



## CLOUD FORESTS

These habitats are evergreen forests growing in mountainous conditions in the tropics or subtropics. They can be wetter even than lowland rainforest and spend much of the time swathed in thick fog. This creates environments of unmatched diversity.

# Measuring the carbon jungle

Where does carbon go in a tropical rainforest? The answer's more complex than you might expect, as **Yadvinder Malhi** explained to **Tom Marshall**.

**Y**advinder Malhi thought 24 hours would be plenty of time to get out of the jungle and onto a plane back to Britain. But when torrential rain put him on the wrong side of five separate landslides, escaping the Peruvian rainforest up the slopes of the Andes started seeming a little trickier.

Malhi's team managed to get their four-wheel-drive over two of them before concluding the road was a goner and taking to the jungle. After a day of scrambling up steep slopes, fighting through thick vegetation and hitching lifts in trucks and even an ambulance, Malhi just made the plane.

When you're working in heavily-forested mountains, the simplest task can turn into a trial. Malhi and his team have spent a long time in the jungle, and even moving about is hard work compared to the comparative comforts of life as a professor at Oxford University's School of Geography and the Environment.

Malhi and postdoctoral researcher Luiz Aragão joke they never need to worry about putting on weight back in Oxford – they'll sweat it off in a few days tramping up and down Peruvian hillsides.

At present Malhi's excited about his team's research in the Manu National Park,

near Cuzco in Peru. The project involves a transect cutting through some 18 kilometres of forest from 200 metres above sea level, deep in the Amazon rainforest, up into the high Andes more than three kilometres above. The core of this project was funded by a NERC research grant set to end next year, but Malhi and his collaborators have attracted numerous additional projects, including PhD studentships, and research grants from sources including the Moore Foundation and Microsoft Research. They aspire to create a unique 'vertical laboratory' to study the effects of climate on tropical forests.

### A forest in the clouds

The fieldwork focuses on numerous 100-metre-square plots of forest that Peruvian students monitor each month. It aims to use the elevation gradient to explore how tropical forest ecosystems function under varying environmental conditions – and how they could respond to a warming climate.

Of the carbon dioxide a tree takes in through photosynthesis, some ends up making carbon compounds stored in leaves, trunks and roots, but much is used up by the tree's normal metabolism. The biomass carbon eventually ends up decaying on

the forest floor, but the rate of decay may be slow under the cold, moist conditions typical of cloud forests (or montane forests, see box). This limits the release of nutrients locked up in the dead matter. It also means a cloud forest stores a large amount of carbon in its soil and litter layers.

Malhi's group has been tracking how much of this carbon goes to different components of biomass and measuring how slowly the dead material decomposes. To explore how the environment affects decomposition, the researchers have moved samples of soil and leaves up and down slope to modify temperatures and are monitoring the samples over several years. At the extreme this has resulted in soils and leaves from the high cloud forest sitting in the Amazon lowlands. The team has also fertilised patches of forest with nitrogen and phosphorus to explore how the supply of nutrients affects the cycling of carbon.

Discovering how these processes of growth and decomposition vary in different kinds of forests is a challenging task because there are so many variables to untangle – are differences caused by altitude alone, or temperature, or nutrients, or levels of ultraviolet light? But insights are emerging.

It seems, for instance, that montane forests are just as productive as lowland



Above: Yadvinder Malhi (in orange) and his team. Below: Measuring the carbon dioxide emissions of tree stems.



## The Andean cloud forests and the adjoining Amazonian lowlands are the most biodiverse region of the planet.

forests but invest much more of this production below-ground in roots. These roots eventually die, and in the cold, humid conditions of the cloud forest they contribute to the build-up of a thick layer of dead biomass.

‘There’s as much carbon in cloud forests as in lowland rainforests,’ Malhi says. ‘It’s just found less above ground in stems and leaves and more underground in humic matter and roots.’ Chiller conditions mean fallen leaves decay more slowly, so that the carbon they contain stays in the soil for longer.

Unravelling the intricacies of how carbon and nutrients move through forests should greatly improve how models simulate their effects on the climate.

### Fragile diversity

The Andean cloud forests and adjoining Amazonian lowlands are the most biodiverse region on Earth – 15 per cent of all plant

species are found here – and the team’s botanists have discovered a few new species and even a new genus of tree in the plots they monitor. But this teeming life may be sensitive to climate change.

The Andean region is warming rapidly, and many species of plants and animals may need to migrate further upslope to keep in equilibrium with local temperatures. Warming temperatures may also cause the clouds that bathe these forests to move uphill, changing both moisture and available light.

It might be expected that the cloud forest would migrate upwards into the grasslands that occur above the treeline, but these grasslands are frequently swept by fire and are exposed to the highest levels of ultraviolet radiation anywhere on the Earth’s surface. It’s uncertain how easily plant species will be able to migrate upslope – the group plans to transplant seedlings to explore this.

‘The highlands are a very fire-dominated landscape,’ says Malhi. ‘Already cloud forests are being pushed further uphill as the lowlands get hotter, while fires seem to be getting more common in the high mountains.’ And because a cloud forest stores more carbon in dead biomass than in branches and leaves, this carbon returns to the atmosphere very quickly when wildfire strikes.

Warmer temperatures could also make dead biomass decompose more quickly, accelerating carbon’s movement through the soil. With so many variables at work, predicting long-term consequences is difficult – particularly since forests influence the climate in complex ways as well as responding to it.

Malhi is keen to invite other scientists to do their own research at the site. ‘We’ve spent a lot of time and effort building the capacity to do high-quality science in some of the most difficult terrain on Earth,’ he says. That’s not just the physical equipment and support networks needed to do research out in the jungle, but also the local relationships that keep a steady stream of Peruvian students and academics willing to help with the research. ‘We aspire to develop this site into a global research facility where researchers can untangle the complex web of interactions between tropical forests and climate,’ he adds.

In the meantime the team is running numerous other projects, investigating topics ranging from cloud formation and water flow to the effects of forest fires and landslides, and the role of fungi and termites.

‘This region is the ‘hottest’ of the global biodiversity hotspots,’ Malhi explains. ‘Every ridge and valley provides unique conditions, but working in this terrain is extremely challenging. So few researchers have studied this area that almost anything we measure will probably be novel science!’ ❖

### MORE INFORMATION

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The research is a partnership between the Universities of Oxford and Edinburgh (under Patrick Meir) in the UK, Wake Forest University, Florida Institute of Technology and NASA in the USA, and San Antonio Abad University in Cuzco. Collectively the teams call themselves ABERG (the Andes Biodiversity and Ecosystems Research Group).