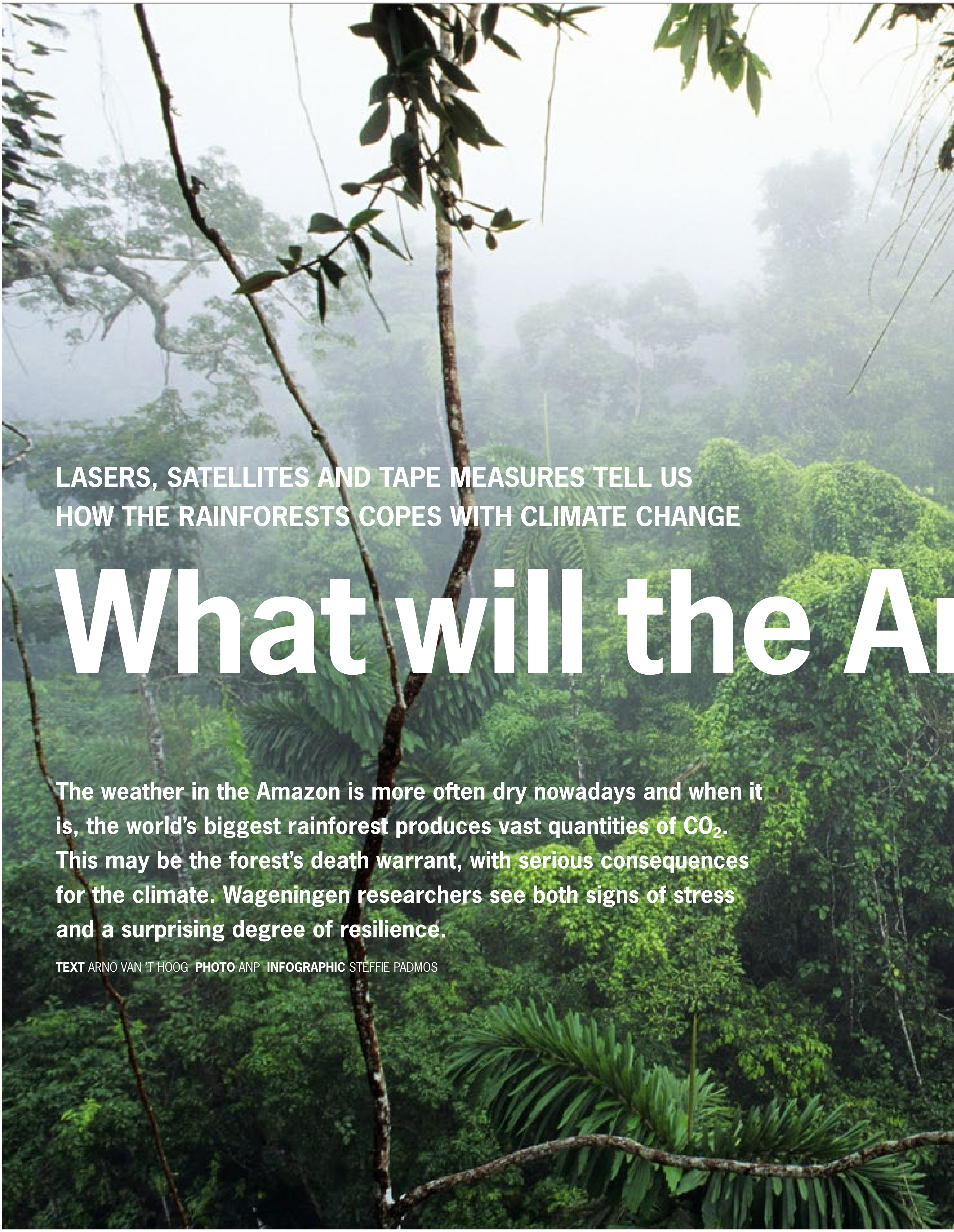

LASERS, SATELLITES AND TAPE MEASURES TELL US HOW THE RAINFORESTS COPES WITH CLIMATE CHANGE

What will the A

The weather in the Amazon is more often dry nowadays and when it is, the world's biggest rainforest produces vast quantities of CO_2. This may be the forest's death warrant, with serious consequences for the climate. Wageningen researchers see both signs of stress and a surprising degree of resilience.

TEXT ARNO VAN 'T HOOG **PHOTO** ANP **INFOGRAPHIC** STEFFIE PADMOS


mazon do?

‘We can already pinpoint the vulnerable areas of the forest’

In Manaus, the capital of the federal state of Amazonas, the weather is always humid and oppressively hot. This metropolis in the heart of the Brazilian rainforest sees little variation in daylight hours or seasons: maximum temperatures in the hottest and coldest months, October and February, are not far apart, at 32 and 30 degrees respectively. The difference between day and night temperatures is bigger, at seven degrees, but it never gets colder than 23 degrees.
The only thing that does vary is the rainfall. Every year there is an extremely wet period and a somewhat less wet period, which falls between June and October. The total rainfall is high: an average of 2100 millimetres per year in Manaus (compared with 880 in the Netherlands). In the far west of the Amazon there are districts which get as much as 3000 to 6000 millimetres of rain per year.

DRY YEARS

A lot of water combined with heat and sunlight provide ideal conditions for luxuriant plant growth. This becomes apparent when rain suddenly becomes scarce, as it did in 2005, 2010 and 2015. The vegetation grew at a slower pace and there were more forest fires. Ingrid van der Laan-Luijkx, a postdoc at the Meteorology and Air Quality chair group, can even see such effects from Wageningen by studying the air quality above the Amazon. ‘We compared air quality data from 2010 and 2011. There was a serious drought in the Amazon in 2010. That is directly reflected in less Co_2 absorption by the trees and in the release of more Co_2 due to the breakdown of biomass and forest fires. So in that dry year the Amazon was a net producer of Co_2, whereas in the more normal year 2011, the Amazon absorbed more Co_2 than it released. Worldwide atmospheric concentrations of Co_2 are rising every year, but they rise faster when there is a big drought in the Amazon. This happened again in 2015 under the influence of the global drought caused by El Niño.’
Van der Laan’s lab is working with Brazilian researchers who take regular air samples from a small plane at different altitudes above the Amazon. Hundreds of bottles of air are posted to the Netherlands where infrared measurements reveal the Co_2 concentrations. The measurements provide the data for the Carbon Tracker computer model, developed by Van der Laan’s colleague Wouter Peters, professor of Carbon Cycle and Atmospheric Composition. Carbon Tracker creates an overview of the carbon balance of the Amazon.
Fluctuations in the carbon balance entail significant quantities, says Van der Laan. The global combustion of oil, gas and coal produces about 35 gigatons of Co_2. During a dry period, the Amazon produces around 0.9 to 1.8 gigatons of Co_2. ‘So it really is significant in relation to fossil fuel emissions. It is equivalent to between five and ten times the Netherlands’ annual Co_2 emissions.’

THINNER CROWN

Drought causes problems for trees and other plants which are used to a humid environment. The crowns of trees thin out and some trees die off completely. But not all forests are affected to the same extent. Jan Verbesselt, associate professor at the Wageningen laboratory for Geo-information Science and Remote Sensing, wants to gain a better understanding of these differences by taking a good look at the recovery of tropical forests after a drought. A forest’s resilience tells you something about how much it will be able to cope with.
Verbesselt works with satellite images. Some modern satellites detect microwaves emitted by vegetation, or they use radar to see through the clouds from an altitude of 700 kilometres. The European Sentinel 1 satellite, for example, films the Amazon several times a week with a resolution of 20 by 20 metres.
When Verbesselt compares and analyses these images, changes in the rainforest gradually emerge over the weeks and months. ‘We look at the quantity of leaves and the photosynthesis. These vary over time because in dry periods the photosynthesis and number of leaves go down. In rainy periods the forest recovers again.’ If the post-drought recovery goes slowly, that is a sign of stress in the forest, says Verbesselt. ‘We can now pinpoint which areas of the Amazon would be vulnerable to even more major droughts, or to fires or felling. We want to use our method to develop a warning signal, so that people can be more careful with vulnerable forests.’
Verbesselt published an article in *Nature Climate Change* in the autumn of 2016, together with Marten Scheffer, professor of Aquatic Ecology and Water Quality Management in Wageningen. The article is based on satellite research on the recovery of rainforest and approaching tipping points: the points at which forests reach a level of stress that will cause widespread death of trees if drought hits again. The big question is whether such devastation is lasting: will the rainforest then change into a drier forest, or even into an open savannah landscape? There are several model studies which suggest that this kind of reversal is possible: tropical forest can indeed change into a savannah landscape after repeated droughts.

FAST RECOVERY

This same issue is the focus of field research in tropical forests for Lourens Poorter, personal professor of Forest Ecology and Forest Management in Wageningen. One thing strikes Poorter repeatedly: tropical vegetation has a great capacity for recovery. If people leave felled or burned tracts of forest, abandoned fields or farmland undisturbed, the land becomes overgrown with weeds, shrubs and trees in no time. Ten years later there is a young forest, and 60 years later a mature one. In the longer term, it is hard to detect signs of earlier deforestation.
Poorter: ‘Even I can’t, and I’ve been knocking around the tropics for years. When I was in Guatemala I saw a gorgeous forest with a strange topography. There were steep climbs and descents. Apparently, the ruins >

Satellites measure the foliage and the photosynthesis using microwaves.

Aeroplanes take air samples to determine the concentration of CO_2.

CARBON BALANCE IN THE AMAZON

The Amazon region plays a major role in the global CO_2 balance, Drought has big implications for carbon sequestration by the tropical rainforest, and that is the key to more precise forecasting of the global climate.

Amazon forest

The Amazon forest is the largest rainforest on earth (5.5m km²), spread over 9 countries.

Annual rainfall in the Amazon
2000 mm

Annual rainfall in the Netherlands
880 mm

Secondary forest

Vast amounts of CO_2 are absorbed by the vegetation that regrows on open tracts of land after felling, fire or farming. In this secondary forest the biomass is restored to its original level.

All the secondary forest in Latin America (most of it in the Amazon) can sequester 31 gigatons of CO_2 in the next 40 years.
That is just as much as was produced in the countries of Latin America between 1993 and 2014.

31 Gton

CO_2 absorption and emissions

Under stable conditions in the Amazon, when numbers of new seedlings and tree deaths are equal, absorption and emissions of CO_2 are more or less balanced:

The large amounts of water, heat and sunlight make for abundant plant growth, leading to CO_2 storage.

When plants are broken down, for example due to microbes which digest dead wood, CO_2 is released.

CO_2 production during drought

The weather is becoming drier in the Amazon. This slows the growth of plants and causes die-off, so that less CO_2 is stored while more is released.

0.9-1.8 Gton

CO2 emissions by the Amazon in dry conditions (5 - 10 x the annual emissions of the Netherlands)

35 Gton

Annual global emissions of CO_2 from the burning of oil, gas and coal

Ecological research shows in detail which species are present.

The capacity of secondary forest to absorb CO_2 is 11 times bigger than that of virgin rainforest.

11X


PHOTO WUR/JEFFREY VAN LENT

Researcher Jeffrey van Lent (left) measures CO_2 emissions from the soil in the Amazon forest.

of an old Maya city were buried in the hills. The vegetation looks like virgin forest but it is actually an overgrown ruin. You have to look very carefully to spot any signs of that old civilization. Ecologists who know the local vegetation well showed me that there are a lot of fruit trees, species which were once planted by the Mayas.'

For Poorter, such observations are evidence of the resilience of the rainforest, which may also tell us something about its likely response to climate change. 'We are all doing research, but we do not understand the real mechanism yet. That makes it so important to pursue a combination of different approaches. With the remote sensing that Jan Verbesselt and Marten Scheffer use, you can see things on a far bigger scale than I can see as an ecologist. Except that from a great height everything just looks green: you don't know whether it is shrubs or trees you are looking at. So it is important to validate your findings on the ground with ecological studies of tracts of forest. Looking for example at which species grow there, and tying a tape measure around every tree to measure its girth. The numbers tell the tale.'

Poorter uses ecological data in new calculation models to predict the effects of climate change. In a publication which came out in August 2016, he and his German colleagues model how forests respond to more frequent droughts. The result came as a surprise to most people: the forest may change in the composition of species present but it remains tropical rainforest, with more or less the same amount of biomass and of sequestrated Co_2.

THE FOREST REGROUPS

The key to this resilience lies in biodiversity, says Poorter: 'Older model studies predicted that things would go badly wrong as a result of climate change: you would end up with dry forest or savannah. But those models work on the basis of plants with only two characteristics: evergreen and deciduous. That is not a realistic reflection of the vegetation of the Amazon. In the new model, we calculate with plants with a wide variety of characteristics. Then you see trees first dying out as conditions get drier. But after that you get succession. The plant community starts regrouping and the trees and plants which are successful are those which are a bit more drought-resistant. The whole system bounces back and the biomass recovers to its original level. So biodiversity is crucial for a healthy and resilient ecosystem.'

He sees similar resilience in the growth of what is known as secondary forest: the vegetation which returns after felling, fire or farming. This almost exponential capacity for recovery after deforestation is no surprise, says Poorter. 'On open patches you get a lot of light, water and nutrients. At first, pioneer plants and young trees can grow unhampered and the growth rate of biomass and the absorption of CO_2 are tremendous. That capacity is 11 times bigger than that of an undisturbed rainforest, because in a stable rainforest trees die off at the same rate as new ones grow, so the absorption and emissions of CO_2 are roughly balanced.' Two articles Poorter published in the spring of 2016 together with Latin American colleagues systematically describe the capacity of secondary forest to absorb carbon using studies of 1500 tracts of forest. The researchers calculate that the secondary forest all over Latin America can sequestrate 31 gigatons of CO_2 over the next 40 years. That is the amount the countries of Latin America produced between them between 1993 and 2014. Most of that secondary forest is in the Amazon.

Poorter hopes his research will generate interest among politicians and policymakers in the natural recovery of secondary forest as a cheap way of protecting biodiversity and storing CO_2. 'It is important to protect virgin tropical forest but we really need to rethink our ideas about the value of secondary forest. The term "secondary" may make it sound second-rate, but it is the way nature goes about restoring forest. If there are still any bits of forest left, we don't have to do much at all for recovery to take place.'

Carbon sequestration is just one of the functions which is saved this way. Tropical forests also have a water cycle: they create their own climate and precipitation, says Poorter. 'Forests pump water around. Trees and plants transpire vast amounts of fluid, which get transported away by air currents, sometimes referred to as "flying rivers". This means that if forests disappear in the Amazon, there are consequences elsewhere in South America, for agriculture in Paraguay or for drinking water in Sao Paulo, for instance.'

'Biodiversity is crucial for a resilient ecosystem'

THE ROLE OF WATER

Lourens Poorter's ecological research delivers a range of data for improving the Carbon Tracker and the underlying biosphere model SiBCASA, says Professor Peters. 'What are the dominant tree species and how much do they grow every year? What does the root system look like? How do they react to dry and wet conditions?'

Water determines the progress of many processes in the Amazon, says Peters. 'You get loads of rain and massive evaporative. And rivers carry water away as well. This balance determines how much water is available for the vegetation and that varies enormously per region of the Amazon. In some districts the root systems of trees go down to a depth of seven metres, so they are less affected by drought. What I want now is to gain a far better understanding of the role of water in the carbon cycle of the Amazon.'

The next stage for Peters is to fine-tune the Carbon Tracker for use in the Amazon, as although the computer model shows us that the Amazon produces CO_2 in dry years, exactly what happens is not clear. Peters: 'There are always two opposing processes at work: the absorption of CO_2 due to plant growth and CO_2 emissions through breakdown by microbes, for example, which digest dead leaves and wood. These two major flows largely balance each other out. What remains is the amount of CO_2 which the Amazon releases in a dry year.'

But those gigatons of CO_2 do not tell us which of the two flows changes the most, says Peters: do the trees absorb much less CO_2 or is much more released due to the breakdown of biomass? 'That question is crucial too for being able to predict what will happen if it gets hotter and drier more often in future.'

MONEY FOR ISOTOPES

New research on isotopes can provide insight into this. Peters had an innovative idea which won him a prestigious ERC grant from the EU in 2015. There are different variants of CO_2 because of the different carbon and oxygen isotopes in existence. Isotopes are chemically identical but vary subtly in mass. There are three oxygen isotopes: the common oxygen-16 and the rarer oxygen-17 and oxygen-18.

'The relative proportions of the three oxygen isotopes tell us something about the processes the CO_2 has gone through,' says Peters. 'Contact between CO_2 and water has a clear impact on the relative proportions of the isotopes because of the exchange between CO_2 and water. Most of this contact takes place in plants. They continuously absorb vast quantities of CO_2 which comes in contact with water molecules. Above the Amazon, you can clearly see the isotope proportions in CO_2 change due to contact with water in plants and trees.'

The isotope research will make it possible soon to isolate the absorption of CO_2 by plants and the emissions from decomposition. Until recently, research on oxygen isotopes was fairly complex, but Peters has now used some of his grant to buy a new piece of equipment which can measure isotopes directly with laser technology. In the years to come this will provide the PhD researchers in Peters' group with a lot of data that will help them improve on the Carbon Tracker. This also means that the air samples from the Amazon won't have to be flown to the Netherlands. Peters: 'This apparatus will be installed in the lab in Brazil early next year. Then we will measure the isotopes right there in the air above the Amazon. We expect to obtain important new insights that way. In particular, the impact of drought on carbon sequestration is the key to more precise forecasting of the global climate in the 21st century.' ■

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