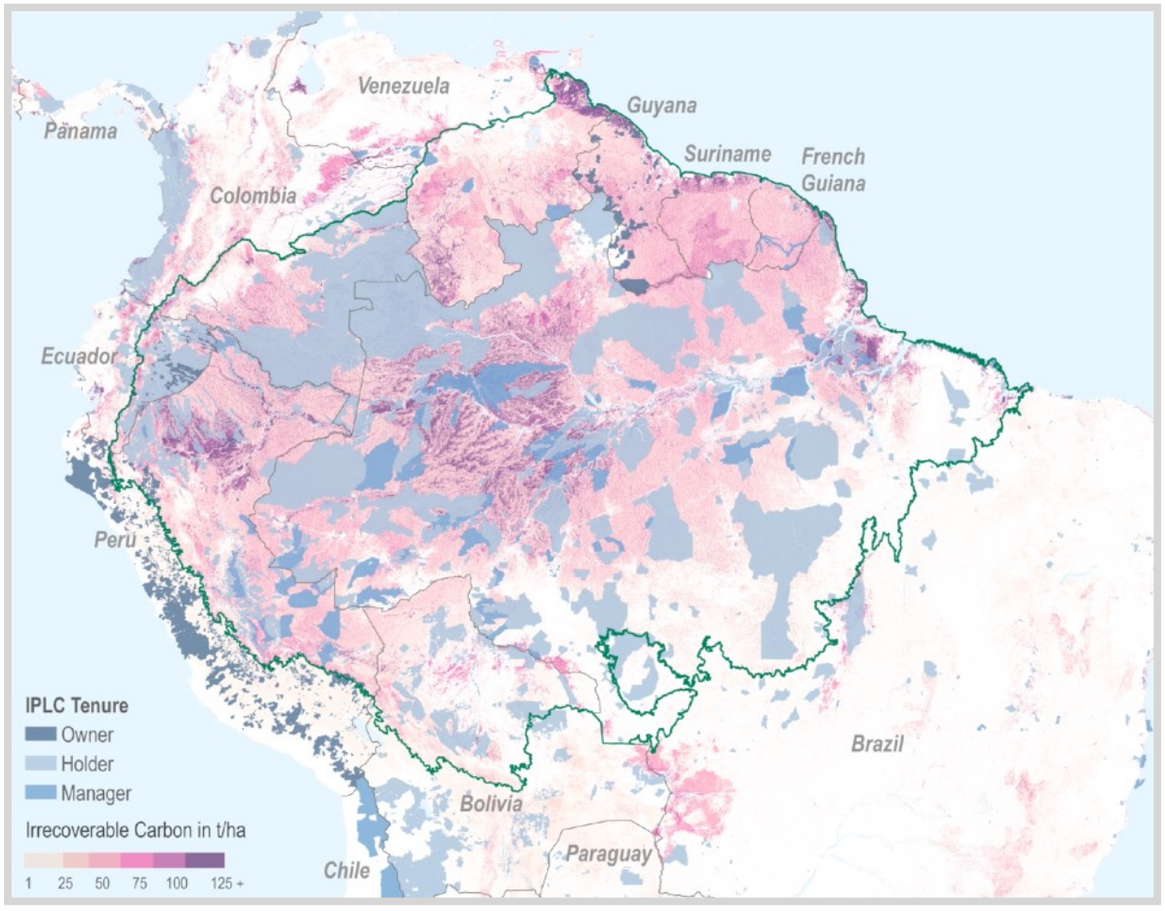


Figure 11: Indigenous and community land tenure overlaps with irrecoverable carbon areas in Amazonia

Note: Map based on lands and territories formally recognized by the national governments. Areas lacking data do not mean the absence of IPLCs lands and territories. Owner, manager, and holder refer to the bundle of land tenure rights that people have over their land, with owner possessing the most comprehensive rights. Indigenous Peoples and Local Communities land governance data is from Conservation International's 'Conservation Atlas' (last updated April 2021).

RECENT LOSS + FUTURE RISK

Photo: © Kate Evans/CIFOR/Flickr Creative Commons

Recent Loss

Over the past decade, at least 4 billion metric tons of irrecoverable carbon have been lost due to land-use change. This is equivalent to roughly 5 percent of fossil fuel emissions over that time period and should be considered just as permanent — this irrecoverable carbon would take at least three decades to recover in a best-case scenario.

Since 83% of irrecoverable carbon areas have tree cover, loss estimates based on global forest change[18] are a reasonable proxy for irrecoverable carbon loss over the last decade. The patterns and rate of irrecoverable carbon loss differs considerably by country: for example, Myanmar has lost 5.4% of its irrecoverable carbon since 2010 (43 Mt) while Peru has lost 1.3% (60 Mt).

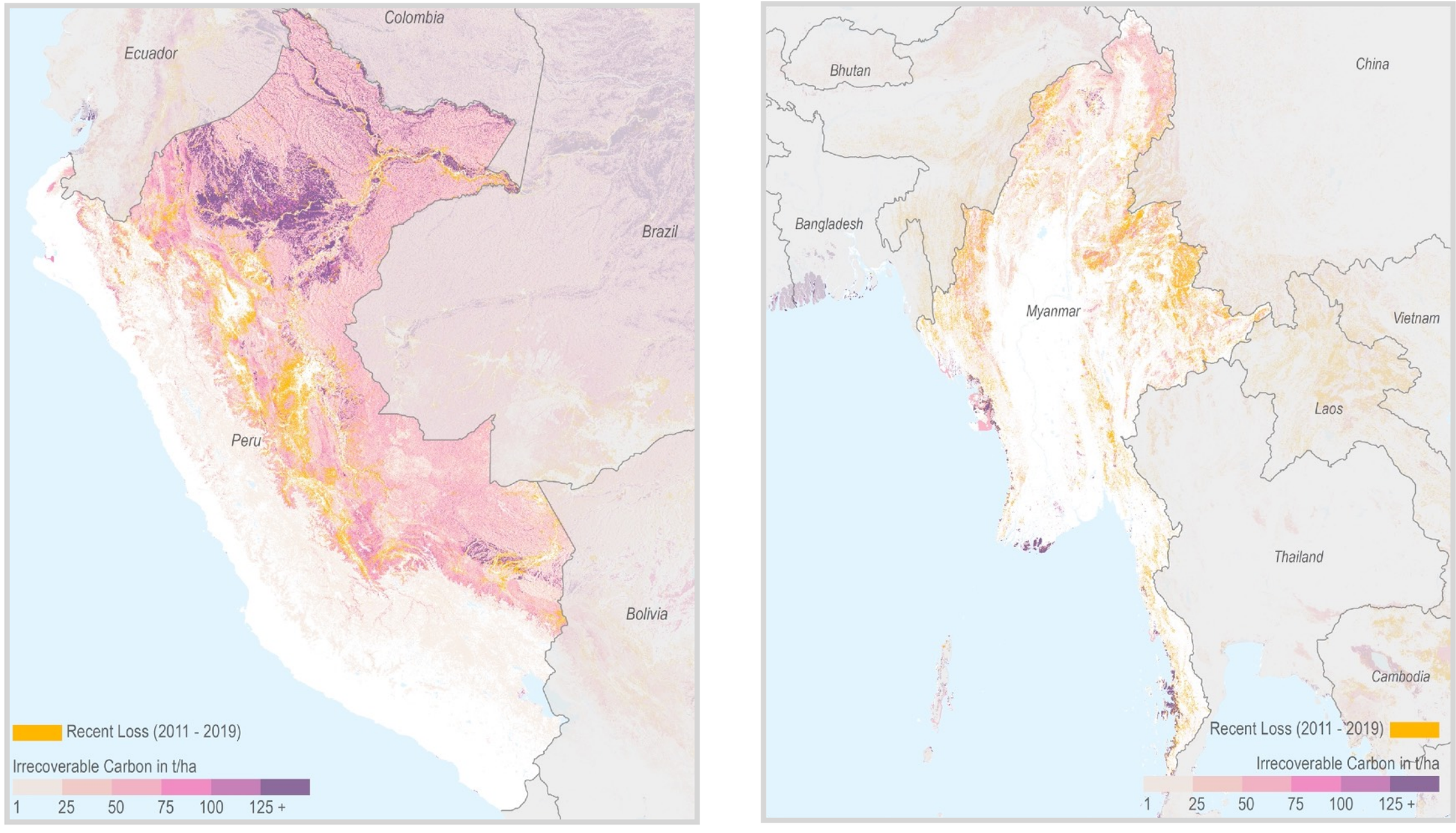


Figure 12: Irrecoverable carbon loss in Peru and Myanmar in the last decade

Key drivers of irrecoverable carbon loss

Commercial agriculture drives 70% of tropical deforestation

Cattle, oil palm, soy, timber and paper pulp are the biggest drivers of deforestation. Malaysia has lost more than 100 million metric tons of irrecoverable carbon — 9 percent of its total — due to deforestation over the last decade. It is the second-largest producer of palm oil globally, and palm oil concessions often overlap with intact forest and tropical peatlands. The country has agreed to limit palm oil cultivation areas to 6.55 million hectares by 2023, but many to-be-developed palm concessions still coincide with areas of irrecoverable carbon. Palm oil is found in thousands of household products, from candy to laundry detergent to shampoo, with demand driven globally.

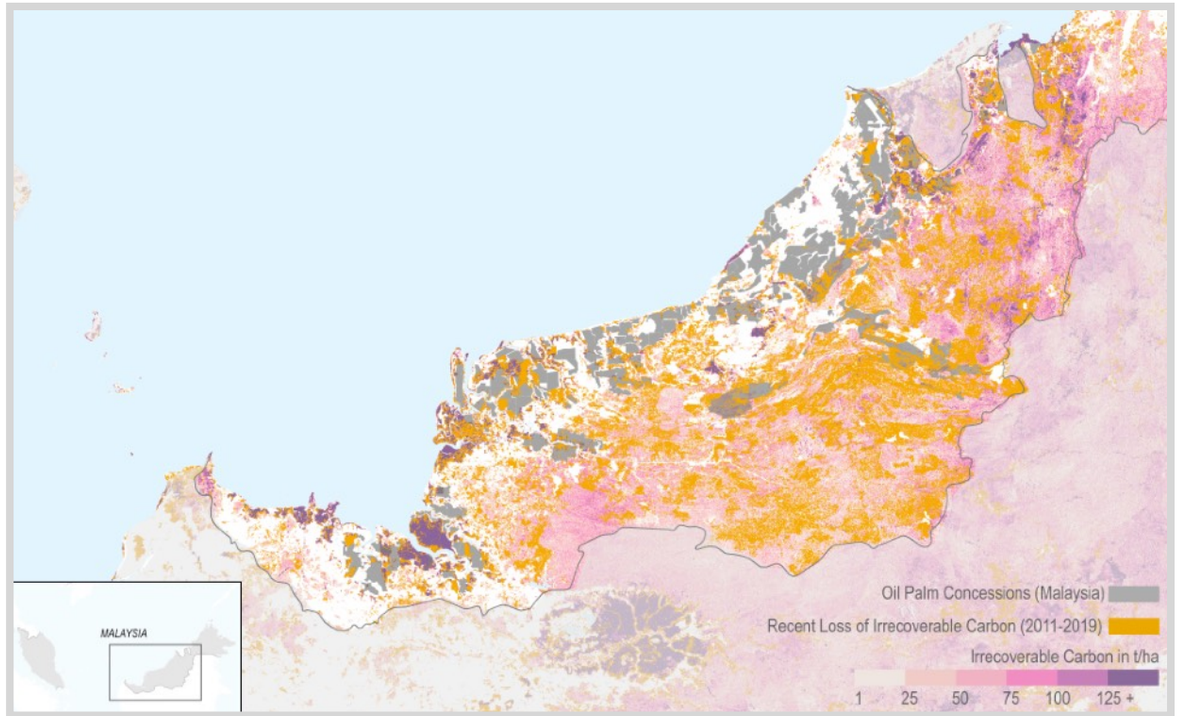


Figure 13: Recent deforestation in Malaysia is driven by palm oil cultivation

Shrimp ponds and other aquaculture threaten mangrove ecosystems

Commercial aquaculture is the main threat to the densest irrecoverable carbon ecosystems on Earth (mangroves). For example, 70 percent of Indonesia's 3.7 million hectares (9.1 million acres) of mangroves have been damaged or degraded by aquaculture, according to the Global Mangrove Alliance. Once drained for shrimp ponds, these coastal ecosystems release the majority of their stored irrecoverable carbon into the atmosphere.

Shrimp ponds are a leading driver of mangroves deforestation.

Photo © Kampee Patisena/Getty Images

Future risks

If deforestation continues at current rates into the future, at least 4.5 Gt of irrecoverable carbon could be lost each decade due to deforestation alone, meaning at least 10% of the irrecoverable carbon stock globally would be gone by 2050. However, the spatial distribution, types and pace of future risks cannot simply be extrapolated from historical trends. While areas of current irrecoverable carbon loss require immediate attention, a view toward future risks — both due to shifting human pressures and a changing climate — is needed to ensure these irrecoverable carbon reserves are maintained over coming decades.

Photo: © Matt Zimmerman

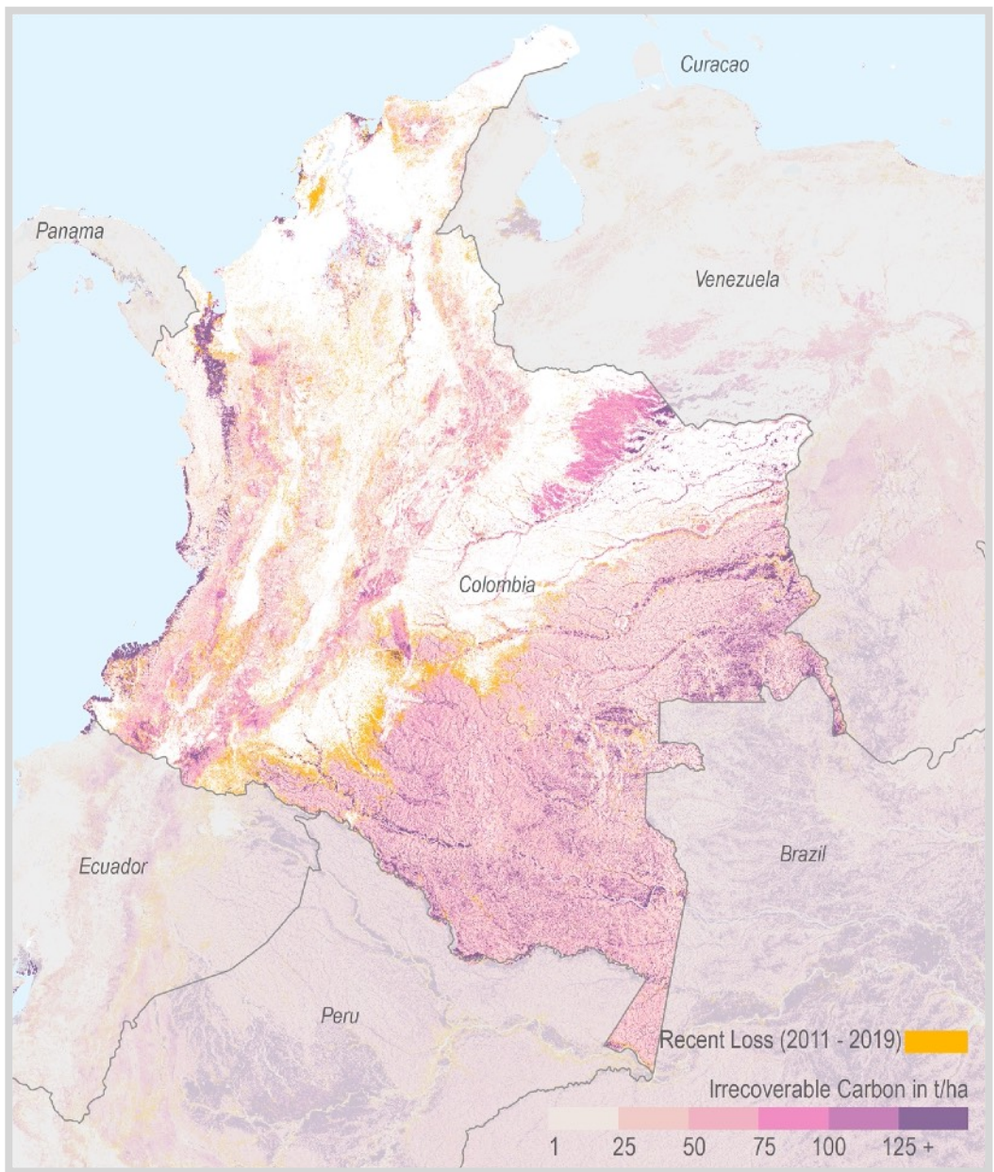


Figure 14: Irrecoverable carbon loss in Colombia from 2011-2019

Deforestation frontiers can shift due to unpredictable market or political forces

Colombia has a relatively clear deforestation frontier on the western edge of the Amazon rainforest. The country has lost about 52 million metric tons of irrecoverable carbon to deforestation in the last decade. The end of Colombia's half-century of armed conflict in 2016 led to increased deforestation, as cattle and cocoa cultivation expanded and previously contested lands opened up for development. Though in 2019 the country's annual deforestation rate dropped for the first time since the peace agreement was signed, Colombia illustrates how socio-political factors can drive environmental outcomes — and how periods of transition can be especially tenuous.

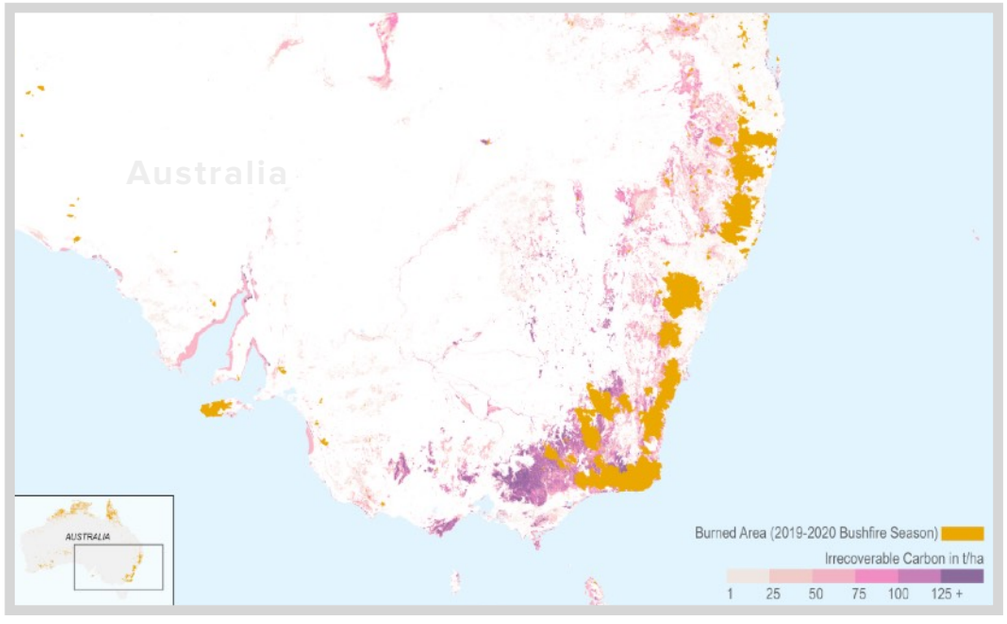


Figure 15: Burn area from the 2019-2020 bush fire season in Australia.
Fires impacted an area of 37 million hectares (91 million acres) across Australia, with over 455 million metric tons of irrecoverable carbon.[19]

Climate change itself increasingly threatens irrecoverable carbon

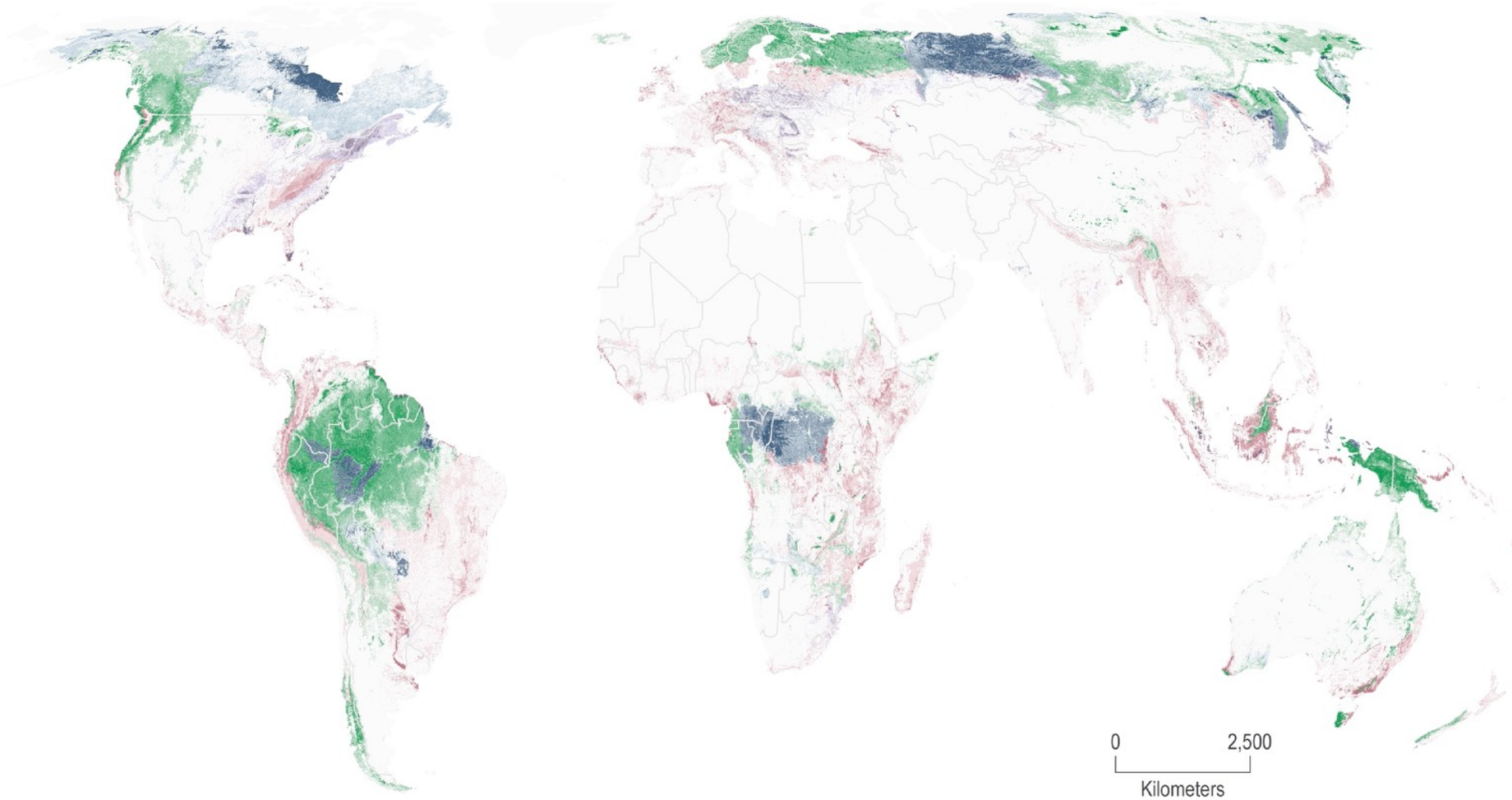
As wildfire, storms, drought, changing rainfall patterns, and species shifts become more acute, some ecosystems storing irrecoverable carbon become more physically vulnerable. For example, record-breaking temperatures, long droughts and strong winds — all related to climate change — have exacerbated forest fires in Australia. These megafires are threatening the eucalyptus forest in the southeast corner of the country, one of the largest carbon-storing forests in the world. Globally, forest fires are burning hotter and longer even in temperate areas adapted to fire, and they are igniting tropical forests where fires are not a natural part of the ecosystem's life cycle. On the coast, sea-level rise, more intense storms and ocean acidification can affect high-carbon ecosystems such as mangroves, seagrasses and tidal marshes. Changing precipitation patterns and higher temperatures can also shift an entire ecosystem to a lower-carbon state. In the Amazon, for example, studies warn the rainforest could reach a tipping point that turns much of it into a savannah.

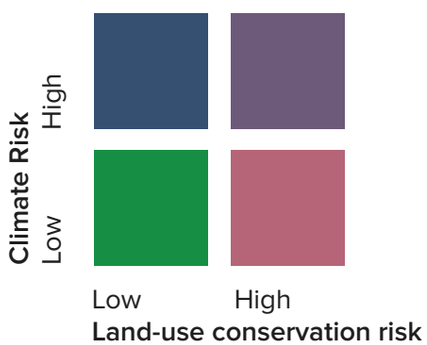
Photo: Agricultural frontiers driven by climate change could open up more farmlands in Russia. © Victoria Borodinova/Pexels

Agricultural frontiers may increase risks in northern latitudes

Rising temperatures brought by climate change mean that more areas in northern latitudes may become suitable for growing crops such as potatoes, wheat, maize and soy. Recent research estimates that an additional 10 million-24 million square kilometers (4 million-9 million square miles) could open up to agriculture in the next 50 years in higher latitudes including Canada and Russia. Without appropriate land-use planning, clearing these northern frontiers for crops could put an additional 18 billion metric tons of irrecoverable carbon at risk in temperate and boreal forests.

Figure 16: Climate and land-use conversion risks to irrecoverable carbon by ecoregion, and strategies for risk mitigation





High climate risk; Low land- use conservation risk

- Land-use planning for climate change
- Adaptive ecosystem management
- Assisted species migration
- Fire and pest management

Low overall risk to irrecoverable carbon

- Monitor climate & land-use change risks
- Proactive protection where possible

High climate risk + High land-use conversion risk

- All strategies are relevant

High land-use conservation risk; Low climate risk

- New protected areas
- More resources to existing protected areas
- Indigenous land tenure
- Payments for avoid deforestation
- Concessions buybacks

Irrecoverable carbon is shaded by density, with colors delineated by ecoregion according to their degree of human modification (with a Human Footprint of 6 or greater considered 'high') and climate change risk (with a Climate Stability Index of 0.5 or lower considered 'high'). Note that these are just two possible datasets for assessing land-use and climate risk, and downscaled risk assessments would be needed to inform action at the country or local scale. Strategies for managing risks to irrecoverable carbon are depicted based on the four major risk categories. Adapted from Noon et al. 2021. *Mapping the irrecoverable carbon in Earth's ecosystems.* Nature Sustainability.

Conclusion and Recommendations

We now know that the world's ecosystems harbor significant irrecoverable carbon which, if lost, could not be recovered in time to address the current climate emergency. The protection of these places must be part of any successful strategy to avoid the most dangerous impacts of climate change. Our effort to map irrecoverable carbon globally reveals a few convenient truths:

1. Irrecoverable carbon is relatively concentrated, with 50% found in 3.3% of Earth's land and 75% found in 7.5% of Earth's land. These areas are the most important to monitor for risk and proactively protect given their carbon would be irrecoverable for at least three decades, if lost.

2. Irrecoverable carbon and areas of high biodiversity overlap in many places, particularly in the tropics. This means that long-term area-based conservation can be a win-win for the climate and biodiversity, with irrecoverable carbon and habitat for threatened species being proactively managed in the same places. The knowledge that certain biodiverse lands are also playing a key function in storing irrecoverable carbon could open up new climate finance mechanisms for those lands.

3. Indigenous peoples and local communities manage at least a third of Earth's irrecoverable carbon. This is a "convenient truth" – in many of these places, no new legal designation or management plan is required — we simply need to support the rights of the people who live there and their ways of life. It is alongside many of the world's traditional cultures that carbon in ecosystems has been maintained generation after generation.

We offer the following high-level recommendations to policymakers, financiers and conservation practitioners:

- Support Indigenous peoples and local communities, who collectively manage more irrecoverable carbon than any other group but face increasing threats to their lands. One of the most powerful ways for governments to support Indigenous peoples is to ensure (or restore) their land tenure rights.

- Rapidly address policies and practices that threaten Earth's last remaining irrecoverable carbon strongholds. This may include, for example, retiring extractive concessions (e.g. oil and gas, mining, logging) and prohibition and/or removal of unsustainable infrastructure (e.g. dams, roads, pipelines) on lands with high irrecoverable carbon.

- Use the irrecoverable carbon map in spatial prioritization and planning efforts, alongside other relevant datasets. For example, irrecoverable carbon values could be used as part of the justification for a new conservation area designation, in addition to biodiversity data.

- For countries seeking to expand their protected and conserved area networks as part of global efforts to protect 30% of land by 2030, consider unprotected irrecoverable carbon lands as high priority for potential places to expand legal protections or recognition of Indigenous peoples and local communities.

- Prioritize areas with high concentrations of irrecoverable carbon in strategies from national governments and multilateral funders such as the Global Environmental Facility, Green Climate Fund and World Bank.

- Create new financial mechanisms for the proactive protection of irrecoverable carbon against land-use change and climate change threats, complementing existing climate finance mechanisms such as REDD+.

- Implement the four pillars of Irrecoverable Carbon Reserves—inclusivity, climate resilience, sustainable finance and technology enabled—so that these areas are "future-fit" and will still be providing their critical carbon storage and sequestration functions in 2050 and beyond.

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