



## More Than a Forest: Counting the Carbon in India's Eastern Hills

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### INTRODUCTION

A tree is made mostly of carbon absorbed from the air. About half of its dry weight is carbon, allowing foresters to estimate carbon content by simply halving the biomass. This means a hectare of forest is essentially a hectare of stored atmosphere. However, the trunk is just the most obvious place carbon ends up. Forests store carbon in five main forms: living wood above ground, roots below ground, dead wood, leaf litter, and soil.

What's surprising is just how much carbon is hidden away in the soil. According to the 2023 India State of Forest Report, soil organic carbon makes up the largest share in Indian forests; about 55 percent. Above-ground biomass accounts for roughly 33 percent, roots about 10 percent, and leaf litter and dead wood combined less than 3 percent. While these numbers are for all of India, studies in the North-East show a similar trend. For example, in Assam's Barak Valley, researchers found that four dipterocarp forests stored about 142 tonnes of carbon per hectare in trees and 118 tonnes in the soil, meaning the ground holds nearly as much as the treetops. Soil carbon is the silent majority, but it's also the part we measure least accurately and can disturb most easily.

### A bank balance and a salary:

Trees pull most of their substance from the air, with about half their dry weight made up of carbon. That's why foresters often estimate a forest's carbon by halving the biomass. In this way, every hectare of forest becomes a kind of bank for the atmosphere. But the trunk isn't the only place carbon is stored. Carbon also fills five different reservoirs in a forest: wood above ground, roots below, dead wood, fallen leaves, and the soil itself.

What's truly remarkable is how much carbon lies hidden in the soil. The 2023 India State of Forest Report notes that about 55 percent of the carbon in Indian forests is found underground as soil organic carbon. Above-ground trees account for around 33 percent, roots for about 10 percent, and less than 3 percent is in fallen leaves and dead wood. These figures represent the national average, but studies from the North-East tell a similar story. In Assam's Barak Valley, for example, researchers discovered that four dipterocarp forests stored roughly 142 tonnes of carbon per hectare in the trees and about 118 tonnes in the soil; so the earth beneath is almost as rich in carbon as the trees themselves. Soil carbon quietly dominates the total, yet it's the part we understand and protect the least.

### Why this corner of India?

According to the Forest Survey's satellite maps, forests and trees cover about 67 percent of the North-East's landscape; an area of nearly 174,000 square kilometres. Six out of the eight states and union territories in India with over 75 percent forest cover are found here: Mizoram, Arunachal Pradesh, Nagaland, Meghalaya, Tripura, and Manipur. Arunachal Pradesh stands out, holding the country's highest forest carbon stock at around 1,021 million tonnes; about one-seventh of India's total.

However, the North-East isn't a single, uniform forest; it's more like a staircase, rising from subtropical river plains to evergreen and semi-evergreen hills, then up to temperate and high-altitude woods. The landscape is dotted with bamboo thickets, shifting cultivation fallows, village groves, tea and rubber estates, home gardens, and plantations. Most of this land belongs to local communities, clans, or councils; not the government; so decisions about carbon storage and land use are shaped by local hands. The region also borders two global biodiversity hotspots, so choices made here always come with trade-offs that go beyond just carbon. It's important to pause for a word of caution. Maps that show forest cover are measuring only the canopy, and that doesn't reveal whether what's underneath is untouched

forest, plantation, or cleared land regrowing. A place might appear "67 percent green" but still be losing its oldest, densest forests; the ones that store the most carbon. So the real question isn't just how much green there is, but what kind, and how old that green really is.

### How much, really?

The numbers, once you start collecting them, come in a bewildering spread. Some of the more careful regional studies give a sense of the range. A large study involving several institutions (Sahoo et al., 2021) found that, on average, living plants in the region hold about 105 tonnes of carbon per hectare in tropical forests, 106 in subtropical forests, and 122 in temperate forests. Looking at the soil down to 45 centimetres, the same research found roughly 73 tonnes of carbon per hectare in tropical forests, 63 in temperate, and 43 in subtropical forests. While these are general averages, what's most striking is that the differences within a single type of forest; depending on how it's managed or disturbed; are often greater than the differences between forest types.

Here are two examples that highlight this variation. In Meghalaya, researchers looked at three types of community-managed montane forests (Mir et al., 2021) and found that sacred forests had above-ground biomass of 273 tonnes per hectare, restricted forests had 195, and village forests had just 75; more than a threefold difference in forests on the same hillside and under the same climate. The authors suggest this gap is linked to how much people disturb these forests. Over in Arunachal Pradesh, another assessment (Das et al., 2021) reported above-ground biomass of about 332 tonnes per hectare in dense forests, 247 in moderately dense forests, and 145 in open forests. This number drops sharply in young jhum fallows (55 tonnes) and even further in freshly cleared jhum fields (less than 17 tonnes). (These numbers refer to dry plant matter or biomass, not carbon. To estimate carbon, halve the biomass figure, and to get the carbon dioxide equivalent, multiply the carbon by about 3.67.)

Why are these estimates sometimes so different? For one, researchers often measure different things: some focus on biomass, others on carbon, some look at just the trees, while others include the whole ecosystem; and the depth of soil measured might be 45 centimetres or a full metre. The forest plots studied are often small, and the forests themselves can be patchy. Plus, the formulas used to turn a tree's girth into its weight were sometimes designed for forests in other parts of the world. Even satellites can't always tell the difference between a dense forest and an even denser one. So, a "carbon per hectare" number that doesn't come with details about how it was calculated is more like a rough story than a reliable measurement.

This is the less explored side of the story. We have a decent understanding of carbon stocks in the region, but annual sequestration rates are much less thoroughly studied. For example, research on dipterocarp forests in Manipur found that the main tree species absorb about 1.5 to 4.6 tonnes of carbon per hectare per year. Another study at a bamboo research center in Mizoram (Devi and Singh, 2021) reported above-ground carbon gains of roughly 15 and 28 tonnes per hectare per year for two bamboo species. These numbers sound impressive, but the study only looked at one site, over two years, focused on above-ground growth, and involved managed bamboo rather than wild forest. Across the region, we still lack long-term, large-scale studies that measure net annual carbon uptake; the kind that truly reveal whether forests are gaining or losing carbon after accounting for respiration, decay, and disturbance. This doesn't mean the forests aren't valuable, but it does mean we should be cautious about claiming they "sequester" a specific number of tonnes each year.

### When the sink leaks

Satellite data offers the most visible evidence of stress in the region's forests. According to an analysis of ISFR data, the North-Eastern states lost around 3,877 square kilometres of forest cover between 2013 and 2023, with about 327

square kilometres lost from 2021 to 2023 alone. Over the past decade, Nagaland lost 794 square kilometres; about 6 percent of its total forest area. Mizoram stands out as an exception, having gained forest cover in the most recent survey. While these figures measure tree cover, not actual carbon, losing dense forest means losing a significant carbon store; and the young growth that replaces it will take decades to recover that loss.

**Fire** is a seasonal risk in the North-East. Most blazes happen during the dry spell from January to May. Over fifteen years (2006–2020), satellite data picked up an average of about 65,000 fires in March and April across this region and neighboring areas. In Meghalaya, state data show that about half the forest area is highly fire-prone, with denser forests experiencing more fires no matter their type. A study from Mizoram links shifting cultivation closely with forest fires. But there's a gap in the research: we still don't have clear answers about how much carbon these fires release, how much vegetation is only scorched, or how quickly the land recovers after burning. Most fire studies here focus on air quality rather than tracking what happens to the carbon.

**Shifting cultivation** is a hotly debated issue, and it's often oversimplified by both critics and defenders. Clearing old forest for jhum comes at a high price: according to the Arunachal study, it results in the loss of about 84 percent of above-ground carbon. In Mizoram, research found that soil carbon dropped most rapidly after forests were turned into shifting cultivation plots; by about 5.7 tonnes per hectare each year; faster than when forests were converted to oil palm, bamboo plantations, or home gardens.

But jhum isn't a one-time event; it's a repeating cycle, and how well the land bounces back depends on how long it's left fallow. In Nagaland, researchers (Borah et al., 2018) found that after 30 years of fallow, the land stores about half as much above-ground carbon as untouched forest, with the length of the fallow period being the key factor in recovery. In the Dampa Tiger Reserve in Mizoram, the

oldest fallow plots had about a third of the ecosystem's total carbon compared to old-growth forest, but they retained 62 percent of their soil carbon; showing that the soil can recover faster than the whole forest system. The team in Nagaland came to a tough but practical conclusion: to protect carbon, it's best to leave old-growth forests alone and focus on making farming more efficient on land that's already cleared. Another study (Borah and Gilroy, 2022) also found that low-intensity shifting cultivation can help support bird life by creating a patchwork of habitats. So, the impact of jhum on carbon isn't a judgment on the practice itself; it really depends on how short the fallow periods have become, whether new fields are being carved out of old forest, and what other options farmers have.

### Rebuilding the sink

If forests lose carbon faster than they can recover it, restoration might seem like the obvious solution; and it does play an important role. Still, this is an area where misunderstandings often arise. The facts about plantations in the region are mixed. A broad study found that subtropical plantations stored about 115 tonnes of carbon per hectare; slightly more than the 106 in subtropical forests. Tropical plantations had around 93 tonnes, while natural tropical forests had 105, and temperate plantations stored just 50 tonnes compared to 122 in temperate forests. In West Kameng, Arunachal Pradesh, mixed dense forests stored about 120 tonnes per hectare, far higher than the 58 in plantations there. The same research found that converting farmland to agroforestry or grassland to plantations increased both plant and soil carbon. In short, plantations can help restore carbon if they replace degraded land, but if they take the place of forests, carbon storage actually drops. Plantations mainly provide timber or latex and some carbon, but they're also more exposed to risks like pests, fires, and drought.

Bamboo's role is complicated. The region has nearly 90 bamboo species; 41 of which are unique to this area; and bamboo is known for its fast growth and ability to bounce

back. The 2023 State of Forest Report showed bamboo areas growing quickly in Arunachal Pradesh but shrinking in Manipur. In Mizoram, however, researchers found that soil under bamboo plantations had the lowest organic carbon of all land uses studied, and converting forest to bamboo plantation resulted in a loss of about 1.6 tonnes of soil carbon per hectare each year. So, quick above-ground growth doesn't always mean healthier soil below.

Some of the most effective strategies are actually the simplest: letting degraded land recover naturally, helping it by protecting it from fire and grazing, planting native species, and integrating more trees into farmland. For example, a study in Manipur (Anonymous, 2020) found that native chestnut and olive trees can help fallow areas regrow more quickly. These quiet approaches don't make headlines, but they add carbon without needing to change whole ecosystems.

Every restoration plan faces an important question: do carbon storage and biodiversity always go together? A multi-state study found only a weak link between the number of tree species and the amount of carbon stored; there was some connection in tropical and temperate forests, but not in all land uses. So, simply increasing diversity doesn't always mean more carbon. The value of complex, diverse forests isn't just about carbon storage. If a project focuses only on carbon, it often ends up planting fast-growing single-species forests, which isn't good for biodiversity hotspots. The key takeaway: carbon should matter in restoration, but it can't be the only goal.

### The people, and the money

In Meghalaya, studies found that sacred forests; protected by long-standing customs; contained the highest levels of biomass. By contrast, village forests that see more frequent use held only about a quarter as much. This isn't simply about one group being more responsible than another; rather, it's a story about how effective institutions are at enforcing rules. When regulations around forest use are respected and enforced, carbon builds

up. Where those rules break down under social or economic pressure, the carbon doesn't accumulate as well. Community-based forest management can be a valuable tool for carbon storage, but it's not a guaranteed solution; especially as traditional systems face increasing pressure from new roads, expanding markets, and changing ways of life.

Carbon finance aims to convert the environmental value of forests into direct financial benefits for local communities. A prominent example in the region is the Khasi Hills Community REDD+ project in Meghalaya, which partners with Khasi community governments and adheres to the Plan Vivo standard. Project reports claim to have protected and restored roughly 23,500 hectares since 2011, prevented more than 532,000 tonnes of carbon dioxide emissions, and distributed over one million US dollars to about 8,000 families by 2024. While these numbers come from the project itself and haven't been independently verified here, the design of such projects sheds light on the mechanics of carbon credits: credits depend on a "baseline" scenario; an estimate of how much forest would be lost if the project didn't exist.

This idea of a baseline leads to four crucial criteria that determine whether forest carbon finance actually helps the climate or just looks good on paper. First, additionality: would the forest have been preserved even without the project? If yes, then the carbon credit doesn't represent real change. Second, permanence: will the stored carbon remain locked away for decades, or could it be released by events like fires? Third, leakage: does protecting one area simply push deforestation into another? And fourth, measurement: can the amount of carbon claimed really be verified, given all the uncertainties? Credits sold on voluntary markets aren't always guaranteed to make a positive impact, and one credit does not necessarily equal one tonne of carbon removed from the atmosphere. Still, such projects can be meaningful; especially when they respect community rights, use honest baselines, and ensure that local people benefit directly.

### What the ledger is really for

Imagine standing in the forest at sunrise. Can North-East India truly be called the nation's great carbon ally? The reality is more nuanced. These forests contain significant and diverse carbon reserves, especially in old, dense stands and in soils that are fragile and easily disturbed. While the forests do absorb carbon each year, the actual amount is difficult to measure and much of this uptake depends on whether disturbed land is given a chance to recover. At the same time, records show that forest area is shrinking overall, and periodic fires continue to erode the region's carbon balance.

This evidence points to a clear set of priorities. First, safeguard existing forests; especially the old, dense ones; because they store centuries' worth of carbon that can't be quickly replaced by new plantings. Second, allow degraded areas and long-term fallows the time and support they need to regenerate. Third, only plant new trees where it truly adds value and doesn't replace ecosystems that are already important. In most cases, conserving what's already there will have a greater impact than starting afresh.

And it's a mistake to measure a forest's value in carbon tonnes alone. These landscapes not only trap carbon, but also store water during dry spells, prevent soil erosion on steep slopes, provide habitat for unique species, and sustain nearby communities. A forest is far more than just a storage tank for carbon; it's a complex, enduring piece of natural infrastructure. Every decision about roads, plantations, carbon credits, or clearing land shapes how much of this legacy will be passed on to future generations.

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