Tropical forests are some of the most diverse and beautiful places in the world; they also represent some of the last stretches of undisturbed or “frontier” ecosystems on the planet. In addition to playing host to some of Earth’s most amazing and unique plants, animals and insects, tropical forests also play a key role in regulating the planet’s climate. That’s because across the globe, the enormous trees in tropical forests store up to 40-50% of the world’s land-based carbon. (The oceans also store a massive amount of the world’s carbon, but we’re not taking that into account here). While this is good news for the Earth’s climate, it also means that any human activities that destroy or degrade tropical forests can have an extremely large impact on climate change.

Currently it’s estimated that humans release roughly 9.2 gigatonnes of carbon per year on average. This amount is so large it is difficult to understand what it means, but this is about equivalent to releasing the weight of 9.2 trillion full-grown cows worth of carbon into the atmosphere, mostly as carbon dioxide gas. Much of this carbon is released into the atmosphere when we use fossil fuels in our vehicles, produce agricultural products, or cut down Earth’s forests. Over the past 250 years these activities have led (and will continue to lead) to considerable changes in Earth’s climate including warmer air and ocean temperatures, droughts, melting glaciers and rising sea levels.

Of humans’ total carbon emissions in recent years from the 1990s through the 2000s, about 12-20% comes from the destruction or degradation of tropical forests – when trees are cut down, the carbon locked up in trees is slowly released into the atmosphere as the wood decays. This is why measuring and mapping carbon (or performing “carbon accounting”) in tropical forests throughout the world is a critical part of climate change science.
FOREST CARBON ACCOUNTING

In one sense, certain aspects of the methods we use to account for the carbon that is locked up in tropical trees and forests are very sophisticated. For example, scientists can now use laser technology mounted aboard airplanes or remotely controlled drones, to produce very detailed forest “carbon maps” in even the most remote tropical forests like the Amazon or Congo rainforests in South America and central Africa. These carbon maps allow us to see where the carbon is stored, and allow us to identify which areas of forest are most important for conservation.

But in other ways, certain parts of the methods we follow when measuring tropical tree and forest carbon are very simple. To measure the amount of carbon stored in a tree, we first use a series of simple tree measurements (i.e. height, diameter) combined with a set of equations to estimate a tree’s “aboveground biomass” – the total weight of a tree’s living tissue minus the weight of water, and not including the roots. Up to 95% of a tree’s aboveground biomass is wood in the main trunk. To measure carbon, we then take a tree’s aboveground biomass and simply divide it by two; in other words we assume 50% of the aboveground biomass in each and every tropical tree on Earth is carbon, regardless of what species it is.

My research (done in collaboration with my Dr. Sean Thomas at the University of Toronto’s Faculty of Forestry) focuses on understanding whether or not this generalization results in a big error in forest carbon accounting. In other words, our research tries to answer the two main questions: 1) do tropical tree species differ in their wood carbon concentrations? And if so, then 2) what are the implications of these differences for tropical forest carbon accounting?

WHY WOULD TROPICAL TREE SPECIES DIFFER IN CARBON?

Tree species of all shapes and sizes have big differences in their wood chemistry. These differences are a large part of the reason why some species are used for certain products like flooring and furniture, while others are used in making entirely different products like text-
books or toilet paper. Differences in wood chemistry across species are largely due to differences in the amount of certain molecules present in their wood. For any given tree (including the trees in your own backyard) two molecules in particular, called lignin and cellulose, make up over 95% of their wood. But the amount of lignin vs. cellulose differs depending on the species: cellulose can make up anywhere between 65-75% of the weight of wood, while lignin can make up anywhere between 20-50%.

Since more weight of lignin molecules is comprised of carbon (63-75%) as compared to the weight of cellulose (40-44% carbon), species with more lignin in their wood should also have higher carbon concentrations.

TESTING SPECIES’ DIFFERENCES IN WOOD CARBON CONCENTRATIONS
To answer our research questions we tested for differences in wood carbon concentrations across 59 different Panamanian tree species. Although this represents only a small fraction of all tropical tree species (we still don’t really know how many exist), this does represent the biggest study to date on differences in tropical tree wood carbon concentrations. Once we determined which species to sample, I went to the rainforest in central Panama and found 3-5 individual trees for each species. All of these trees were of similar size, located under similar environment conditions in the forest, and did not have any major damage (i.e. large open wounds in the main stem, major branch loss, etc.); this was to ensure our results would not be influenced by these random factors. From each tree we extracted a “core”: a small wood sample about the size of a new pencil, which we removed from the tree using a “core borer” (essentially a specialized corkscrew designed to sample wood from live trees). Once we collected all of the cores in Panama, we shipped them to the University of Toronto in Canada. In a woodshop lab at the University of Toronto, we grinded up the cores into a fine powder and freeze-dried the ground wood. The freeze-dried powder was then analyzed in an elemental analyzer for wood carbon concentrations. The elemental analyzer essentially burns the samples at a high temperature, and analyzes the properties of the gas to determine how much carbon is in the sample.

WHAT DID WE FIND?
Our study, published in the journal PLoS ONE5, found evidence that wood carbon concentrations varied a lot across tropical tree species. In the 59 species we tested, wood carbon concentrations ranged from 41.9-51.6%, and averaged 47.4%. The values we found are much lower than the val-
ues commonly assumed during forest carbon accounting (i.e. the 50% value; Figure 1). Specifically, our data suggests that if scientists assume all wood in trees (or all aboveground biomass) contains 50% carbon, this will overestimate the amount of carbon in forests by roughly 5.2%. It also means that scientists are likely overestimating how much carbon is lost from deforestation and degradation by about 5.2%. (We calculated this by taking our assumed carbon concentration value (50%), subtracting our observed carbon concentration value (47.4%), and then multiplying by two.)

SO WHAT?
A difference of only 5.2% might not sound like much, but these small differences in tropical tree wood carbon concentrations represents an extremely large error in forest carbon accounting. In forest carbon accounting, we measure how many megagrams or metric tonnes of carbon is stored in aboveground biomass, for each hectare of forest. A hectare is an area that is 100m by 100m, or about the size of a Major League Baseball diamond (these range from 0.83-1.12 hectares in size); a megagram or metric tonnes is approximately the weight of a full-grown cow.

If you assume all trees contain 50% carbon, then you would estimate the Panamanian rainforests where we did our research store about 136.8 metric tonnes of carbon per hectare in aboveground biomass. But if you factor in our data that shows trees vary in wood carbon concentrations (averaging 47.4%) then you would estimate the forest to store 129.9 metric tonnes of carbon per hectare: a difference of 6.9 metric tonnes per hectare (Figure 2). Still not convinced this is a big difference? Considering there are at least 4.3 million hectares (or Major League Baseball diamonds) of forest in Panama, this means that overlooking small differences in tree species wood chemistry can result in an extremely large error when performing forest carbon accounting.

WHAT’S NEXT IN OUR STUDIES OF WOOD CHEMISTRY AND FOREST CARBON ACCOUNTING?
After our study of Panamanian trees, my coauthors and I have begun to wonder if trees from forests throughout the world also vary in their wood carbon concentrations. To examine this we first reviewed all existing data on wood carbon concentrations in trees from 1) “temperate” or “boreal” forests in North America and Europe; 2) “subtropical forests” such as those in the Mediterranean; and 3) other tropical forests such as those in Africa and Southeast Asia.

Overall we found there is not much data available. Carbon concentrations were available for only 135 tropical tree species (this includes our study of 59 Panamanian trees), 90 temperate or boreal tree species from Europe and North America, and only 28 tree species from subtropical locations like Spain and Portugal.

Much like Panamanian trees, most trees did show a lot of variation in wood carbon concentrations, and most species differ from the 50% value that is commonly used in forest carbon accounting. One important point is that conifer species (like pine or spruce trees) tend to always have higher carbon concentrations in their wood as compared to hardwood species (like maple, oak, and birch trees).
WRAPPING UP

Our study of Panamanian trees showed that small differences in wood chemistry of tropical trees have very big impacts on forest carbon accounting\(^5\). These big differences in forest carbon accounting then have important implications for how well we can understand and predict climate change. But our research also shows that there really isn’t very much data available on wood carbon concentrations for trees globally\(^6\). So to truly understand how small differences in wood chemistry can lead to big impacts on forest carbon accounting, we need scientists to continue locating and sampling many more tree species in all forest types, from the remote boreal forests in North America and Europe through to the lush and undisturbed rainforests throughout the tropics.

RESOURCES

Figure 1. Differences in wood carbon concentrations across 59 different Panamanian rainforest tree species. Along the x-axis are species codes of 59 different tree species. These correspond to species in our published paper (Martin and Thomas 2011), but are not that important here. The height of the bar above each species represents the wood carbon concentration (listed on the y-axis), which ranges from 41.9-51.6%. The average wood carbon concentration for all 59 species is 47.4%, and is represented by the thick solid horizontal line. This average was much less than the 50% value that is often used in forest carbon accounting, when converting tree aboveground biomass to carbon (represented by the thin dashed horizontal line). Also on each species' bar are lines representing the standard error. This shows how much variability in wood carbon concentration there is in a species, across different individual trees.

Figure 2. What our data means for forest carbon accounting. The x-axis represents two different methods of forest carbon accounting in a rainforest in central Panama, where forest carbon is measured in metric tonnes per hectare (one metric tonne weighs approximately the same as a full-grown cow, and one hectare is about the size of a Major League Baseball diamond). The first method of carbon accounting, represented by the dark bar, assumes all tree aboveground biomass contains 50% carbon. The second method of carbon accounting, represented by the light bar, uses our data on wood carbon concentrations to convert aboveground biomass to carbon. Also on each bar are lines representing the standard error. This shows how much variability in forest carbon stocks there are in the forest, depending what method you use.
Q&A WITH DR. ADAM ROBERT MARTIN

How would you describe your scientific approach?

I am personally very interested in fieldwork, and I think my scientific approach reflects this fundamental interest. I have always been excited by the prospect of going to different locations throughout the world, and spending a lot of time in forest. I’ve never been particularly good with numbers or math. So although the science that I do does make use of things like statistical analysis, I am fundamentally interested in going into the forest and collecting information from trees (and tree species) that is easy to understand. I think my work on wood carbon concentrations is a good example of this. Although the results have large implications for global climate science (which is a very math- and physics-intensive field), fundamentally my work in this field deals simply with collecting, measuring and interpreting wood samples from trees.

What is your day-to-day work life like as a Forestry research scientist?

My day-to-day life as a research scientist in forest ecology can take one of two shapes. When doing fieldwork, my day commonly consists of getting up early to get to our forest sites, and spending anywhere between 4-8 hours collecting data in the forest. This can include a range of things from measuring and mapping individual trees, to collecting leaf and wood samples, to setting up field experiments. This is definitely the best part of the day. The afternoons are usually a little less eventful, and are spent in the lab making some final measurements on the samples that we collected, or entering data into a computer for later analysis.

When I’m not doing fieldwork, my day-to-day is still quite exciting – just minus the monkeys. For the most part I am in my office analyzing data and writing scientific papers (this may sound dreadfully boring, but I’ve surprised myself in now finding that I really enjoy writing and data analysis). Aside from that I also do a fair amount of teaching, so I do spend a considerable amount of time giving lectures and helping students in undergraduate forest ecology courses. I really love teaching and always learn a lot from students.

I also spend a fair bit of time trying to attend different presentations across campus. I’m especially interested in a number of other fields including food security, climate change, and human rights, so I try to see speakers from these fields as much as possible. My office life is also considerably less active than doing fieldwork, so I try to make it to the gym for an hour a day. It’s not the same as hiking in the forest, but being a researcher gives me the flexibility to get out of the office whenever I need a break.

What is the most fulfilling aspect of working in your research field?

The most fulfilling aspect of working in my field has definitely been having the opportunity to travel to some very exciting, very beautiful and very remote tropical forests. My research in Panama was based in forests that were filled with amazing wildlife like howler monkeys, parrots, toucans, and sloths, among others. A lot of my research was also been based in the rainforests of Dominica, a small island in the Caribbean (not to be confused with the Dominican Republic). Dominica and its forests were incredible, having hardly been touched by humans. They’re also the only home of the world’s largest parrot species called the Imperial Parrot, an amazing bird that is about a half metre long, and a brilliant purple and green color. I remember once having lunch right under an Imperial Parrot nest, while one walked around on the branches above us.

Earlier in my career I also spent time in forests in Malaysia and Ecuador. These places were much more remote, and are some of the most diverse forests in the world. They also hosted a large number of incredible animal species including gibbons and other monkeys, and a number of large spotted cats like margays and jaguars (though I admittedly have not seen a jaguar). I remember once trying to keep up with gibbons that were swinging through the rainforest canopy in Malaysia. They swung from branch to branch far faster than my friend
and I could run through the forest floor. These are just a couple of examples, but I think myself and my other friends who work in forest ecology and forestry, would say that the experience of seeing incredible forests throughout the world is the most fulfilling part of doing research in forest ecology.

What advice would you give to high school and undergraduate students interested in forestry or forest ecology?

I would suggest that you consider even your basic interest in working outdoors, as an indication that forestry or forest ecology might be right for you. Prior to going into this field I didn’t have an extensive background in ecology or biology, but I did enjoy working outdoors. It seems straightforward, but ultimately this was my main factor when deciding to go into forest ecology. There is a lot of ecology and biology associated with forestry or forest ecology, but you can certainly learn that along the way. I think considering how much you enjoy spending time in a certain type of ecosystem (like forests, rivers, oceans, or even your own backyard) is the most important aspect when deciding if it’s right for you.

If you’re more ambitious and excited about forestry or forest ecology, I would also suggest looking at early volunteer opportunities with your local environmental groups, like conservation authorities. Specifically, these groups provide great opportunities for people to get out and help plant trees. Believe it or not, the simple act of planting trees is excellent preparation for pursuing a career in forestry or forest ecology.