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High-risk forests, high-value returns

A co-benefits assessment for decision-makers



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Lead authors: Lian Pin Koh (National University of Singapore), Steve Hoong Chen Teo (National University of Singapore), Katrina Harina Borromeo (UNEP), Gabriel Labbate (UNEP)

Co-authors: Sze Koy Ho (National University of Singapore), Tasya Vadya Sarira (Duke University), and Mark Mulligan (King's College London)

Layout and design: Dino Dans (UNEP)

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A co-benefits assessment for decision-makers



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Abbreviations

CO₂e	Carbon dioxide equivalent
ESA-CCI	European Space Agency Climate Change Initiative
GDP	Gross Domestic Product
Gt	Gigatonnes
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
kg	Kilogram
km	Kilometre
M	Million
N	Nitrogen
NTFP	Non-timber forest product
REDD	Reducing Emissions from Deforestation and Forest Degradation
SDG	Sustainable Development Goals
STEAM	Simple Terrestrial Evaporation to Atmosphere Model
t	Tonnes
UN	United Nations
US\$	United States Dollars
VCS	Voluntary Carbon Standard
WAM- 2layers	Water Accounting Model–2 layers
yr⁻¹	Per year

Executive summary

01

One in every four people living near pantropical forests, about 53 million out of 215 million, depend on forests at high risk of loss.



This report finds that the tropical forests most at risk of being lost, defined here as “high-risk forests”, are also the most vital to people.

High-risk forests, as referenced in the report, are areas with high carbon stocks, significant additional ecosystem services, and a high likelihood of deforestation. Together they cover about 391 million hectares, an area comparable to the European Union.

Because of their combined carbon and ecosystem value, high-risk forests represent a strategic focus for climate mitigation. Protecting these will prevent the release of large-scale emissions but also helps maintain vital ecosystem services, safeguarding a substantial share of co-benefits that would otherwise be lost.

The added value of this report lies in its use of spatial data and quantified evidence to identify where these forests are most threatened and where protection would deliver the greatest benefits. This approach provides countries, policymakers, and investors with practical information to prioritize action and to help meet global targets such as the United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation's (UN-REDD) target of reducing 1 GtCO₂e of deforestation emissions per year.

The report finds that high-risk forests provide essential services that directly sustain people, economies, and ecosystems across Asia, Latin America and Africa:



**10–14%
of rainfall**

recycled by forests keeps rivers flowing and water available for people, farms, and energy.

- **They regulate water resources and improve water quality.** Each year, these forests retain about 2.3 million tonnes of nitrogen, equivalent to Canada's annual fertilizer use—which prevents harmful nutrient pollution that can trigger algal blooms, kill fish, and contaminate drinking water. They also keep 527 million tonnes of soil and sediment from washing into rivers, the same as filling 150,000 Olympic-size swimming pools with mud. This helps keep rivers clean and protects reservoirs, irrigation canals, and hydropower dams from clogging and damage. By recycling 10–14 per cent of regional rainfall, high-risk forests also maintain rainfall patterns and river flows, ensuring steady water supplies for households, farms, and energy production across large areas.



**10 million
people**

receive the equivalent of their annual nutrition from crops supported by pollinators sustained by high-risk forests.

- **They help secure food.** By supporting pollination, high-risk forests make possible crop harvests that provide nutrition for around 10 million people. This natural service is particularly important in rural and low-income regions where farming is small-scale, diets depend on local crops, and alternatives to wild pollination are limited or unaffordable.



**111 million
tonnes**

of fuelwood every year – plus fruits, nuts, fibers, and medicinal plants that millions depend on.

- **They sustain livelihoods.** Every year, these forests provide 111 million tonnes of fuelwood and a wide variety of non-timber products such as fruits, nuts, fibers, and medicinal plants. Together, these resources meet the basic energy, food, and income needs of about 25 million materially poor people. Women and Indigenous Peoples, in particular, depend on these resources for household cooking, heating, and nutrition, as well as for local trade and cultural practices.



**US\$ 81
billion**

in annual GDP protected each year by high-risk forests from natural hazards.

- **They strengthen climate adaptation.** By stabilizing soils, slowing water runoff, and buffering extreme weather events, high-risk forests reduce the risks of floods, landslides, and storms. Their protection prevents an estimated US\$81 billion in annual GDP losses by avoiding damage to roads, bridges, homes, farmland, and other infrastructure—safeguarding both lives and national economies.

The analysis also shows that protecting high-risk forests can create trade-offs with other land-use demands. Restricting timber extraction or agricultural expansion in these areas may reduce short-term income opportunities, especially where viable alternatives are limited. Trade-offs may also occur between conserving water flows for downstream users and expanding irrigation or hydropower, or between sustaining pollination services and converting land for cash crops. These risks underscore the need for policies and investments that integrate conservation and development, rather than treating them as competing goals.

Realizing the benefits of high-risk forests requires coordinated action and sufficient investments. Policymakers and investors should direct finance to the most valuable and threatened areas, using co-benefit data to guide priorities and reduce risks. Governments should embed forests into national climate strategies, development plans, and resilience frameworks, recognizing their role as critical natural infrastructure that brings multiple benefits.

Equally important, forest-proximate communities, particularly women and Indigenous Peoples, need to be empowered and rewarded as stewards of these landscapes, with secure rights and equitable access to benefits. With decisive action, countries can achieve large-scale climate mitigation while safeguarding the ecosystems and communities that depend most on high-risk forests.



In Nawandigi Forest, members of Umoja Veterans Sacco in Buwama, Uganda, are helping restore forests with UN-REDD's support to protect community rights and promote local benefits. Copyright 2025 UNEP/Donguk Shin

Why forests matter for climate and people

02



Source: Copyright 2025 UNEP/Donguk Shin

Tropical forests are foundational to planetary health and human well-being, regulating the global carbon cycle and ecosystem processes to support life on Earth.

Between 1990 and 2019, forests absorbed about 13.1 ± 1.4 GtCO₂e yr⁻¹, around half of global fossil fuel emissions, highlighting the essential role of forest conservation, sustainable management and restoration in climate mitigation (Pan et al., 2024).

Beyond carbon, forests also provide numerous ecosystem services critical to human well-being. Studies show that natural ecosystems directly underpin at least half of the United Nations (UN) Sustainable Development Goals (SDGs) (Neugarten et al., 2024). For instance, forest ecosystems regulate water cycles, securing the availability and quality of freshwater for agriculture, industry, and communities (Teo et al., 2022). They support food security by maintaining soil health, regulating local climates, and providing habitats for crop pollinators (Siopa et al., 2024). Tropical forests are also central to the livelihoods of millions of Indigenous Peoples and local communities (IPs and LCs), supplying fuelwood and non-timber forest products such as food and medicine (Shackleton & de Vos, 2022).

These benefits are not shared equally. Women and vulnerable groups often depend most on forests for cooking fuel, nutrition, and household income, yet face barriers such as insecure land rights and exclusion from decision-making, leaving them especially vulnerable when forests are lost (Bitzer et al., 2024). Moreover, intact forests serve as natural infrastructure, enhancing climate resilience by protecting communities from floods, landslides, storms, and other extreme weather events (Sudmeier-Rieux et al., 2021).

Yet, tropical forests face intense pressures from agricultural expansion, infrastructure development, logging, and resource extraction (Curtis et al., 2018). In the last two decades, the world has lost approximately 10 million hectares of tropical forest per year, an area the size of Republic of Korea, releasing 5.1 ± 0.5 GtCO₂e yr⁻¹ of carbon and diminishing ecosystem services that sustain people's daily lives (Feng et al., 2022; Laso Bayas et al., 2022). Forest loss disrupts local water supplies, undermines food production, and threatens economic stability, disproportionately impacting vulnerable populations. Biodiversity loss further compromises ecosystem resilience, heightening vulnerability to climate impacts and economic shocks (IPBES, 2024). Without effective intervention, the continued degradation and deforestation of tropical forests represent a profound risk to global climate stability and sustainable development.

International climate frameworks recognize the urgency of protecting of forests. The UN's Reducing Emissions from Deforestation and Forest Degradation (REDD+) framework supports the Paris Agreement by working with developing countries to implement measures that reduce human pressure on forests resulting in greenhouse gas emissions. The UN-REDD Programme's 2021-2025 strategy aims to realize 1 GtCO₂e yr⁻¹ of forest-based GHG emission reductions and enhanced removals. Although reducing deforestation is high on the political agendas of the UN, G20, G7, African Union, and other major political dialogues, there is a lack of sufficient ambition and concrete targets (UNEP, 2024).

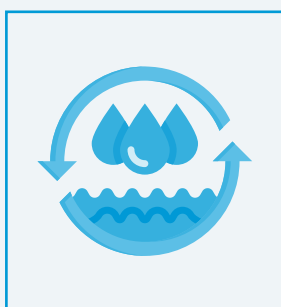


In San Juan Forest, Paraguay, community members help monitor their forests. The UN-REDD Programme supports the country's National Forest Monitoring System to track forest cover and carbon stocks. Copyright 2019 UNEP/Nelson Roman

Recognizing and valuing forest co-benefits can help raise ambition and strengthen protection efforts. Equally important is understanding where these co-benefits overlap with high deforestation risk, so that protection can be prioritized and scarce resources directed where they will have the greatest impact.

This is where the present report makes its contribution. It provides spatially explicit, evidence-based analysis to identify where tropical forests are most threatened and where protection would generate the greatest combined benefits for climate and people.

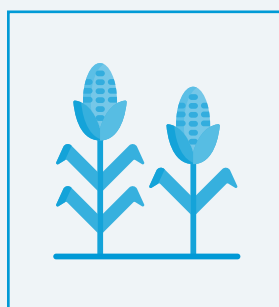
Using global spatial datasets and a consistent modelling framework the analysis evaluates seven co-benefit layers grouped into four themes (see Annex 2):



1. Water regulation –
nitrogen retention,
sediment retention,
and moisture recycling;



2. Food security –
pollination-supported
nutrition;



3. Livelihoods –
access to non-timber
forest products and
fuelwood;



4. Climate adaptation –
GDP benefiting from
hazard mitigation.

These layers were selected because they represent quantifiable services with direct impacts on people's lives, while also enabling comparability across regions. Together, they provide a strategic basis for prioritizing forest protection where it can deliver the greatest combined benefits. At the same time, forests offer a far broader range of ecological, cultural, and social contributions than can be fully captured here.

For example, Gross Domestic Product (GDP) exposure is included as a tangible proxy for climate adaptation to demonstrate economic resilience, though additional dimensions of social vulnerability and indirect impacts may also be significant. Likewise, other critical forest contributions such as biodiversity conservation and the vital roles of Indigenous Peoples and local communities, as well as women and girls in forest stewardship, are beyond the current analytical scope but should also be acknowledged as essential elements supporting forest resilience.

The findings in this report should thus be viewed as indicative rather than prescriptive. The analysis is based on global models that cannot fully reflect local ecological dynamics, climate risks, or community priorities. These results are best used to guide strategic decisions and highlight where more detailed, country-level assessment and inclusive planning are most needed. Therefore, the findings presented here provide a starting point that should be complemented by participatory processes, local knowledge, and recognition of the broader spectrum of benefits that forests deliver.

Achieving forest climate mitigation in the pantropics

03



Source: Copyright 2023 UNEP / Eriz Taufany

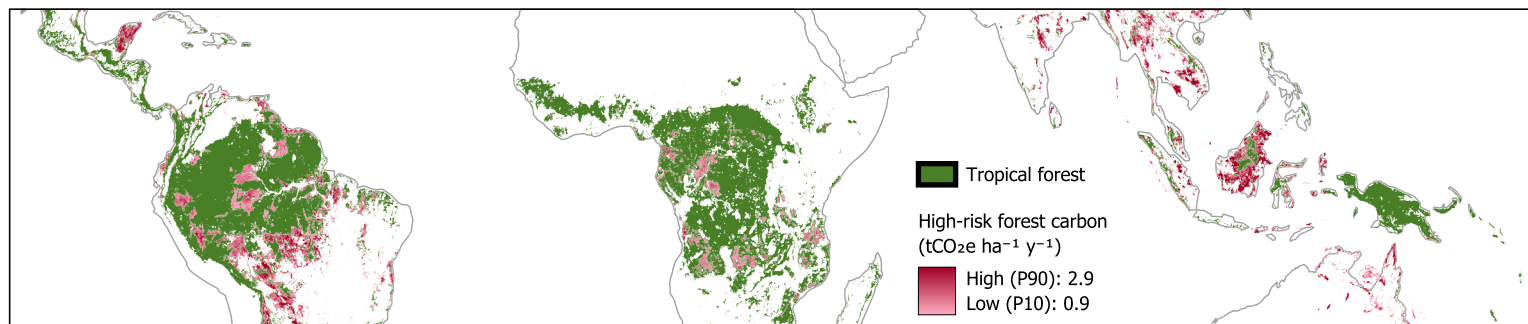
Several international frameworks highlight the importance of forests for meeting global climate and development goals, including the Paris Agreement, the Global Biodiversity Framework, and commitments under the G20 and African Union.

For this analysis, the UN-REDD Programme's 2021–2025 mitigation target was used, i.e. to achieve an initial 2025 target of 1 GtCO₂e yr⁻¹ of reduced emissions and enhanced removals per year as a benchmark. This target was selected because it provides a clear, measurable reference point and is directly linked to country-level action on reducing deforestation and forest degradation.

Building on this benchmark, the analysis identified the minimum extent of tropical forest that would need protection to contribute to the 1 GtCO₂e yr⁻¹ goal while also securing important co-benefits. This was done by prioritizing areas with the highest values of forest carbon stock multiplied by predicted deforestation risk (see Annex 1 for details).

¹ This 1 GtCO₂e yr⁻¹ target for avoided deforestation emissions is for the period 2021-2025. Although this specific target period is ending, the scale and ambition it represents remains relevant as an illustrative benchmark for future global forest protection efforts.

Figure 1a. Total pantropical forest extent and high-risk forest carbon (tCO₂e ha⁻¹ yr⁻¹). Spatial distribution of carbon at risk from deforestation in high-risk tropical forests. These forests represent the minimum extent needed to achieve a 1 GtCO₂e yr⁻¹ target.

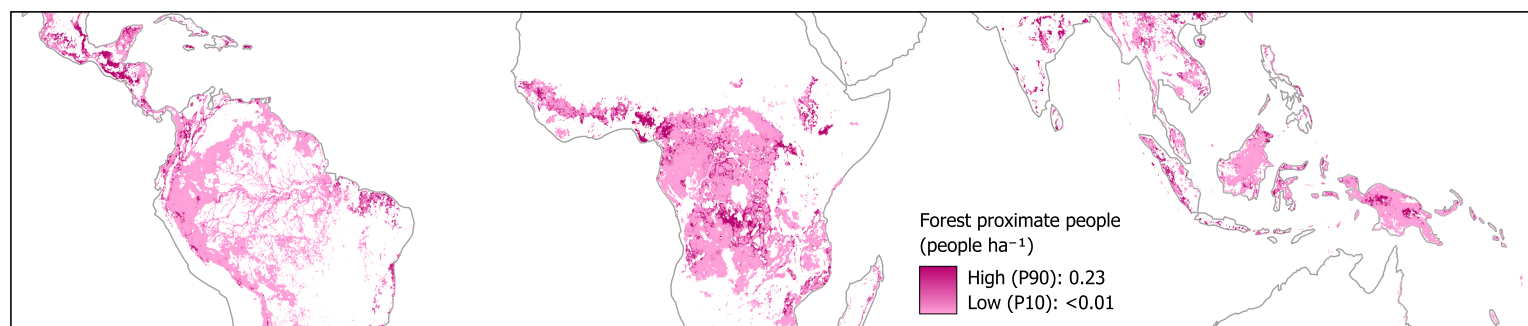


**391 million hectares
of high-risk forests**

comparable to the size of
the entire European Union.



Figure 1b. Forest-proximate populations (people ha⁻¹). Population density of people living within 5 km of tropical forests. These are communities likely to be highly reliant on forest ecosystem services.



**One in every four
people living near
pantropical forests,**

about 53 million out of 215
million, depend on forests
at high risk of loss.

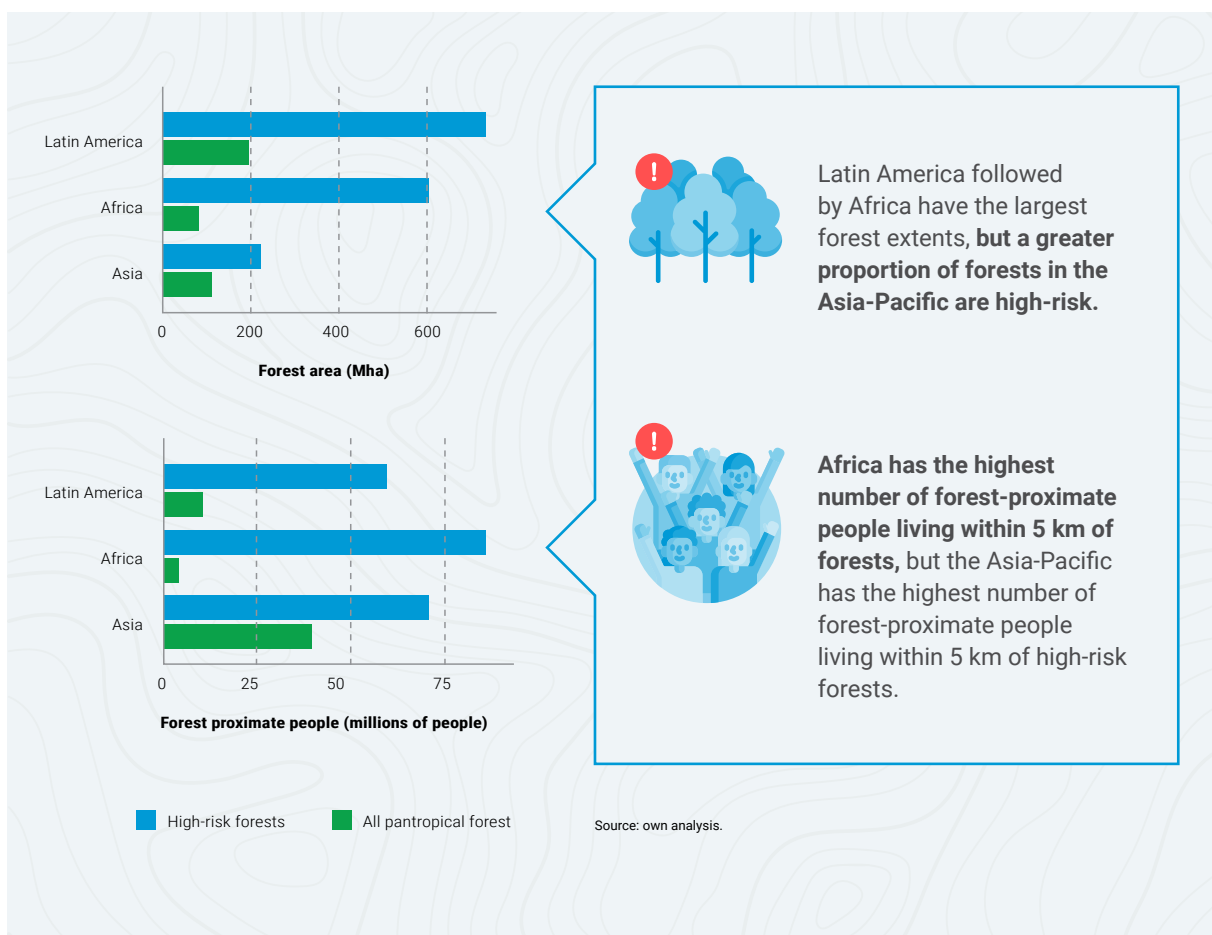


These high-risk forests amount to **391 million hectares²**, out of a total **1.6 billion hectares** of pantropical forest. To grasp the scale of this area, 391 million hectares is nearly the size of the entire European Union, or almost half the size of China (See Figure 1a and Figure 2).

Crucially, protecting forests also means protecting the livelihoods and daily needs of millions of people who depend on forest resources. This is particularly so for forest-proximate people, defined as those living within 5 km of forests (Newton et al., 2020), who are most vulnerable to losing forest ecosystem services from deforestation while also being the most immediate stewards and potential beneficiaries of community-driven REDD+ programmes.

Out of **215 million forest-proximate people** across the pantropics, there are **53 million people** living near these high-risk forests. The following sections of this report provide a detailed quantification of how protecting high-risk forests secures multiple co-benefits for both forest-proximate peoples and those beyond, while contributing UN-REDD's forest mitigation target simultaneously (See Figure 1b and Figure 2).

Figure 2. High-risk forest area and total forest extent (Mha), as well as the number of forest-proximate people (millions) for three pantropical regions.



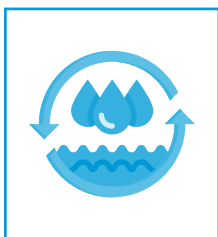
² This area corresponds to the amount of tropical forest that would be expected to generate approximately 1 GtCO₂e of avoided emissions each year (the product of carbon stock and deforestation risk) if protected. The estimate reflects the combined effect of relatively high carbon stocks and elevated deforestation risk in these locations. Please see Annex for full methodology.

Key finding 1: Forests regulate water resources and improve water quality



Source: 2022 UNEP/Eriz Taufany

Healthy tropical forests play a critical role in regulating water cycles and ensuring freshwater availability and quality.

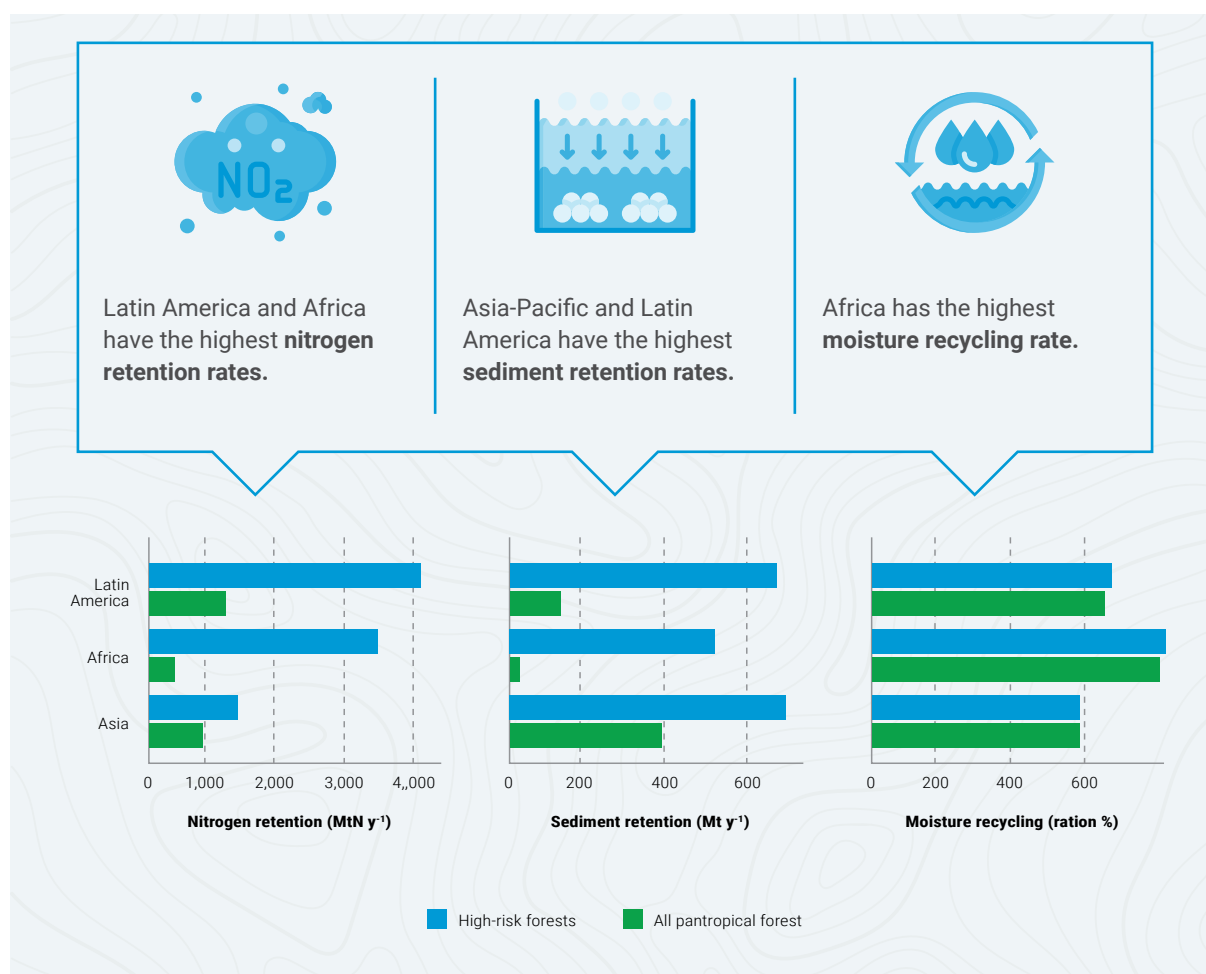


By anchoring soils and filtering runoff, forest vegetation traps sediments and pollutants, which can affect aquatic biodiversity, fisheries, and downstream water flow and quality (Conley et al., 2009; Jones et al., 2022). At the same time, trees recycle massive amounts of moisture back into the atmosphere through evapotranspiration, which enhances local and regional rainfall patterns (Ellison et al., 2017; Teo et al., 2022). These hydrological services help stabilise water flows, reduce erosion, and ensure clean water for ecosystems and human use.

Our analysis shows that protecting high-risk tropical forests delivers major water-related benefits (see also Figures 3 and 4).

- **Keeping rivers clean by filtering pollutants:** Forest vegetation traps harmful substances like nitrogen from agricultural runoff. Our analysis indicates that protecting high-risk tropical forests would continue to prevent significant nutrient and sediment pollution from entering waterways. These protected forests annually retain approximately **2.3 million tonnes of nitrogen pollutants**, comparable to the annual nitrogen fertilizer consumption of Canada (Ludemann et al., 2022).

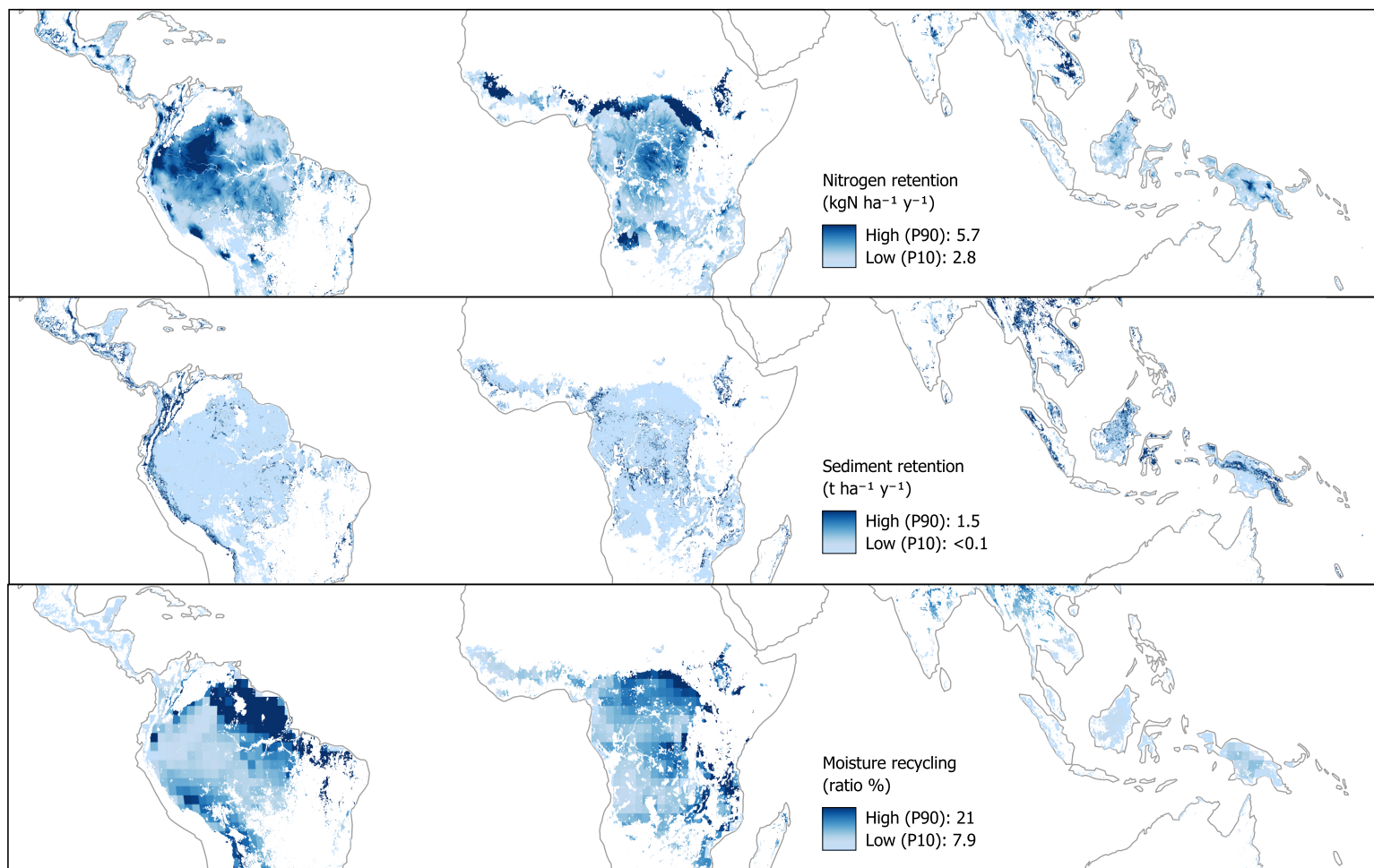
Figure 3. Total nitrogen retention (MtN yr⁻¹), total sediment retention (Mt yr⁻¹), and average moisture recycling (ratio %) in high-risk versus all pantropical forests for three pantropical regions.



Pantropical forests retain a total of the 9 million tonnes of nitrogen pollutants, comparable to the annual nitrogen fertilizer consumption of the United States of America. This matters because excess nitrogen, often from fertilizers, can cause harmful algae blooms and damage water quality, a problem known as eutrophication. By keeping this pollution out of rivers, protecting high risk forests helps safeguard the clean drinking water of millions of people across tropical regions.

- **Reducing erosion and sediment runoff:** Forests also help keep rivers clean by preventing soil erosion. When forests are cleared, rain washes large amounts of soil into rivers, which can clog waterways, damage infrastructure, and reduce farming productivity. Protecting high-risk tropical forests can prevent about **527 million tonnes** of sediment from entering rivers each year, enough to fill around 150,000 Olympic-size swimming pools. This is out of **1.9 billion tonnes** across the pantropics. This translates into substantial avoided costs in water purification, infrastructure maintenance, and enhanced agricultural productivity.
- **Sustaining rainfall through moisture recycling:** Forests release moisture into the atmosphere through evapotranspiration, which then returns as rain. Preventing deforestation in tropical forest areas helps sustain regional rainfall patterns, with an estimated **10-14 per cent of regional rain** recycled locally by high-risk forests. Doing so helps to stabilize local climates and sustain water availability for agriculture and human consumption.

Figure 4. Maps of nitrogen retention ($\text{kgN ha}^{-1} \text{ yr}^{-1}$), sediment retention ($\text{t ha}^{-1} \text{ yr}^{-1}$), and moisture recycling (ratio %). Tropical forests provide critical water regulating and provisioning services, including nitrogen retention, sediment retention, and moisture recycling.



2.3 million tonnes

of nitrogen retained each year -
equal to Canada's annual fertilizer use.



527 million tonnes

of sediment blocked every year -
Equivalent to 150,000 Olympic
swimming pools of mud



10-14%

of rainfall recycled by forests
- Helps sustain agriculture &
regional water supplies

Box 1. Moisture recycling and forest tipping points

Tropical forests play a vital role in sustaining regional rainfall through moisture recycling where water transpired by trees into the atmosphere returns as precipitation locally or downwind. This ecological feedback loop helps stabilise hydrological regimes at regional scales, thereby ensuring the stability of forest ecosystems while supporting livelihoods.

In the Amazon, this process manifests in so-called *flying rivers*, vast air currents that transport moisture thousands of kilometres across South America, feeding rainfall as far away as the Andes and agricultural regions of southern Brazil. Disruption of these atmospheric rivers through deforestation directly threatens water security far beyond the forest itself (Staal et al., 2023).

However, these systems are approaching critical thresholds. Deforestation and climate change can weaken this feedback, triggering abrupt ecological transitions. Current observational evidence shows that tropical deforestation has already led to reductions in precipitation (Smith et al., 2023). In the Amazon, studies suggest that 20-40 per cent deforestation could push parts of the basin past a tipping point, weakening the forest-rainfall feedback and reducing regional precipitation. This could risk large-scale forest dieback and a transition to a savannah state (Boers et al., 2017; Lovejoy & Nobre, 2018; Sampaio et al., 2007; Walker et al., 2019). The impact on the global climate would be disastrous.

Preventing these tipping points by ensuring deforestation remains within safe operating boundaries is critical.



In Inle Lake, Myanmar, a local community member fishes along forest-lined banks beside the farmlands of Indein village. Copyright: 2016 UNEP/Maw Htun

Key finding 2: Forests help ensure food security

05



Source: 2022 UNEP/Eriz Taufany

Tropical forests significantly enhance agricultural productivity and food security through their role in sustaining pollinators and regulating local climates.

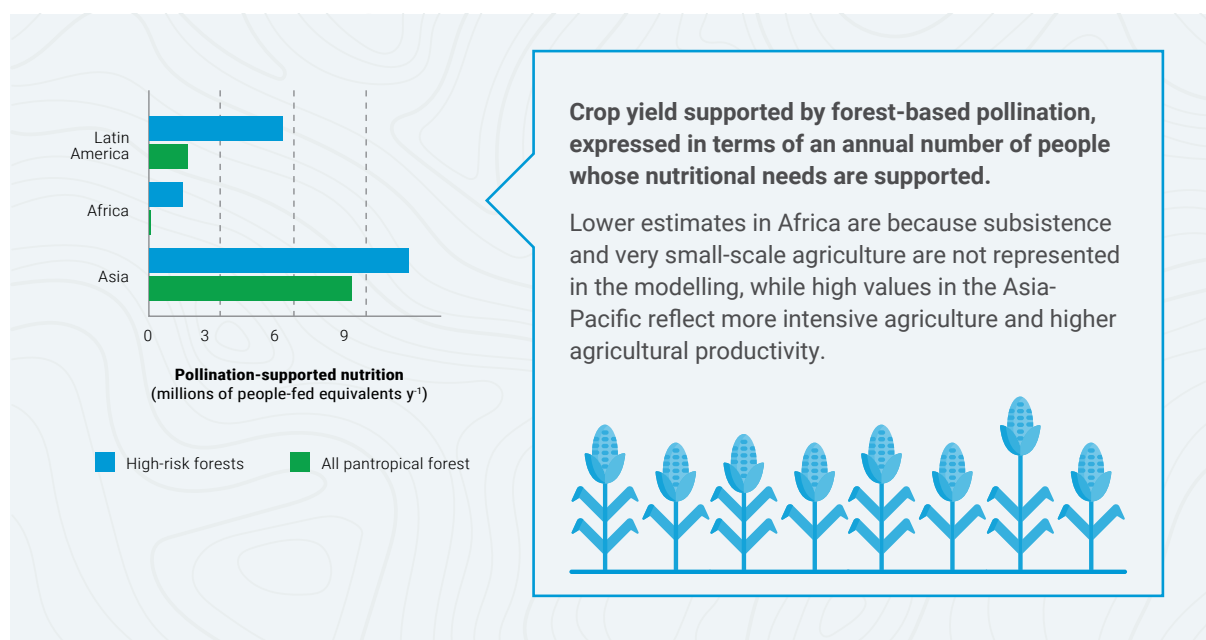


Pollination-dependent agriculture, which includes many fruits, vegetables, nuts, and oil crops, relies on wild pollinators that thrive near intact forests. Nearly three-quarters of the world's crop species benefit from animal pollination to varying degrees (Siopa et al., 2024), which boosts yields of vitamin-rich foods. Without healthy ecosystems for pollinators, diets could shift to less nutritious staples, undermining global nutrition efforts.

The analysis shows that protecting high-risk forests would sustain crop pollination, which boosts crop yields **equivalent to the nutritional needs** of around **10 million people annually** (see Figure 5). **Across all pantropical forests, pollination-supported crop yields provide the equivalent of the nutritional needs of 18 million people annually³.** While these numbers may appear modest in global terms, they reflect only the proportion of nutrition directly attributable to pollination. Therefore, a much larger population of individuals rely on crops sustained by forest pollination to meet part of their nutritional needs.

³ For comparison purposes, this is approximately the population of Portugal.

Figure 5. Pollination-supported nutrition (millions of people-fed equivalents yr⁻¹) for three pantropical regions.



While these numbers may appear modest in global terms, they reflect only the proportion of nutrition directly attributable to pollination; therefore, a much larger population of individuals rely on crops sustained by forest pollination to meet part of their nutritional needs. Moreover, these benefits are concentrated in rural and low-income areas where people are most dependent on local food systems and least able to afford nutritional losses (Abrol, 2012).

In such contexts, the loss of pollination services due to deforestation could lead to lower yields of high-value crops, reduced income for smallholder farmers, and a shift toward less diverse, calorie-dense staples undermining both nutrition and resilience. While pollination is a critical service, it represents only one of the ways in which forests support agriculture. Forests also regulate other climate and ecological processes that underpin agricultural sustainability and productivity.

Box 2. Pollination services boost coffee yields in Costa Rica

Intact tropical forests sustain populations of wild pollinators that are critical for many high-value crops. This ecosystem service directly supports food production and farmer incomes, especially in tropical landscapes where managed pollination is not widely used.

In Costa Rica's Valle General region, coffee farms located near forest fragments experienced significantly higher fruit set and yields due to enhanced pollination by native bees. Ricketts et al. (2004) found that farms within 1 km of forest received more pollination, resulting in **a 20 per cent increase in coffee yields** compared to farms farther away. Each hectare of forest translated to an estimated US\$ 380 increase in income from coffee yields, highlighting the tangible economic value of forest-based pollination services.

This case illustrates that even relatively small forest patches embedded in agricultural landscapes can sustain vital ecological functions. Maintaining forest cover near farms contributes directly to food security and livelihoods, particularly for smallholders in low-input systems.

Figure 6. Maps of pollination-supported nutrition (people-fed equivalents $\text{ha}^{-1} \text{yr}^{-1}$). Spatial distribution of nutrition supported by forest-based crop pollination. Values are highest in tropical agricultural frontiers such as the Andes-Amazon transition zone, West Africa, Borneo and Sumatra.



10 million people

receive the equivalent of their
annual nutrition from crops
supported by pollinators sustained
by high-risk forests.



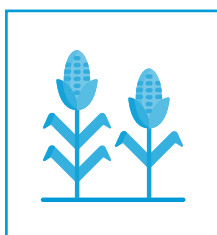
Key finding 3: Forests sustain livelihoods

06



Source: 2012 CIFOR /Olivier Girard

Forests provide essential resources and livelihoods for millions of people, particularly in developing regions.



Women, in particular, play a central role in forest-based livelihoods, often responsible for collecting fuelwood, water, and non-timber forest products for household use and income generation. Indigenous Peoples (IPs) are also central to these systems: their customary practices and ecological knowledge sustain diverse livelihood strategies that depend on forests for food, medicine, fibres, construction materials, and spiritual well-being. Beyond subsistence, both women and Indigenous communities generate cash incomes from non-timber forest products, sustainable timber, and eco-cultural tourism, while maintaining cultural traditions that reinforce sustainable use. However, forest loss, climate change, and lack of recognition of these contributions increasingly undermine these systems.

The report finds that forest resources are especially critical for forest-proximate populations, many of whom are vulnerable to economic and environmental shocks, since they are among the most materially poor⁴ with limited access to income, infrastructure, and services (Bailis et al., 2015; Shackleton & Pandey, 2014). Additionally, non-timber forest products (NTFPs), including fruits, nuts, medicinal plants, and fibres support both subsistence and market-driven incomes, underpinning rural economies.

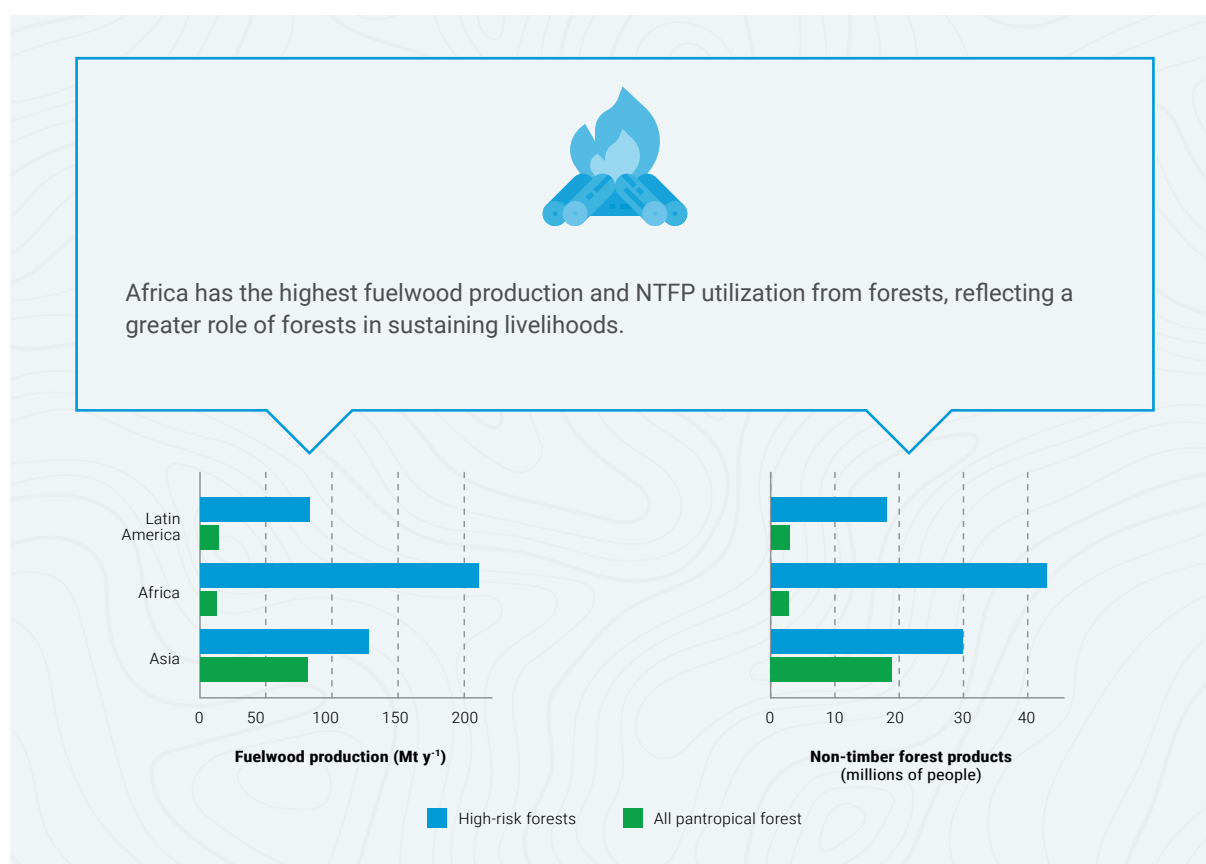
⁴ Below a poverty line of US\$ 2 per day.

In this context, two sets of forest contributions are especially important:

- Forests provide **fuelwood**, which remains the primary source of energy for cooking and heating in many rural areas. Conserving high-risk forests to achieve a 1 GtCO₂e annual emissions reduction target would secure annual sustainable supplies of approximately **111 million tonnes of fuelwood**, out of **423 million tonnes** provided by all pantropical forests⁵. This supports energy security among forest-proximate people, who are often among the most materially poor and reliant on biomass for daily cooking and heating needs. Yet these benefits also carry risks: unsustainable fuelwood harvesting can degrade forests, reduce biodiversity, and deepen poverty traps.
- Forests provide **non-timber forest products (NTFPs)** such as fruits, nuts, medicinal plants, fibres, and bushmeat, which are harvested for household use and local trade. These products provide seasonal income, nutritional diversity, and a safety net during times of economic or agricultural stress. The analysis shows that **25 million material-poor people** depend on NTFPs from these protected forests, out of **91 million material-poor people** across the pantropics who depend on NTFPs from forests.

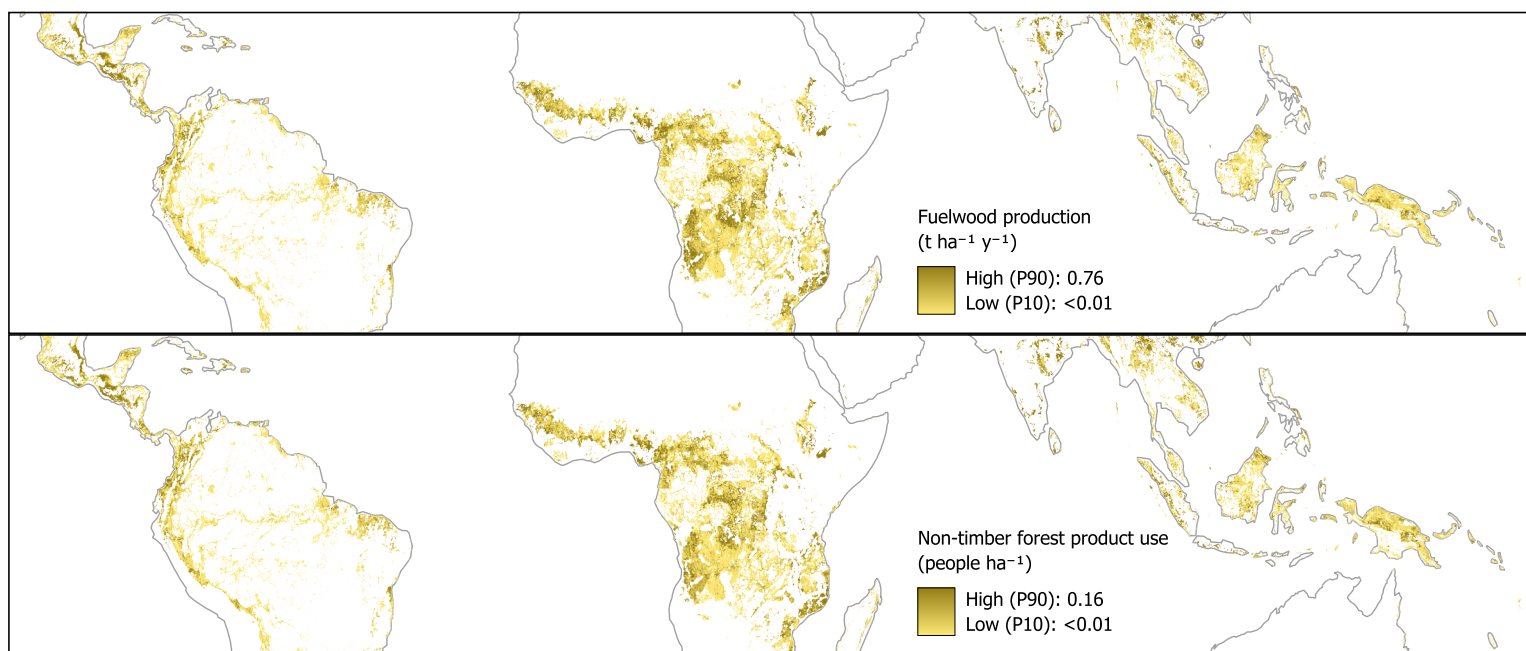
These co-benefits highlight the essential role of forest conservation in poverty alleviation, rural development, and the stabilization of livelihoods, aligning clearly with global development objectives and national policy priorities.

Figure 7. Total fuelwood production (Mt yr⁻¹) and number of people in millions utilizing non-timber forest products (NTFPs) for three pantropical regions.



⁵ Enough for approximately 6 million households under conservative, high-use assumptions, and up to 55 million households under typical household-use scenarios. For forest-proximate communities, this is core energy security.

Figure 8. Maps of fuelwood production (t ha⁻¹ yr⁻¹) and non-timber forest product (NTFP) reliance (people ha⁻¹). High provisioning generally reflects overlaps between forest areas and denser populations, with the largest spatial extents in Africa.



111 million tonnes

of fuelwood are used each year as the main source of cooking and heating energy for rural households.



25 million people

rely on forest products for food, medicine, and income.



Box 3. Nepal's Community Forestry Programme

Forests help sustain rural livelihoods through the provision of non-timber forest products (NTFPs) such as fruits, medicinal plants, and fibres, resources that are especially critical for poorer households. Nepal's Community Forestry Programme offers a notable example of how inclusive forest governance can strengthen both conservation and socioeconomic outcomes.

By 2009, 1.6 million Nepalese households participated in Community Forest User Groups (CFUGs), managing more than 1 million hectares of forest, which was more than a quarter of Nepal's forest area. Community forestry has helped reverse deforestation trends and improve forest conditions, while also delivering material benefits to local people. In longitudinal studies of the Koshi Hills, community forestry enhanced the supply of NTFPs, leading to a 61 per cent increase in annual income after 5 years and poverty reduction among Dalits and ethnic minorities (Ojha et al., 2009).

Notably, women's participation in CFUGs has been linked to improved forest governance and equitable benefit distribution. Gender quotas and leadership training have empowered women to take active roles in forest management, enhancing both conservation and social outcomes.

Beyond subsistence, community forests have become platforms for inclusive development, supporting local employment, small enterprises, and the empowerment of women and vulnerable groups. This model demonstrates how community-based forest management can align ecological stewardship with livelihood resilience.



In Nepal's Ilam District, community members harvest green tea. Nepal is among several Asia-Pacific countries receiving UN-REDD technical support to access results-based payments. Copyright: 2017 UNEP/Leona Liu

Key finding 4: Forests help strengthen climate adaptation

07



Source: 2023 Florian Füssstetter/UNEP

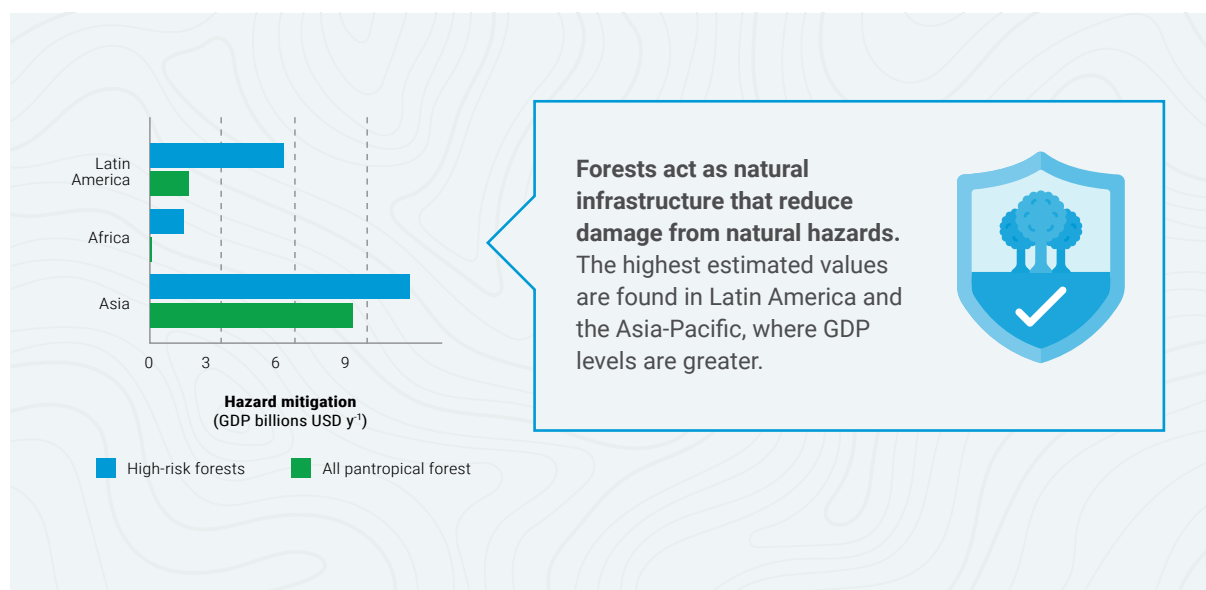
Protecting forests is also an investment in natural disaster risk reduction and climate adaptation.



Forests help stabilize soils and regulate runoff, which can significantly reduce the frequency and severity of floods and landslides in vulnerable areas (Bradshaw et al., 2007). In coastal zones, mangrove and peat swamp forests protect communities by dampening storm surges and coastal erosion. These protective services directly benefit millions of people living in climate-vulnerable areas. Forests reduce the risk of losing homes, crops, and critical infrastructure, especially for low-income and forest-proximate populations who often lack access to formal insurance or engineered defenses.

Protecting high-risk forests not only help to achieve the UN-REDD mitigation target but also enhances climate adaptation, protecting **US\$ 81 billion in annual GDP** by avoiding damage from natural hazards to infrastructure, homes, and agriculture. **Hazard mitigation services** provided by all pantropical forests amounts to a total of **US\$ 187 billion in annual GDP** (See Figure 9). Such protection underscores the role of forests as natural insurance for communities, a co-benefit that complements their carbon sequestration.

Figure 9. Hazard mitigation (GDP billions US\$ yr⁻¹) for three pantropical regions.



As mentioned in earlier sections, forests also support long-term adaptation by sustaining water availability, regulating local climates, and providing fallback resources such as food, fuelwood, and medicinal plants during times of crisis. For many rural and Indigenous communities, forests are a critical safety net that enhances their capacity to cope with and recover from climate shocks. Therefore, integrating forest conservation into climate adaptation strategies leverages these benefits to build resilience. In synergy with the Paris Agreement and the SDGs, forest-based solutions enhance not only mitigation but also the ability of societies to withstand and bounce back from climate extremes.

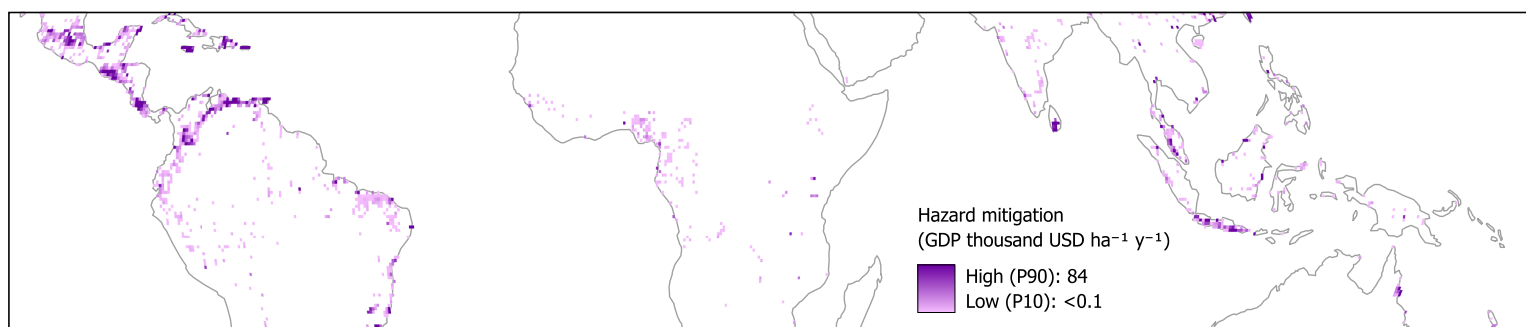
Box 4. Mangroves as coastal defences in India

Forests buffer communities from natural hazards by stabilizing slopes, reducing runoff, and mitigating floods, landslides, and storm surges. In coastal areas, mangrove forests provide a frontline defence against extreme weather, shielding lives and infrastructure from damage.

A notable example is found in India, where a super cyclone in 1999 caused over 10,000 fatalities across the region. In the Kendrapara district of Odisha, villages with intact mangrove belts experienced significantly fewer casualties than neighbouring settlements lacking such protection (Das & Vincent, 2009). The protective function of mangroves in dissipating wave energy and storm surges has since been quantified and widely cited in coastal planning and disaster risk reduction.

This case underscores that conserving coastal forests go beyond biodiversity and carbon objectives, saving lives and protecting communities during disasters. As climate extremes intensify, forests can provide natural insurance for the most vulnerable communities, reducing both human and economic losses.

Figure 10. Maps of hazard mitigation (GDP in thousands of US\$ ha⁻¹ yr⁻¹) provided by forests. Annual value of avoided natural hazard damages from forest cover, expressed in protected GDP. Map pixels resampled to 0.5o resolution to aid visualization. Areas proximate to human and urban economic activity exhibit particularly high levels of forest-based hazard mitigation.



US\$ 81 billion

in annual GDP is
protected by high-risk
forests from natural
hazards.



Conclusions and recommendations

08

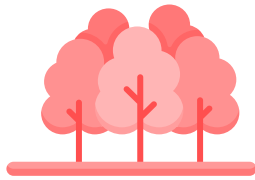


This report shows that the tropical forests most at risk of being lost, 391 million hectares across the pantropics, are also those most vital to people.

Protecting these high risk forests could prevent 1 GtCO₂e of emissions annually while simultaneously securing essential ecosystem services that underpin water quality, food security, rural livelihoods, and climate resilience. Together, these services underpin the well-being of millions of people, particularly the 53 million forest-proximate people who live closest to high-risk forests and depend most directly on them.

Overview

High-risk forests



391 million of the world's 1.6 billion hectares of tropical forests are at high risk of loss, and are among the most vital to people.



**10–14%
of rainfall**

recycled by forests keeps rivers flowing and water available for people, farms, and energy.



**10 million
people**

receive the equivalent of their annual nutrition from crops supported by pollinators sustained by high-risk forests.



**111 million
tonnes**

of fuelwood every year – plus fruits, nuts, fibers, and medicinal plants that millions depend on.



**US\$81
billion**

in annual GDP protected each year by high-risk forests from natural hazards.

High-value returns

53 million of the 215 million people living near tropical forests across the pantropics depend directly on forests at high risk of loss.



The analysis also suggests that realizing the co-benefits of forest protection requires deliberate, coordinated, and inclusive action. Current finance, planning, and policy frameworks often overlook the full range of forest co-benefits, leaving investments misaligned and communities underserved. This report provides the spatial evidence needed to close that gap, showing where protection would deliver the greatest combined returns for people, nature, and economies.

To unlock these benefits of tropical forests for climate and sustainable development goals, forest decision-makers and investors should:

- 1. Channel finance to high-risk forest areas.**

Direct public and private capital toward high-risk tropical forests that offer both high carbon mitigation and measurable co-benefits, such as water security, food production, and disaster risk reduction. These areas deliver outsized returns on investment for climate, people and economies. For example, these forests prevent 527 million tonnes of sediment from clogging rivers each year and retain nitrogen pollutants equivalent to Canada's annual fertilizer use. Targeting finance to these areas delivers outsized returns for water security, food production, and disaster risk reduction alongside carbon mitigation.

- 2. Use co-benefit data to de-risk and prioritize investments.**

Spatial metrics on nitrogen retention, rainfall recycling, pollination-supported nutrition, and hazard mitigation provide practical tools to identify priority areas. Integrating these into carbon project pipelines, investment screening tools and national forest strategies enables smarter targeting of resources and helps de-risk investments by aligning them with multiple development outcomes.

- 3. Incentivize forest stewardship by local communities.**

Forest-proximate communities, especially women and Indigenous Peoples, are central to forest protection yet often excluded from decision-making. Policymakers must secure land and resource rights, establish fair benefit-sharing mechanisms, and ensure gender-responsive governance. This matters because 25 million materially poor people depend directly on non-timber products and fuelwood from high-risk forests; without their participation, conservation cannot succeed.

- 4. Embed forests in climate strategies as well national development and resilience planning.**

Forests must be recognized as critical natural infrastructure for water, food, energy, and disaster resilience, not only as carbon sinks. National governments should integrate forest protection into climate strategies, adaptation plans, infrastructure development, and budget frameworks. Doing so avoids economic losses estimated at US\$ 81 billion annually from natural hazards, while strengthening long-term resilience and growth.

5. Strengthen forest data systems to improve monitoring, equity, and decision-making.

Protecting high-risk forests requires reliable, comparable, and regularly updated data on both carbon and co-benefits. Governments and partners must invest in strengthening forest monitoring systems, improving data quality, and ensuring comparability across regions so that analyses like this report can be repeated over time rather than remaining one-off exercises. Within these systems, gender-responsive approaches are essential: sex-disaggregated data and gender indicators should be integrated to capture the specific roles, needs, and vulnerabilities of women and men. National monitoring frameworks must also support inclusive governance, guaranteeing participation and leadership of women, Indigenous Peoples, and vulnerable groups. This combination of robust technical data and socially inclusive metrics ensures forest protection delivers effective, equitable, and sustainable outcomes.

Moving forward

The findings also show that that co-benefits are not always synergistic. Trade-offs may arise between carbon, water, food, and livelihood outcomes, particularly in areas facing competing land-use demands. Recognizing and managing these trade-offs requires inclusive planning that integrates local knowledge, addresses gender inequalities, and recognizes the leadership of Indigenous Peoples and local communities.

Protecting high-risk forests is therefore both a global and local priority. It is central to achieving international climate goals while directly supporting the daily needs and resilience of millions of people. With the right policies and investments, guided by spatial evidence and grounded in equity, countries can achieve large-scale climate mitigation while protecting the ecosystems and communities that depend most on them.



References

09

- A** Abrol, D.P. (2012). *The Role of Pollination in Improving Food Security and Livelihoods*. In D. P. Abrol (Ed.), *Pollination Biology: Biodiversity Conservation and Agricultural Production* (pp. 737–770). Springer Netherlands. Available from: https://doi.org/10.1007/978-94-007-1942-2_22. [Accessed on 30 August 2025].
- Avitabile, V., Herold, M., Heuvelink, G.B.M., Lewis, S.L., Phillips, O.L., Asner, G.P., Armston, J., Ashton, P.S., Banin, L., Bayol, N., Berry, N.J., Boeckx, P., de Jong, B.H.J., DeVries, B., Girardin, C.A.J., Kearsley, E., Lindsell, J.A., Lopez-Gonzalez, G., Lucas, R. and Willcock, S. (2016). *An integrated pan-tropical biomass map using multiple reference datasets*. *Global Change Biology*, 22(4), 1406–1420. Available from: <https://doi.org/10.1111/gcb.13139>. [Accessed on 30 August 2025].
- B** Bailis, R., Drigo, R., Ghilardi, A. and Masera, O. (2015). *The carbon footprint of traditional woodfuels*. *Nature Climate Change*, 5(3), 266–272. Available from: <https://doi.org/10.1038/nclimate2491>. [Accessed on 30 August 2025].
- Boers, N., Marwan, N., Barbosa, H.M.J. and Kurths, J. (2017). *A deforestation-induced tipping point for the South American monsoon system*. *Scientific Reports*, 7(1), 41489. Available from: <https://doi.org/10.1038/srep41489>. [Accessed on 30 August 2025].
- Bradshaw, C.J.A., Sodhi, N.S., Peh, K.S.H. and Brook, B.W. (2007). *Global evidence that deforestation amplifies flood risk and severity in the developing world*. *Global Change Biology*, 13(11), 2379–2395. Available from: <https://doi.org/10.1111/j.1365-2486.2007.01446.x>. [Accessed on 30 August 2025].
- C** Chaplin-Kramer, R., Neugarten, R.A., Sharp, R.P., Collins, P.M., Polasky, S., Hole, D., Schuster, R., Strimas-Mackey, M., Mulligan, M., Brandon, C., Diaz, S., Fluet-Chouinard, E., Gorenflo, L.J., Johnson, J.A., Kennedy, C.M., Keys, P.W., Longley-Wood, K., McIntyre, P.B., Noon, M. and Watson, R.A. (2023). *Mapping the planet's critical natural assets*. *Nature Ecology & Evolution*, 7(1), 51–61. Available from: <https://doi.org/10.1038/s41559-022-01934-5>. [Accessed on 30 August 2025].
- Conley, D.J., Paerl, H.W., Howarth, R.W., Boesch, D.F., Seitzinger, S.P., Havens, K.E., Lancelot, C. and Likens, G.E. (2009). *Controlling Eutrophication: Nitrogen and Phosphorus*. *Science*, 323(5917), 1014–1015. Available from: <https://doi.org/10.1126/science.1167755>. [Accessed on 30 August 2025].
- Curtis, P.G., Slay, C.M., Harris, N.L., Tyukavina, A. and Hansen, M.C. (2018). *Classifying drivers of global forest loss*. *Science*, 361(6407), 1108–1111. Available from: <https://doi.org/10.1126/science.aau3445>. [Accessed on 30 August 2025].
- D** Das, S. and Vincent, J.R. (2009). *Mangroves protected villages and reduced death toll during Indian super cyclone*. *Proceedings of the National Academy of Sciences*, 106(18), 7357–7360. Available from: <https://doi.org/10.1073/pnas.0810440106>. [Accessed on 30 August 2025].
- Defourny, P., Lamarche, C., Brockmann, C., Boettcher, M., Bontemps, S., De Maet, T., Duveiller, G.L., Harper, K., Hartley, A., Kirches, G., Moreau, I., Peylin, P., Ottlé, C., Radoux, J., Van Bogaert, E., Ramoino, F., Albergel, C. and Arino, O. (2023). *Observed annual global land-use change from 1992 to 2020 three times more dynamic than reported by inventory-based statistics*. In Preparation.
- E** Ellison, D., Morris, C.E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., Gutierrez, V., Noordwijk, M.van., Creed, I.F., Pokorny, J., Gaveau, D., Spracklen, D.V., Tobella, A.B., Ilstedt, U., Teuling, A.J., Gebrehiwot, S.G., Sands, D.C., Muys, B., Verbist, B. and Sullivan, C.A. (2017). *Trees, forests and water: Cool insights for a hot world*. *Global Environmental Change*, 43, 51–61. Available from: <https://doi.org/10.1016/j.gloenvcha.2017.01.002>. [Accessed on 30 August 2025].
- Elvidge, C.D., Sutton, P.C., Ghosh, T., Tuttle, B.T., Baugh, K.E., Bhaduri, B. and Bright, E. (2009). *A global poverty map derived from satellite data*. *Computers & Geosciences*, 35(8), 1652–1660. Available from: <https://doi.org/10.1016/j.cageo.2009.01.009>. [Accessed on 30 August 2025].

- F** Feng, Y., Zeng, Z., Searchinger, T.D., Ziegler, A.D., Wu, J., Wang, D., He, X., Elsen, P.R., Ciais, P., Xu, R., Guo, Z., Peng, L., Tao, Y., Spracklen, D.V., Holden, J., Liu, X., Zheng, Y., Xu, P., Chen, J. and Zheng, C. (2022). *Doubling of annual forest carbon loss over the tropics during the early twenty-first century*. Nature Sustainability, 5(5), 444–451. Available from: <https://doi.org/10.1038/s41893-022-00854-3>. [Accessed on 30 August 2025].
- H** Hewson, J., Crema, S.C., González-Roglich, M., Tabor, K. and Harvey, C.A. (2019). *New 1 km Resolution Datasets of Global and Regional Risks of Tree Cover Loss*. Land, 8(1), Article 1. Available from: <https://doi.org/10.3390/land8010014>. [Accessed on 30 August 2025].
- I** IPBES. (2024). *Summary for Policymakers of the Thematic Assessment Report on the Interlinkages among Biodiversity, Water, Food and Health of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. IPBES secretariat. Available from: <https://doi.org/10.5281/zenodo.13850289>. [Accessed on 30 August 2025].
- J** Jones, J., Ellison, D., Ferraz, S., Lara, A., Wei, X. and Zhang, Z. (2022). *Forest restoration and hydrology*. Forest Ecology and Management, 520, 120342. Available from: <https://doi.org/10.1016/j.foreco.2022.120342>. [Accessed on 30 August 2025].
- K** Keys, P.W., Wang-Erlandsson, L. and Gordon, L.J. (2016). *Revealing Invisible Water: Moisture Recycling as an Ecosystem Service*. PLOS ONE, 11(3), e0151993. Available from: <https://doi.org/10.1371/journal.pone.0151993>. [Accessed on 30 August 2025].
- Koh, L.P., Zeng, Y., Sarira, T.V. and Siman, K. (2021). *Carbon prospecting in tropical forests for climate change mitigation*. Nature Communications, 12(1), 1271. Available from: <https://doi.org/10.1038/s41467-021-21560-2>. [Accessed on 30 August 2025].
- L** Laso Bayas, J.C., See, L., Georgieva, I., Schepaschenko, D., Danylo, O., Dürauer, M., Bartl, H., Hoffhansl, F., Zadorozhniuk, R., Burianchuk, M., Sirbu, F., Magori, B., Blyshchyk, K., Blyshchyk, V., Rabia, A.H., Pawe, C.K., Su, Y.F., Ahmed, M., Panging, K. and Fritz, S. (2022). *Drivers of tropical forest loss between 2008 and 2019*. Scientific Data, 9(1), 146. Available from: <https://doi.org/10.1038/s41597-022-01227-3>. [Accessed on 30 August 2025].
- Lovejoy, T.E. and Nobre, C. (2018). *Amazon Tipping Point*. Science Advances, 4(2), eaat2340. Available from: <https://doi.org/10.1126/sciadv.aat2340>. [Accessed on 30 August 2025].
- Ludemann, C.I., Gruere, A., Heffer, P. and Dobermann, A. (2022). *Global data on fertilizer use by crop and by country*. Scientific Data, 9(1), 501. Available from: <https://doi.org/10.1038/s41597-022-01592-z>. [Accessed on 30 August 2025].
- M** Meng, X., Qian, N. and Yared, P. (2015). *The Institutional Causes of China's Great Famine, 1959–1961*. The Review of Economic Studies, 82(4), 1568–1611. Available from: <https://doi.org/10.1093/restud/rdv016>. [Accessed on 30 August 2025].
- Mokany, K., Raison, R.J. and Prokushkin, A.S. (2006). *Critical analysis of root: Shoot ratios in terrestrial biomes*. Global Change Biology, 12(1), 84–96. Available from: <https://doi.org/10.1111/j.1365-2486.2005.001043.x>. [Accessed on 30 August 2025].
- Mulligan, M., van Soesbergen, A., Hole, D.G., Brooks, T.M., Burke, S. and Hutton, J. (2020). *Mapping nature's contribution to SDG 6 and implications for other SDGs at policy relevant scales*. Remote Sensing of Environment, 239, 111671. Available from: <https://doi.org/10.1016/j.rse.2020.111671>. [Accessed on 30 August 2025].
- N** Natural Capital Project. (2025). *InVEST 3.16.0a1* [Dataset]. Available from: <https://doi.org/10.60793/natcap-invest-3.16.0>. [Accessed on 30 August 2025].
- Neugarten, R.A., Chaplin-Kramer, R., Sharp, R.P., Schuster, R., Strimas-Mackey, M., Roehrdanz, P.R., Mulligan, M., van Soesbergen, A., Hole, D., Kennedy, C.M., Oakleaf, J.R., Johnson, J.A., Kiesecker, J., Polasky, S., Hanson, J.O. and Rodewald, A.D. (2024). *Mapping the planet's critical areas for biodiversity and nature's contributions to people*. Nature Communications, 15(1), 261. Available from: <https://doi.org/10.1038/s41467-023-43832-9>. [Accessed on 30 August 2025].
- Newton, P., Kinzer, A.T., Miller, D.C., Oldekop, J.A. and Agrawal, A. (2020). *The Number and Spatial Distribution of Forest-Proximate People Globally*. One Earth, 3(3), 363–370. Available from: <https://doi.org/10.1016/j.oneear.2020.08.016>. [Accessed on 30 August 2025].
- O** OECD. (2006). *Chapter 15 Energy for Cooking in Developing Countries*. In World Energy Outlook 2006. Available from: https://www.oecd.org/en/publications/world-energy-outlook-2006_weo-2006-en.html. [Accessed on 30 August 2025].

- Ojha, H., Persha, L. and Chhatre, A. (2009). *Community forestry in Nepal: A policy innovation for local livelihoods* (No. 913; IFPRI Discussion Paper). International Food Policy Research Institute. Available from: <https://hdl.handle.net/10568/161840>. [Accessed on 30 August 2025].
- Pan, Y., Birdsey, R.A., Phillips, O.L., Houghton, R.A., Fang, J., Kauppi, P.E., Keith, H., Kurz, W.A., Ito, A., Lewis, S.L., Nabuurs, G.J., Shvidenko, A., Hashimoto, S., Lerink, B., Schepaschenko, D., Castanho, A. and Murdiyarso, D. (2024). *The enduring world forest carbon sink*. *Nature*, 631(8021), 563–569. Available from: <https://doi.org/10.1038/s41586-024-07602-x>. [Accessed on 30 August 2025].
- P** Panagos, P., Van Liedekerke, M., Borrelli, P., Köninger, J., Ballabio, C., Orgiazzi, A., Lugato, E., Liakos, L., Hervás, J., Jones, A. and Montanarella, L. (2022). *European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies*. *European Journal of Soil Science*, 73(6), e13315. Available from: <https://doi.org/10.1111/ejss.13315>. [Accessed on 30 August 2025].
- R** Ricketts, T.H., Daily, G.C., Ehrlich, P.R. and Michener, C.D. (2004). *Economic value of tropical forest to coffee production*. *Proceedings of the National Academy of Sciences*, 101(34), 12579–12582. Available from: <https://doi.org/10.1073/pnas.0405147101>. [Accessed on 30 August 2025].
- S** Sampaio, G., Nobre, C., Costa, M.H., Satyamurty, P., Soares-Filho, B.S. and Cardoso, M. (2007). *Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion*. *Geophysical Research Letters*, 34(17). Available from: <https://doi.org/10.1029/2007GL030612>. [Accessed on 30 August 2025].
- Shackleton, C.M. and de Vos, A. (2022). *How many people globally actually use non-timber forest products?* *Forest Policy and Economics*, 135, 102659. Available from: <https://doi.org/10.1016/j.forpol.2021.102659>. [Accessed on 30 August 2025].
- Shackleton, C.M. and Pandey, A.K. (2014). *Positioning non-timber forest products on the development agenda*. *Forest Policy and Economics*, 38, 1–7. Available from: <https://doi.org/10.1016/j.forpol.2013.07.004>. [Accessed on 30 August 2025].
- Siopa, C., Carvalheiro, L.G., Castro, H., Loureiro, J. and Castro, S. (2024). *Animal-pollinated crops and cultivars—A quantitative assessment of pollinator dependence values and evaluation of methodological approaches*. *Journal of Applied Ecology*, 61(6), 1279–1288. Available from: <https://doi.org/10.1111/1365-2664.14634>. [Accessed on 30 August 2025].
- Smith, C., Baker, J.C.A. and Spracklen, D.V. (2023). *Tropical deforestation causes large reductions in observed precipitation*. *Nature*, 615(7951), 270–275. Available from: <https://doi.org/10.1038/s41586-022-05690-1>. [Accessed on 30 August 2025].
- Sudmeier-Rieux, K., Arce-Mojica, T., Boehmer, H.J., Doswald, N., Emerton, L., Friess, D.A., Galvin, S., Hagenlocher, M., James, H., Laban, P., Lacambra, C., Lange, W., McAdoo, B.G., Moos, C., Mysiak, J., Narvaez, L., Nehren, U., Peduzzi, P., Renaud, F.G. and Walz, Y. (2021). *Scientific evidence for ecosystem-based disaster risk reduction*. *Nature Sustainability*, 4(9), 803–810. Available from: <https://doi.org/10.1038/s41893-021-00732-4>. [Accessed on 30 August 2025].
- T** Teo, H.C., Raghavan, S.V., He, X., Zeng, Z., Cheng, Y., Luo, X., Lechner, A.M., Ashfold, M.J., Lamba, A., Sreekar, R., Zheng, Q., Chen, A. and Koh, L.P. (2022). *Large-scale reforestation can increase water yield and reduce drought risk for water-insecure regions in the Asia-Pacific*. *Global Change Biology*, 28(21), 6385–6403. Available from: <https://doi.org/10.1111/gcb.16404>. [Accessed on 30 August 2025].
- U** UNEP. (2024). *Raising ambition, accelerating action: Towards enhanced Nationally Determined Contributions for forests*. Available from: <https://www.un-redd.org/document-library/raising-ambition-accelerating-action-to-wards-enhanced-nationally-determined>. [Accessed on 30 August 2025].
- V** VCS. (2017). *Agriculture, Forestry and Other Land Use (AFOLU) Requirements—VCS Version 3 Rules and Requirements*. Available from: <https://verra.org/programs/verified-carbon-standard/vcs-version-3-rules-and-requirements/>. [Accessed on 30 August 2025].
- W** Walker, R.T., Simmons, C., Arima, E., Galvan-Miyoshi, Y., Antunes, A., Waylen, M. and Irigaray, M. (2019). *Avoiding Amazonian Catastrophes: Prospects for Conservation in the 21st Century*. *One Earth*, 1(2), 202–215. Available from: <https://doi.org/10.1016/j.oneear.2019.09.009>. [Accessed on 30 August 2025].

Annex: Methodology

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This study quantified key co-benefits of protecting forests equivalent to 1 GtCO₂e yr⁻¹ of avoided emissions. A pantropical forest mask was first constructed, corresponding to forest areas which generate 1 GtCO₂e yr⁻¹ of avoided emissions when protected, then overlaid with a suite of spatial layers representing water-quality regulation, water availability, food security, economic provisioning through supported livelihoods, and climate adaptation through hazard mitigation.

Annex 1: Forest climate mitigation

A 1 GtCO₂e yr⁻¹ pantropical forest mask was derived by prioritizing tropical forests with the highest per-ha volume of carbon facing deforestation risk (Koh et al., 2021). All types of tropical forests, as defined by the European Space Agency Climate Change Initiative (ESA-CCI) land cover dataset, between 23.44°N and 23.44°S were included (Defourny et al., 2023). Investible forest carbon is the volume of forest carbon stock facing deforestation risk and hence fulfilling additionality criteria, with deductions made for permanence and leakage (Koh et al., 2021). These can represent priority candidates for REDD+, since protecting these forests can generate additional emissions reduction, which allow for the possibility of generating carbon credits and other financial incentives for host nations.

Established carbon accounting methodology was used to derive the corresponding forest carbon, following Koh et al. (2021). Aboveground biomass was first extracted from recent spatial data on aboveground biomass representing 2012-2016 (Avitabile et al., 2016). Belowground biomass was derived by applying two different allometric equations relating root to shoot biomass (Mokany et al., 2006) to the aboveground biomass map (Avitabile et al., 2016): belowground biomass = $0.489 \times \text{aboveground biomass}^{0.89}$; and belowground biomass = $0.26 \times \text{aboveground biomass}$. Aboveground and belowground biomass was converted to carbon values by applying a stoichiometric factor of 0.475 followed by a conversion factor of 3.67 to derive CO₂e values. Soil organic carbon was represented by the soil organic carbon density of the topsoil layer (0–30 cm) obtained from the European Soil Data Centre (Panagos et al., 2022). The aboveground carbon pool was assumed to be emitted in the same year it was deforested, while a conservative 10-year decay estimate was assumed for the belowground carbon pool.

Additionality criteria to reflect avoided deforestation emissions was imposed by determining only the volume of forest carbon under threat of loss based on best available proxy data on projected future deforestation rates across the tropics (through to the year 2029) (Hewson et al., 2019), and annualized over the prediction period (15 years). A 20 per cent buffer pool deduction for leakage and non-permanence was then made, in line with Voluntary Carbon Standard (VCS) criteria (VCS, 2017).

The forest mask was processed at 0.00833 degrees (~1 km) spatial resolution, with the final output resolution at 5 arc-min (~10 km).

Finally, to illustrate the number of people whose livelihoods and well-being are potentially supported by forests, spatially modelled estimates of forest-proximate people living within 5 km of forests were extracted from Newton et al. (2020), and overlaid against the 1 GtCO₂e yr⁻¹ pantropical forest mask and the full pantropical forest extent.

Annex 2: Co-benefit layers

The 7 co-benefits layers were selected across four main themes; water, food, livelihoods, and climate adaptation (Table 1).

Table 1. Co-benefit layers used in this study.

No.	Layer	Source	Units	Output resolution
Water regulation				
1	Nitrogen retention	InVEST, Chaplin-Kramer et al. (2023)	kg nitrogen retained	10 arc-sec (~300 m)
2	Sediment retention	InVEST, Chaplin-Kramer et al. (2023)	tonnes sediment retained	10 arc-sec (~300 m)
3	Moisture recycling	Keys et al. (2016)	Fraction of evapotranspiration from vegetation that is providing precipitation to land	1.5 degrees
Food security				
4	Pollination-supported nutrition	InVEST, Chaplin-Kramer et al. (2023)	"People fed equivalents"; average of pollination-derived energy (KJ), folate, and vitamin A production divided by annual dietary requirements per capita	1.5 arc-min (~2.4 km)
Livelihoods				
5	Non-timber forest products	Co\$ting Nature v3, Mulligan et al. (2020)	Number of local material-poor people accessing non-wood forest products	5 arc-min (~10 km)
6	Fuelwood	Co\$ting Nature v3, Mulligan et al. (2020)	tonnes y-1 of sustainable fuelwood consumption by local people	5 arc-min (~10 km)
Climate adaptation				
7	GDP benefitting from hazard mitigation	Co\$ting Nature v3, Mulligan et al. (2020)	GDP \$ y-1 benefitting from nature-mitigated hazard(s)	5 arc-min (~10 km)

All co-benefits layers were initially modelled at the native spatial resolutions of core spatial datasets used. Layers using the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) and Co\$tingNature models used ESA-CCI land cover data at 300 m spatial resolution as input. Only the moisture recycling dataset used climatological data at a coarser 0.5 degree resolution. Spatial resolutions of the model outputs depend on the model used and are indicated in Table 1. Where necessary, finer-scale layers were resampled by sum or mean aggregation (as appropriate) to 5 arc-min (~10 km) before masking with the forest mask to derive the corresponding co-benefits from achieving the forest protection target.

A summary of the methods used to generate each layer is provided below.

Water regulation

1. Nitrogen retention for downstream populations (kgN y⁻¹). Forests help to regulate water quality for downstream populations by retaining pollutants, such as nitrogen from fertiliser runoff. Nitrogen retention was modelled as the difference between nitrogen load and nutrient delivery, using the InVEST Nutrient Delivery Ratio model (Natural Capital Project, 2025) which is based on fertiliser application, precipitation, topography and the retention capacity of vegetation.
2. Sediment retention for downstream populations (tonnes y⁻¹). Sediment in waterways decreases water quality, can clog waterways, or carry water-borne illnesses, but forests can reduce erosion and thus sediment load. Sediment retention was modelled as the difference in sediment load between any given pixel and its downstream pixel, using the InVEST Sediment Delivery Ratio model (Natural Capital Project, 2025) which calculates soil loss per pixel per year that reaches waterways.
3. Moisture recycling (ratio, %). Vegetation-regulated moisture recycling refers to water that evaporates from vegetated land covers and subsequently returns as terrestrial rainfall, playing a critical role in sustaining ecosystems, replenishing groundwater, and supporting agriculture, industrial, and domestic water use. The Simple Terrestrial Evaporation to Atmosphere Model (STEAM) was first used to partition evaporation fluxes by source. The Water Accounting Model-2layers (WAM-2layers) was then used to track the atmospheric transport and redistribution of this moisture to determine the proportion that returns as precipitation. Current vegetated land cover was compared against a hypothetical desert scenario to quantify moisture recycling as the ratio of moisture recycled under current conditions versus the desert scenario.

Food security

4. Pollination-supported nutrition (number of people). Forests can support wild pollinators that are crucial for crop pollination, thus supporting human nutritional needs. Pollination-supported nutrition measures the number of people fed by pollination-dependent crops and is attributed to ecosystems within pollinator flying distance to croplands. Farmlands were designated as natural pollination-dependent if surrounded by at least 30% natural habitat within 2 km. Crop production reliant on pollination was modelled using InVEST (Natural Capital Project, 2025), calculating the nutritional output (energy, folate, vitamin A) and dividing by individual nutritional needs to derive the number of beneficiaries, which was mapped to surrounding natural habitats.

Livelihoods

5. Non-timber forest products (number of materially poor people). NTFPs refer to a broad range of biological resources harvested from forests such as fruits, fungi, medicinal plants, and wild animals, excluding timber and fuelwood. These products are critical for subsistence, particularly among materially poor populations living in rural areas with limited access to income, infrastructure, and services. In this analysis, dependence on NTFPs is estimated as the product of fractional tree cover in rural areas and the normalised population in poverty, defined as those living on \$2 per day or less (Elvidge et al., 2009), as per the Co\$tingNature model version 3. This is based on the assumption that reliance on forest resources increases with poverty; individuals in these areas are more likely to meet daily needs through direct forest use, making them disproportionately vulnerable to forest degradation and loss.
6. Fuelwood (tonnes y⁻¹). Fuelwood is essential for heating and cooking, particularly in rural communities. Sustainable fuelwood availability was derived by multiplying carbon stock by fractional tree cover, then taking the reciprocal of the number of years required to develop that stock at the annual dry matter productivity rate, and finally applying accessibility constraints by linearly scaling slope gradient and rural population density. Per-capita annual demand was represented by a coefficient from OECD (2006), as implemented in the Co\$tingNature model version 3.

Climate adaptation

7. GDP benefitting from hazard mitigation (GDP \$ y⁻¹). Forests reduce risks associated with natural hazards. Hazard mitigation benefits were quantified for landslide/erosion control, coastal protection, flood storage/mitigation, and flow regulation as a function of ecosystem characteristics, such as tree cover and protected areas upstream, using the Co\$tingNature model version 3. GDP per year at risk of damage downstream and nearby reflect hazard exposure and were thus used to quantify risk mitigation benefits provided by ecosystems.



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