Field research in the forest: Susan Trumbore seeks to understand how long plants and soils store carbon dioxide, and how climate changes influence the carbon balance.

# Seeing the Forest for the Trees

Plants and soils play an important role in the global carbon cycle and in the Earth's climate, not least because they absorb large amounts of carbon dioxide. Yet little is known about how global warming affects these natural sinks. **Susan Trumbore**, Director at the **Max Planck Institute for Biogeochemistry** in Jena, has dedicated her research to this subject, and even enjoys getting her hands dirty in search of answers.

TEXT **TIM SCHRÖDER**

I may quickly overtake you," says Susan Trumbore as we part, glancing over to her bicycle helmet hanging on the coat rack. "Lately, I'm almost always faster than the bus. Due to the construction site." Susan Trumbore doesn't own a car – an attitude that certainly suits a scientist who has dedicated her career to researching the effect of global climate change. Every morning she pedals uphill to the institute. When not traveling by bike, she takes the train. "It really is a shame that they cancelled the high-speed train service to Jena. Now we feel even more cut off." Truth be told, Jena is no metropolis, she concedes, soft-spoken as always. "But when I moved here, I happened to come across a ranking in the Economist, according to which the people living in Jena are the most educated in all of Germany. Not bad, huh?" she says with a smile.

Susan Trumbore has been serving as Director at the Max Planck Institute for Biogeochemistry since 2009. To her, Jena feels very international indeed. Her research group currently consists of 40 researchers from many different countries. The walls in the hallway are decorated with photos of the field trips the Max Planck researchers from Jena have undertaken – photographs depicting a slim red-and-white tower observatory, and steel cases full of equipment in the Brazilian rainforest. Trumbore also spends several months out in the field each year. Her mission: to study the effects of climate change on soils, plants and forests in different regions around the globe. The western US has been experiencing increasingly long periods of drought for several years now, for example. Juniper forests have already started dying off in Arizona and New Mexico. Similar effects have been observed in Australia.

Researchers still can't estimate exactly how much carbon dioxide is absorbed or released by soils and forests. As a result, most climate models are inevitably based on simplified versions of this carbon cycle, which flows through the leaves, trunks and roots down into the soil and back into the atmosphere. The computations are based on average

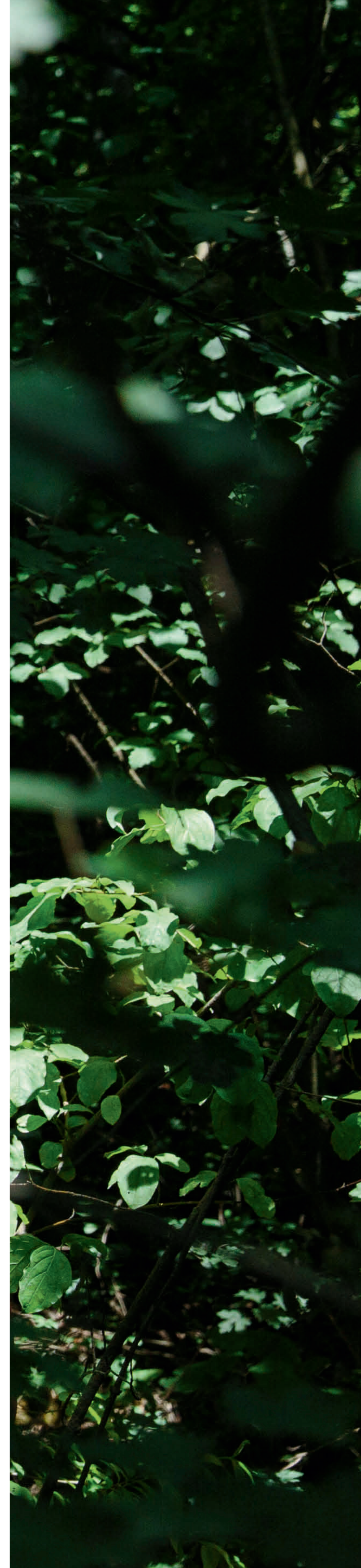


Photo: Sven Döring

worldwide or regional values. Yet the Earth is home to many different types of soils and forests.

As a climate researcher, Susan Trumbore wants to gather data on this subject, not only in hopes that it will help her hone her analyses, but also to show agricultural experts and politicians in no uncertain terms what happens when territories are altered by human activity. In her opinion, the most important region for this type of research is the tropics. “Due to the large amounts of direct sunlight they are exposed to, they serve as the Earth’s climate engine – what happens here has an impact everywhere else.”

For Susan Trumbore, travelling to the tropics herself means making a 36-hour journey by plane and bus. First the flight to Manaus, the capital city of the state of Amazonas in northern Brazil. Manaus is one of her favorite places, she says, reminiscing about the bustling city and the warm weather. She then continues her journey by bus for several more hours before finally reaching the areas in which she conducts her research: the forest along the Amazon River and the large soy plantations, the former increasingly being sacrificed for the latter.

Susan Trumbore studied geology because it is a subject that goes beyond pure chemistry: the history of plants, of the climate, of the entire Earth system. As a student at Columbia University she was told that having a solid grasp of chemical reactions, of stoichiometry and molar ratios, would suffice to comprehend the global cycle of chemical elements. Back then, biology was mostly relegated to the sidelines. “Today we know that biological systems have a significant impact on global material flows. There are feedback loops and adaptation mechanisms. Thankfully I work at an institute that focuses on a very central question: How does living nature influence the large-scale global cycles?”

Working on this question for so many years has given her food for

Actively protecting the climate: Susan Trumbore doesn’t own a car; she travels through Jena by bike, or else she takes the train whenever possible.

Photo: Sven Döring

» I enjoy being outdoors and believe it's important that I myself also take samples. One of my favorite places to be is outside in a soil pit!«

thought. She looks down at the table and pauses: "I wonder what kind of world we are creating with our actions. I mean, sure, people are making an effort to protect the environment and establish nature reserves. But what exactly are we protecting?" In this vein, she is thinking about the Hainich, a very old primordial forest, now a national park in the German federal state of Thuringia, where studies on plant stress are also being conducted. She is a cooperation partner in this endeavor. "Yet the Hainich is located on land that has been significantly shaped and altered by us humans – a very artificial situation," she says. That isn't yet the case in large parts of the tropical rainforest, but those forests are nevertheless endangered.

The German terrain is a prime example of how land management is changing the landscape. "This area used to be covered in forest, but it has since been converted into farmland. In terms of the carbon cycle, this transformation represents a radical change." She explains that the cycle changes not only when fossil fuels are combusted, but also when forests are burned down or cleared. That's why she believes it's so crucial to understand how and why forests die in today's world – not just directly at the hands of humankind, but also indirectly as a result of climate change.

The geochemist is fully aware that her research can't change the world. "But the question we have to ask ourselves is how we intend to feed over nine billion people in the future." The question of whether land management will continue to destroy forests isn't a scientific matter, but rather a socioeconomic one. Mankind needs protein, she explains – soy, if need be. And when the commodity prices for soy go through the roof because of the rising demand for biodiesel in the US, more and more Brazilian rainforest will be converted into plantations. She considers herself a realist, not a fatalist.

When conducting their field studies in the rainforest, for example, Trumbore and her team lug around the cases containing the gas measurement equipment. Even though she has a large staff working for her, she likes to pitch in herself. "I enjoy being outdoors and believe it's important that I myself also take samples. One of my favorite places to be is outside in a soil pit!" Besides, she says, out in the field she and her crew are often faced with challenges that they would never come across in a laboratory. "Solving problems together and sharing experiences brings everyone in our group closer together."

## HOW MUCH GREENHOUSE GAS DOES THE SOIL CONTAIN?

The researchers place bottomless acrylic boxes on the soil surface and extract the air trapped inside. How much carbon dioxide does the soil release? How much nitrous oxide? How much methane? These are all greenhouse gases. The researchers shovel dirt into small sample flasks and drill holes into tree trunks. The soil and wood samples are later analyzed in Jena. Susan Trumbore has been using this method for years to gain valuable insight into the extensive carbon cycle.

The cycle's underlying principle was discovered long ago. Plants take up carbon dioxide and convert it into sugars and other carbohydrates during photosynthesis. If the plants or their leaves are eaten by animals or decomposed by microorganisms after the plant material dies, these compounds are broken down again. The carbon dioxide is released. One key question with regard to climate change is how long the carbon dioxide remains in the plants or in the partially decomposed plant material in the ground. In other words, to what extent is less carbon dioxide absorbed if a forest is cut down by humans or destroyed in a drought?

Unfortunately, the carbon cycle is extremely complex because the essential factors that need to be taken into account include not only the plants, but also the soils, which – in the shape of dead leaves and other decomposing plant material – store roughly two to three times more carbon dioxide than

Keeping track of plant metabolism: The researchers in Jena use glass flasks to trap the gases emitted by a tree trunk (left). They then analyze the isotopes present in the sample to determine how long carbon dioxide remains stored in the trunk. A device that measures gas exchange reveals the amount of greenhouse gases absorbed by plants during a drought experiment (right).

Photos: Sven Döring

> One of the questions the scientist seeks to answer is what happens to the trees and soil when forests die off due to drought and heat.

the atmosphere. Therefore, a number of different factors determine how much carbon dioxide is absorbed or released: the climate, the microorganisms in the soil, the type and composition of the plant material, and the geographical location. In the case of deep-frozen permafrost soil in the Arctic Circle, for example, no carbon dioxide is released at all until the soil thaws. Human activities have a significant impact on this whole process. By clearing woodland, we set free large amounts of carbon dioxide in one fell swoop – carbon dioxide that had been stored in trees and soils for a long period of time. Yet how much carbon dioxide is stored in the soil of the farmland that now covers a formerly wooded area? As yet, this question remains largely unanswered.

## A NEW TECHNIQUE IN BIOGEOCHEMISTRY

Susan Trumbore was able to shed light on many details pertaining to the carbon cycle thanks to what could be considered her greatest contribution to science: she adapted a technique that was hitherto only applied in other fields, and rendered it suitable for research in biogeochemistry. This technique can be used to analyze precisely how long carbon compounds hidden in soils have existed there. With the help of accelerator mass spectrometry, she searches for radiocarbon, an isotope that can be used to date carbon compounds found in plant tissue or soil. Isotopes of any given element are defined as atoms with a different number of neutrons, the uncharged nuclear particles, which means they also differ in mass. An accelerator mass spectrometer sorts very rare isotopes, such as radiocarbon, by accelerating them very rapidly in a circular orbit using a magnetic field. Due to the fact that each of the particles has a slightly different weight, they hit the detector in succession, one after the other.

She familiarized herself with this technique after completing her doctoral thesis in 1989. Back then, she spent quite some time at ETH Zurich, which featured one of the world's first accelerator mass spectrometry laboratories. She later switched to the Lawrence Livermore National Laboratory near San Francisco, where she helped set up a new machine.

Today she uses the accelerator mass spectrometer located in the basement of the institute in Jena: a piece of equipment made from stainless steel, the size of three oil tanks, to which countless steel pipes are attached. Fewer than one hundred of these devices exist worldwide, but Susan Trumbore explains the inner workings of this machine with such ease that one could believe she was talking about something as simple as the engine of a small car. A technician is busy adjusting the bolts on one of the pipes. She gives him a quick nod. He smiles. The ventilation unit starts up, so she raises her voice a little. Every now and again she briefly points to one part or another, to a curved steel tank or to a type of steel terminus toward the back.

Susan Trumbore and her team use the accelerator mass spectrometer to analyze the amount of a heavy carbon isotope known as 14C present in a given material in order to determine the age of a soil sample, for example. Archeologists have been applying the radio carbon dating method for decades to establish the age of organic finds and artifacts by means of the 14C content. They, however, are at an advantage, because the concentration of this radioactive type of carbon in the atmosphere remains relatively constant for thousands of years, since that is where the isotope is recreated over and over again by cosmic radiation.

When plants convert carbon dioxide into sugar, they also incorporate radio carbon, the amount of which is equal to the concentration present in the air. But after the plants die, the radioactive decay of the isotope causes the carbon share to decrease with a half-life of 5,730 years, meaning this factor can be used to determine the age of organic materials.

## THE CARBON UPTAKE OF WOOD WAS OVERESTIMATED

Susan Trumbore uses a slightly different version of the radio carbon dating method, one that is suitable for analyzing samples taken within the past 60 years and for determining their age down to the exact year. The slow radioactive decay of the heavy carbon doesn't play a role in this process. What did have an impact, however, was the fact that the amount of 14C in the atmosphere rose by a factor of 100 in the 1950s due to the atomic bomb tests that were being conducted above ground.

Ever since atmospheric nuclear tests were banned in the early 1960s, this concentration level dropped again; firstly, because plants, animals and the oceans absorbed large quantities of the isotopes, and secondly, because it mixed with less carbon dioxide containing 14C resulting from the combustion of fossil fuels. This caused the concentration levels of 14C to change radically, much more so than radioactive decay would have done. For the team of researchers headed by Susan Trumbore, this steep decline serves as a reference that allows them to calculate the exact year in which their new-age soil and wood samples originated.

Since her time in Zurich, Trumbore has analyzed and dated several wood and soil samples using the accelerator. While still in Zurich, her boss once even placed a fragment of the Turin Shroud on her laboratory bench for examination. The result: the shroud is considerably less than 2,000 years old. "The examination didn't fascinate me all that much, because in the end, it didn't change anything: the skeptics feel vindicated, and the believers continue to believe that the Shroud is sacred."

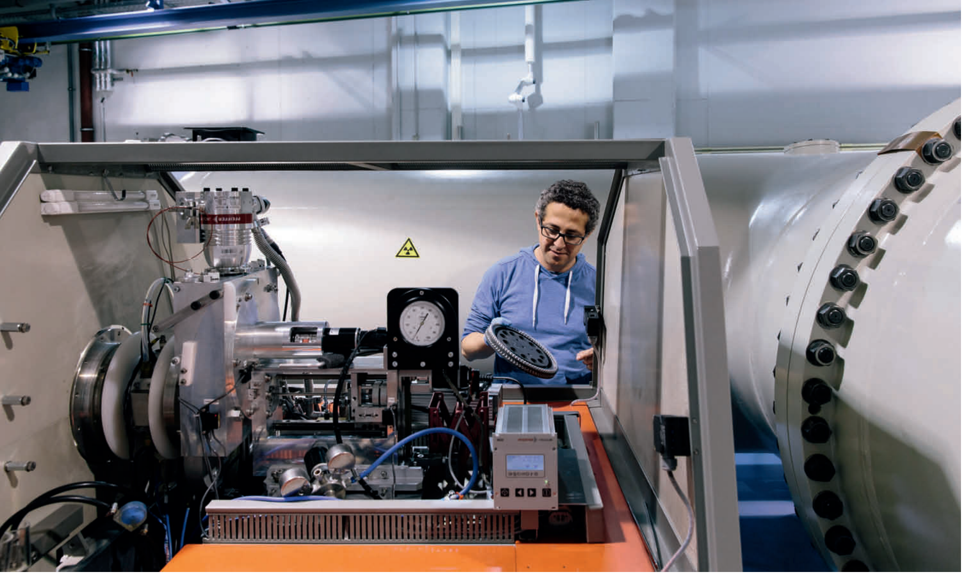
She finds the results of her scientific work much more exciting. For example: Susan Trumbore and other researchers now know that the high-energy carbon compounds that a tree uses as its reserves are stored mainly in the middle section of the trunk for many years. On the other hand, large amounts of carbon dioxide escape via the leaf stalks or the trunk directly after they are absorbed. In the tropics, the conversion of carbon from photosynthesis to wood can be especially inefficient. "That's why modern-day climate researchers overestimate the amount of carbon taken up by tropical wood," she says – an error that is now being corrected in climate models.

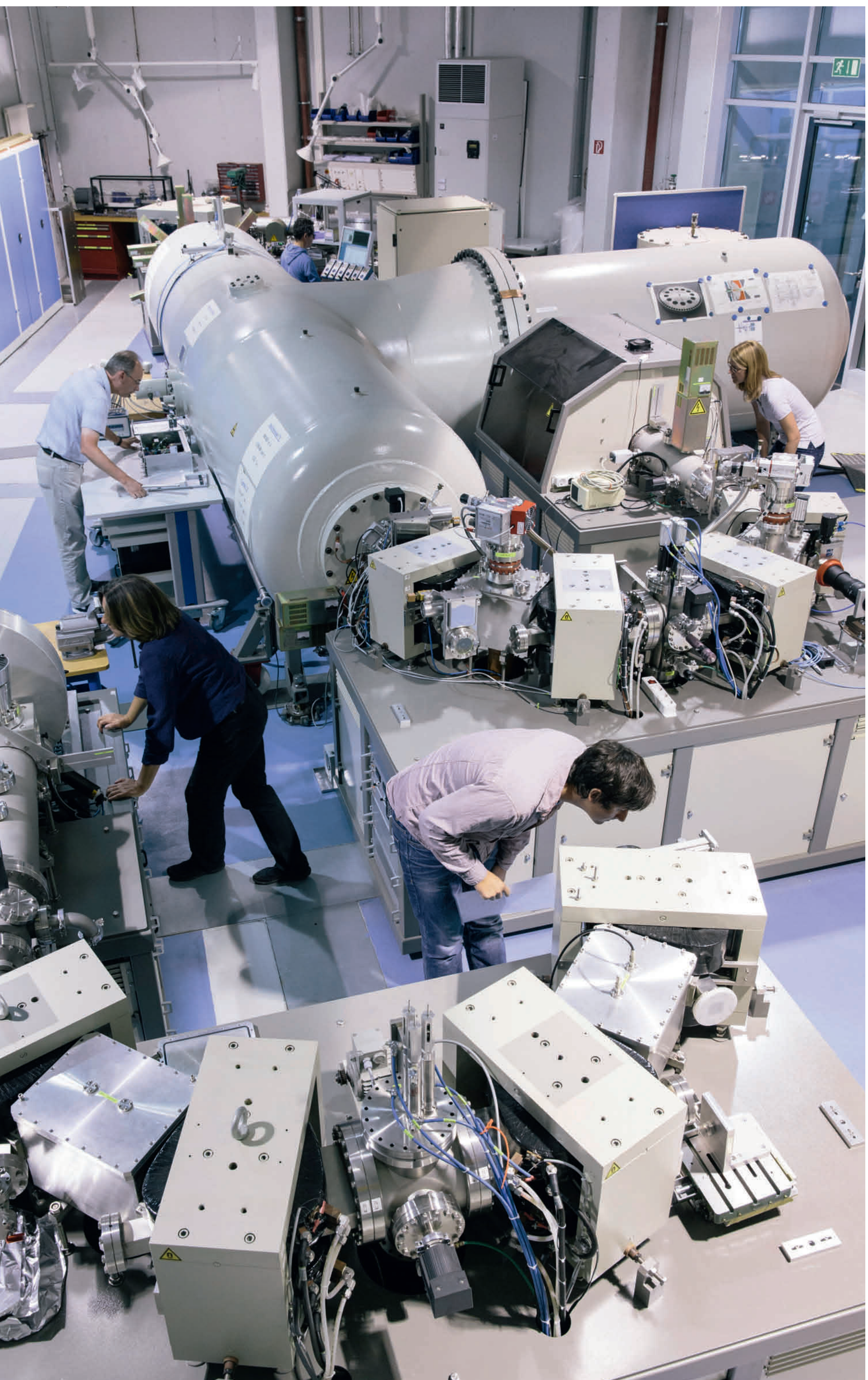
The scientific findings relating to the soil are equally important. The most robust carbon compounds are the ones that are created by fire: charcoal-like substances that can survive in the ground for many hundreds of years. Furthermore, studies analyzing 14C have shown that a range of different environmental influences can accelerate the breakdown of old carbon compounds, for example when dry soil suddenly becomes waterlogged, when ground that has remained closed for a long time breaks open, when the vegetation changes, and of course when permafrost starts to thaw.

From among this list of factors that influence how long carbon dioxide is stored in plants and soils, the two that are of particular interest to Susan Trumbore are drought and heat, not least because both of these aspects are likely to become exacerbated and more frequent as a result of climate change. One of the questions the scientist seeks to answer is what happens to the trees and the soil when forests die off due to droughts and heat. Together with her students, she studies what happens when trees starve to death. Plants take up carbon dioxide via tiny stomata in the leaves. At the same time, water evaporates through

Science around the globe: Standing on a platform, the Max Planck researchers from Jena also extracted sediment samples from Taruo Lake in Tibet (left). When taking samples at a plantation in Brazil, for example, Susan Trumbore likes to pitch in herself. She wants to find out exactly how the carbon balance shifts when rainforest is cleared and replaced by soy fields.

Photos: MPI for Biogeochemistry





these same pores. If the weather is too hot and arid, the plants close the stomata, thereby also preventing the uptake of carbon dioxide – consequently halting the formation of sugar. The plant is thus forced to use up its stored energy reserves, namely the high-energy carbohydrates. If the drought persists, these reserves will eventually be used up, causing the plant to die, the theory states.

Adjacent to the institute, Henrik Hartmann, one of the Research Group Leaders in Susan Trumbore's department, had a shelter built, under which six-foot tall potted conifers were placed – a rain exclusion experiment designed to simulate drought. Looking at the setup, one might think a Christmas tree delivery service forgot a whole truckload of trees underneath a carport. Trumbore reaches for one of the twigs and rubs the needles between her fingertips. A number of trees have been covered with large plastic bags, allowing the researchers to measure the gas exchange taking place underneath. Some of the tree trunks are surrounded by a cuff. The doctoral students use these cuffs to monitor the trunk's change in girth as the tree takes up water. "We don't yet fully understand tree mortality induced by drought. There are several possible explanations." One is that the water shortage disrupts the transport of water up to the crown of the tree like a water column in a drinking straw – spelling certain death for the tree.

Susan Trumbore speaks English. Her German isn't good enough yet, she says, with a hint of embarrassment. Yet it's easy to forgive someone who is constantly travelling back and forth between the Old and the New World. She has little time to spare for language courses or other activities. She used to play the clarinet, mostly classical pieces. "When I have the time, I enjoy going to the opera or to classical music concerts in Jena, Berlin or Leipzig." She has also been to the famous

New insights thanks to a new technique: Trumbore's team uses an accelerator mass spectrometer to analyze the amount of heavy 14C carbon contained in plant and soil samples. These findings allow the researchers to deduce how long the carbon remains stored in the materials. Carlos Sierra prepares a sample tray for the measurements (top).

Photos: Sven Döring (2)

» Susan Trumbore followed in her father's footsteps: »He was the one who instilled in me this passion for science.«

opera house in the Brazilian city of Manaus, where she has been teaching as a guest professor at the university since January. One of her colleagues in Brazil set up an initiative in which children craft musical instruments using wood from dead tropical trees. "The children demonstrated their instruments at a concert in the opera house."

Susan Trumbore isn't married. She doesn't have children. "But I do have almost 40 doctoral students and postdocs," she says, laughing. She lives for science, following in her father's footsteps: he was a chemistry professor in her hometown of Newark, a small town in Delaware on the East Coast of the US. "He was the one who instilled in me this passion for science. He always put his heart and soul into it."

## THE FIRST WOMEN TO HAVE THE WORLD AT THEIR FEET

Susan Trumbore is a woman of a somewhat short stature, but a big name in the scientific community. She says that she is part of the first generation of women who have the whole world at their feet – with less chauvinism and no pressure to conform to traditional gender roles. Her mother was a librarian. "When I think of her, I realize how many opportunities were open to me." As a student, for example, she also spent some time as a guest in the laboratories of Paul Crutzen – one of the scientists who discovered the hole in the ozone layer.

Despite these opportunities, she is one of only a handful of women in her field. In fact, only a small number of women have assumed management or director positions in Germany, she says. "At the University of California, 25 percent of the professors are women." She still collaborates with her former work group at the University of California in Irvine, where she worked until 2009. She visits her colleagues every few months.

She has noticed numerous differences between Jena and Irvine. Irvine, for example, is a planned city that was built from scratch by a company in the 1960s. With a population of just over 200,000, it really could be called a large city. "But in Irvine you meet many people from many different countries, and I love that. It's the same here on our international science campus, but not so much over in the town." Suddenly, Jena starts to feel like a pretty small place again. Nevertheless, she likes Germany and Jena: Germans get down to work. They start projects with an extraordinary level of optimism. "I mean, it's unbelievable that there are so many solar arrays here in Germany, but only a comparatively small number in California – even though we get less sunshine over here."

Hanging on her office wall is a poster charting the hiking trails in the region surrounding Jena. She enjoys going for a stroll with friends through the forests directly bordering the city outskirts. The red trail is the longest. Once a year, a 100-kilometer footrace takes place along this route. "The sign-up sheets always fill up right away." Has she ever taken part in the race herself? "No," she answers. "But some of the people from my research group participate every year." She prefers riding her bike. And Jena is the perfect place to do just that. In Irvine, she says, that was always a bit of a challenge – due to the long distances and the heavy traffic. ◂

Susan Trumbore knows the limits of her research: Whether land management will continue to destroy forests isn't a scientific matter, but rather a socioeconomic one.

Photo: Sven Döring

## GLOSSARY

**Accelerator mass spectrometry:** This type of mass spectrometry distinguishes between particles that differ in mass, thus making it possible to separate very rare isotopes of an element – such as 14C – from among neighboring molecules and molecule fragments that have the same mass. The molecules are broken down by first being accelerated and then being subjected to strong positive ionization in a gas or thin carbon foil.

**Isotope:** Variants of a given chemical element. Isotopes each have a different number of neutrons in their atoms, and therefore also differ in mass.

**Carbon cycle:** Geoscientists define the carbon cycle (also known as the carbon dioxide cycle) as the movement of carbon dioxide from the air through plants and soils, as well as through bodies of water and the organisms that live in them, and ultimately back into the atmosphere. Humans also heavily intervene in this cycle, especially by combusting fossil fuels and clearing woodlands. There are numerous feedback loops between the carbon cycle and the Earth's climate.