The 'breathing' forest: mist over the Amazon forest canopy at dawn. Picture taken from a 50 m research tower that rises above the forest canopy

What future for the Amazon?

Oliver Phillips

We know humans are having huge impacts on the Amazon, but what does this mean for biodiversity, and for climate change? This very readable article describes work being done in the Amazon to monitor changes in the forest, and discusses what those changes mean, what the future holds for the Amazon, and what we can do to protect the region. If you are studying climate change, or threats to ecosystems or biodiversity you should read this article

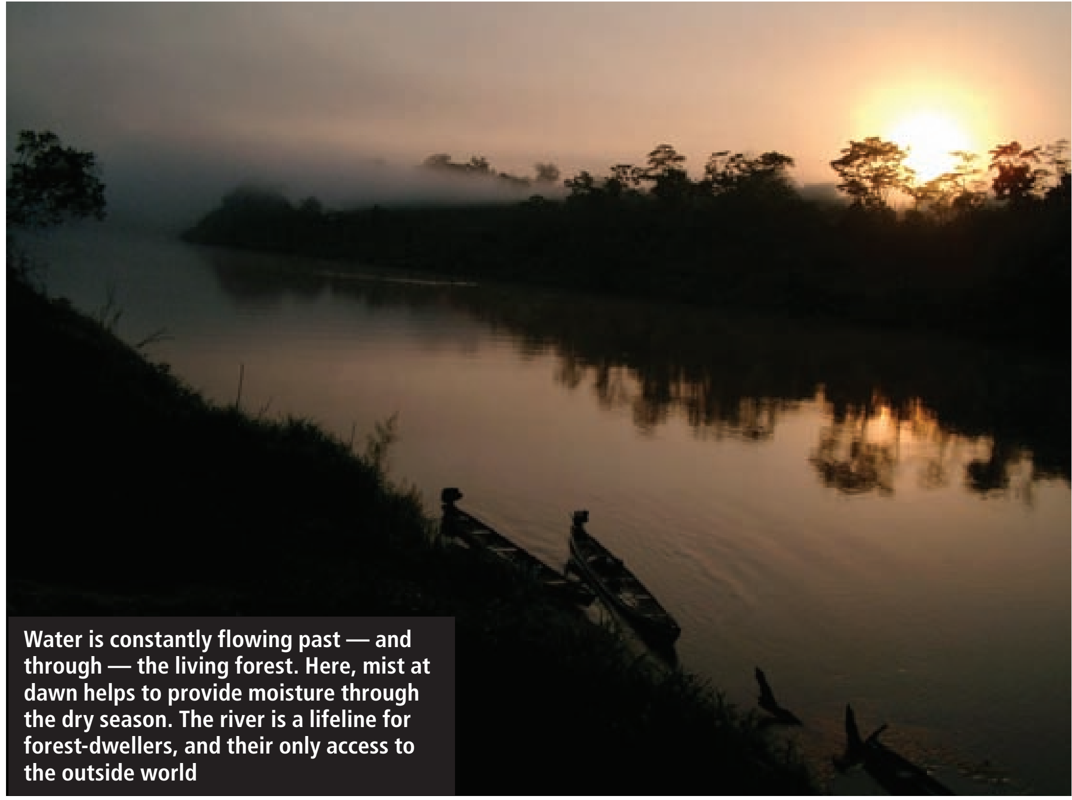
The Amazon forest is vast and magnificent. So huge in fact that it is possible to fly over it for hours on end, with nothing below but a seemingly endless carpet of green, interrupted here and there by winding, giant rivers and small oxbow lakes. Sometimes the rivers are coloured milk chocolate by the mud which washes off the towering Andes to the west. Sometimes they are sparkling and transparent, draining the ancient, crystalline rocks of the great Brazilian Shield to the south. And sometimes they are like black tea, stained by the tannins washed out from billions of leaves rotting on the forest floor of the north, where lush vegetation somehow manages to thrive on deep white sand.

The Amazon is many things to many people. But to a biologist or a physical geographer it is something akin to paradise. The sun glints back at you from these watery surfaces, and it is easy to imagine that it was always like this, and that it always will be...

Inset 1 Where is the world's carbon dioxide going?

Without the moderating effect of the biosphere, we would already be deeply into what most scientists consider would be dangerous climate-change territory (i.e. 470 parts per million of carbon dioxide in 2010). Of the huge gap between emissions and atmospheric storage, rainforests explain about one quarter. The rest is due to other carbon sinks elsewhere on the land surface, as well as the absorption of carbon dioxide by the world's oceans (a process which may be helping the climate but is also making the sea more acidic and threatening marine life).

Of course, the behaviour of these sinks might change, in fact it almost certainly will. Only by carefully monitoring forests on the ground will we know for sure what their role is in controlling climate change.



Water is constantly flowing past — and through — the living forest. Here, mist at dawn helps to provide moisture through the dry season. The river is a lifeline for forest-dwellers, and their only access to the outside world

Human impacts, human benefits

Yet the forest is shifting, and in many ways that are not immediately obvious to the human eye. One fifth of the Amazon rainforest has been destroyed. While there are some optimistic signs that deforestation can be controlled, the destruction is undeniable, and more subtle changes are occurring too. The climate is changing, as we will discover below. And wherever the big mammals and birds have been hunted out for food, the trees that need these animals to disperse their seeds may continue to fruit year after year, but their seedlings have little chance of survival, suffocated under deep shade and the heavy load of fungal pathogens supplied by their parents. Intensive hunting can kill tree species — eventually — just as effectively as it kills animals.

But there are reasons for hope too. One of these is that people are realising the valuable role that forests play in our climate. Not only do forests recycle huge amounts of water and bring rains that feed crops even beyond their borders, but they also store huge amounts of carbon (around 100 billion tonnes), so keeping it out of the atmosphere (Figure 1 and Inset 1). This benefits us all.

Research has also found that for decades now, the trees in the Amazon forests which do remain have actually been growing bigger, taking up an extra half billion tonnes of carbon each year. In fact, over recent decades, tropical forests worldwide have absorbed one fifth of global fossil fuel emissions, approximately equivalent to all the world's emissions from cars and lorries. In several ways then, nature is doing us all a very big favour in helping to slow climate change.

Drought and forest vulnerability

The question, though, is how long can this continue? Like most of the planet, tropical forests have already warmed noticeably. Continuing climate change means it is inevitable that the Amazon will become hotter this century. It may also become drier. While plants may be able to deal with extra heat, if the great Amazon water cycle becomes disrupted and droughts also intensify, plants may find it harder to cope (Inset 2). Our research team of more than 100 scientists has worked throughout the Amazon for years, and now we have the first solid evidence that drought can cause big carbon losses in tropical forests, mainly through killing trees.

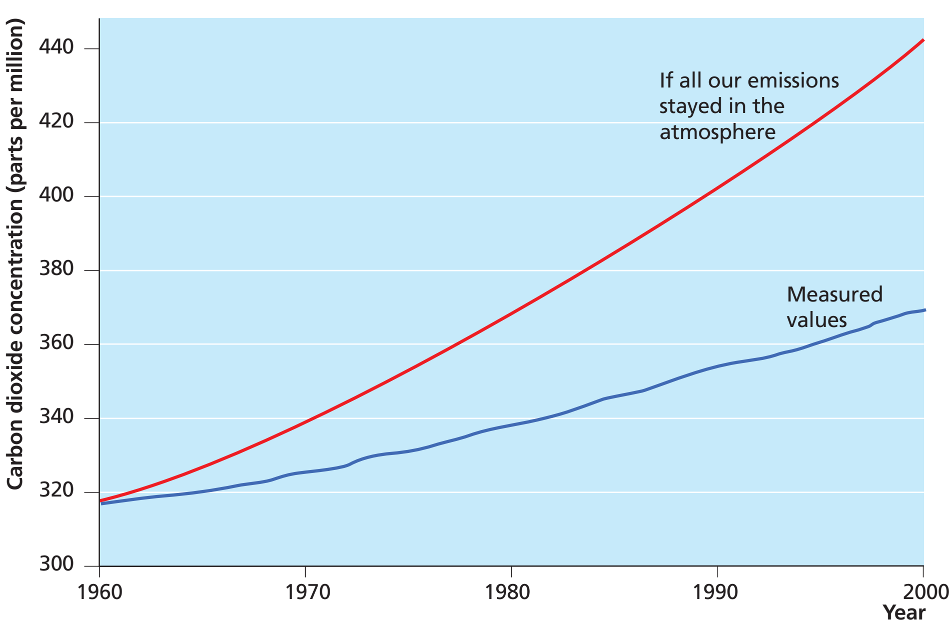
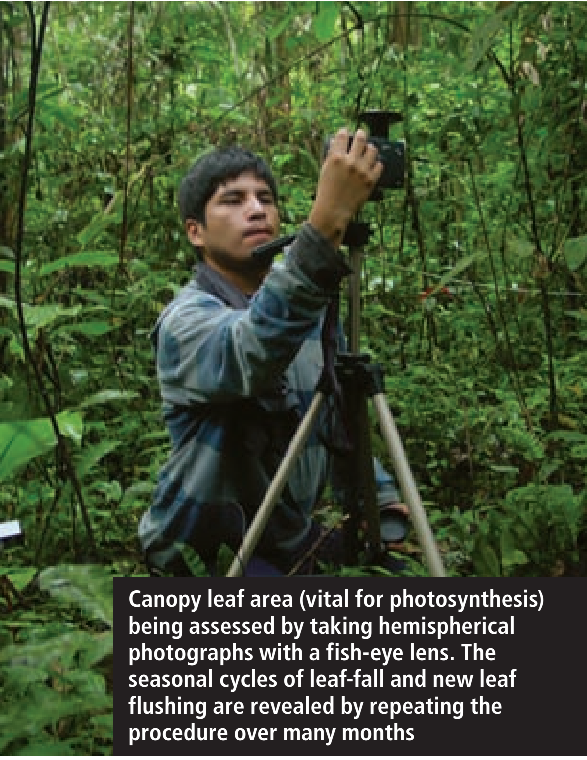


Figure 1 What goes up often comes down. In fact, less than half the carbon dioxide that the human economy produces stays up in the atmosphere

Inset 2 The Amazon hydrological cycle

In the western part of Amazonia most of the rain that falls has already been cycled at least once by the forest. This is because plants need to take up carbon dioxide from the atmosphere in order to photosynthesise and grow, and when they do so they must lose water vapour by transpiration. Prevailing winds from the Atlantic carry the ocean's moisture into the Amazon basin, often to fall as rain and be transpired again and again.

Eventually, most of the water fills the vast river network and flows out near Belem in northeastern Brazil. But some of the atmospheric moisture makes its way far to the south to the main agricultural areas of southern Brazil. Here, the dynamic economy built on energy from hydroelectric power and sugar-cane therefore depends in part on the moisture provided by the trees of the distant Amazon forest.



Canopy leaf area (vital for photosynthesis) being assessed by taking hemispherical photographs with a fish-eye lens. The seasonal cycles of leaf-fall and new leaf flushing are revealed by repeating the procedure over many months

To calculate the biomass of a tree it is important to have accurate measurements of its diameter and wood density. Diameter is measured with a tape, above the large buttresses that some trees have

Inset 3 Monitoring the world's forests

How do we know what effect forests are having on the world's carbon cycle? RAINFOR forest plots are randomly chosen patches of 100 100 metres in the huge Amazon forest. The large majority had biomass gains in the period up to 2005 (Figure 2).

To understand the trajectory of biomass change on this scale requires measuring hundreds of thousands of trees, and returning to the same plots again and again to discover how they have grown or died over the years. We also need to identify the species, itself no small task. There can be up to 300 tree species in one of our hectare plots, compared to about 50 native tree species in the whole of the UK. Naturally, this sort of work requires dedication by teams of scientists working across all the different nations of the Amazon (Bolivia, Brazil, Colombia, Ecuador, French Guyana, Guyana, Peru, Suriname and Venezuela).

Using the same techniques, in 2009 we discovered that African forests have been doing exactly the same, and we estimate that in most years tropical trees have stored an extra 1.2 billion tonnes of carbon. This is equivalent to locking up all the emissions of every car on the planet. The Amazon drought of 2005 temporarily reversed this enormous sink by killing millions of trees. We are trying to understand whether or not this represents the start of a permanent change in forest behaviour, as the world's forests become hotter and, perhaps, drier.

The 2005 drought

We based our study on the unusual 2005 drought in the Amazon. This gave a glimpse into the region's potential future climate, in which a warming tropical North Atlantic may cause hotter and more intense dry seasons. By measuring thousands of trees for years before the drought and then through the event itself, we were able to discover how they responded to the unusual conditions.

The 2005 drought reversed decades of carbon absorption in which nearly 6 million km^2 of Amazon forest has helped to slow climate change (Inset 3 and Figure 2). To our eyes most of the forest appeared much as before — tree deaths did increase but not enough to affect the complex structure of the forest. Only by examining the records from dozens of plots did we discover an increase in the death rate of trees, one that appeared to

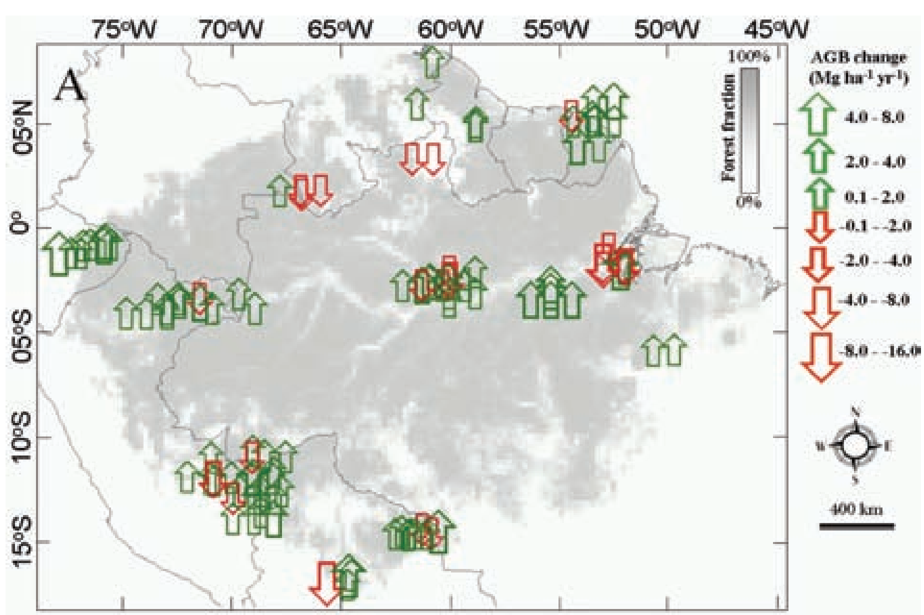


Figure 2 Annual change in above-ground biomass per hectare, on Amazon plots monitored in the years and decades before the 2005 drought

Further reading

Information on the ways in which tropical forests are affected by global changes can be found at **http://rainforests.mongabay.com/amazon/amazon_conservation.html**.

Original Amazon research is described at the RAINFOR website **www.rainfor.org**. Scientific papers available here of particular interest include:

Malhi and Phillips (2004) 'Tropical forests and global atmospheric change: a synthesis', *Philosophical Transactions of the Royal Society of London*, Series B, Vol. 359, pp. 549–555.

Phillips et al. (2009) 'Drought sensitivity of the Amazon rainforest', *Science*, Vol. 323, pp. 1344–47

GeographyReview*Online*

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Slash-and-burn creates space to grow crops for a few years, fed by some nutrients from the burnt forest. Along with carbon dioxide a host of other pollutants are sent skyward, affecting the quality of air and light over huge areas and sometimes shutting down regional airports

be closely linked to the increase in moisture stress experienced. At the small scale of each 1 hectare plot, the effects were very modest, but because the region is so vast, these small ecological effects add up to mean a large impact on the planet's carbon cycle.

Species change

We found a few species to be especially vulnerable, including some palm trees, which could not get enough water to supply their huge leaves. This means that, as well as releasing carbon, we can expect drought to have some subtle but important effects on the forest's plant and animal species. No other ecosystem on Earth is home to so many species. If we fail to stop climate change, much of the forest itself might remain, but the complicated fabric of life which underpins it will certainly change. Some species will gain, others will lose, and many adapted to the wettest areas may find themselves with nowhere to go.

The biggest danger

Yet the biggest danger to the Amazon is probably not climate change. It is not even hunting or logging or agriculture (and the deforestation which accompanies it). Rather it is the combination of *climate change plus development*. A drier forest is certainly a vulnerable forest but it will still remain a forest unless it burns. Fires, set to clear land for farming, easily escape out of control in a drought. Amazon trees evolved without fire. They have none of the protective features like thick bark or heat-resistant seeds evolved by their relatives in areas which burn naturally. Once burned, the canopy thins, dead wood accumulates on the ground, the hot tropical sunlight pours in, and the whole system can be primed to burn again.

The future Amazon

To keep the Amazon forest standing in a changing climate will require better ways of living in the region, with much less use of fire, and much more value placed on the forest dwellers who want to protect their land.

Other models of development exist. Using mixtures of compost and charcoal, for example, indigenous peoples have managed to turn patches of normally nutrient-starved tropical soils into artificial, rich 'black earths' that can yield bountiful crops in small farms.

Key points

- Amazonia is the greatest tropical forest on Earth, an immense ecosystem pulsing with life, and with huge flows of water and carbon.
- In many unseen ways it affects our lives, including helping to slow climate change by absorbing and storing carbon.
- Drought, development, and the global demand for commodities like soya beans, beef, palm oil, iron, gold, and petroleum, all pose growing threats to the forest.
- The long-term health of the forests, and the world's climate, will depend on finding ways to reward tropical people for keeping their forests standing.

The push of industrial farming into forests is driven by some unlikely forces — including the meat that we eat (many cows in Britain are fed with soya beans grown in the Amazon), and global commodity demands which make monocultures such as palm oil plantations more attractive investments than the hyper-diverse, locally-managed forests they replace. With the right knowledge and action these forces can be reversed.

And, last but not least, if we can find ways to reward those countries that help us all by keeping their climate-protecting, carbon-rich forests intact and standing, the Amazon and its millions of species may still have a bright future. It is in all our interests to make sure this happens.

Questions for discussion and research

1 In what ways do tropical forests affect the global climate?

2 How do drought and other atmospheric processes affect the Amazon forests?

3 What needs to be done to help ensure that the Amazon can survive the twenty-first century?

Oliver Phillips is professor of tropical ecology, University of Leeds. He coordinates the RAINFOR project, an international network of scientists who are working to understand the ecology of Amazonian forests and how they are changing in the twenty-first century.