Charles Cannon: Measuring a Tree’s Pulse and Its Relationship to Tree Health

This transcript is auto-generated. Please direct any questions to isa@isa-arbor.com.

Music: [00:00:00] In every country, you know, we can work together and learn what we need to meet the challenge. Traditional skills and modern techniques, whatever language you speak, you have a world to offer every day climb with the ISA.

Dr. Tom Smiley: Welcome to the ISA Science of Arboriculture podcast series. This is Dr. Tom Smiley at the Bartlett Tree Research Laboratory host of this podcast series, which is brought to you by the International Society of Arboriculture and the F A Bartlett Tree Expert Company. Today's podcast is by Dr. Charles Cannon, who is the director of the Center for Tree Science at the Morton Arboretum. He'll be speaking on measuring a tree's pulse and its relationship to tree health.

Charles Cannon: Hello everyone. And thanks for attending our presentation on measuring a tree's pulse in relation to tree health. We hope you leave today with a better understanding of the importance of sap flow in trees, the environmental and physiological factors that affect water relation in trees and how gaining a more detailed knowledge of how it responds to climate could lead to better preventative care and management of trees. Particularly in the urban environment.

This work was a team effort involving folks from across the pond, across the border, the Northern at least, and from down under. So before we get into it, I'd like to introduce the team starting with Dr. Andy Hirons. He's a senior lecturer in Agriculture and Urban Forestry at University Myerscough.

A man, he's the man who wrote the book on applied tree biology and is an expert on tree water relations. Newton Tron has brought a wealth of expertise and knowledge about measuring sap flow along with several other aspects of tree [00:02:00] physiology to the Morton Arboretum, and has remained a solid contributor during the pandemic from his home in Canada, where he's happily been stranded since March.

Alec Downey contributed his endless passion enthusiasm for creating solutions and sparking collaborations and research. Caitlin Bride is an undergraduate and in integrative biology at UIC University of Illinois Urbana-Champaign and she was our virtual research experience for undergraduates program this past summer, working on data that we are presenting today. You'll hear directly from her.

Samantha Panock is a research assistant in the Center for Tree Science and directly manages the instruments and data collection and our tree observatory platform, and has many other responsibilities associated with this project. You'll also hear from her directly in a minute. And finally, Dr. Chai-Shian Kua, the Urban Tree Science Leader at the Morton Arboretum has been connecting dots and bringing together folks with great ideas for years and has been the glue holding the tree observatory together.

And now I want to hand the mic over to Andy, how.

Dr. Andy Hirons: Well, hello, all and thanks to Chuck, for introducing the team, it's really fantastic to be able to work in collaboration with you all. I'd like first to introduce some fundamental concepts relating to tree water relations and sap flow. Of course, when you look at the percentage of water within the tree and the roles it plays, it's easy to see that it's fundamental to tree.

Up to 95% of the non wood plant parts are made up of water. Even wood can be around 50% water when it's fresh. It's important for numerous biological processes, such as photosynthesis and nutrient acquisition. And it provides a substrate for biological processes. And as a solvent for gases minerals and growth regulators. Is critical to cellular structure. One of the interesting things about water and trees and [00:04:00] plants also in general, if you like, is that despite its value, only about 5% of water is taken up by the tree is and retained in the biomass. Most is lost back to the sky. In a sense is a highly [unknown] process then isn't it.

But one which is remarkable because all that water uptake the tree goes through, it doesn't need to expend any metabolic energy to get it from the roots right up to the leaves. That's potentially well over a hundred meters away.

While the remain some controversies in the academic community, the overwhelming majority of plant scientists, except what is known as the cohesion tension theory. The origins of this theory actually go back a long way to 1727. When Stephen Hails wrote for tho it is plain by many experiments that the sap enters the sap vessels of plants with much vigor and it's probably carried up to great heights in those vessels by the vigorous undulations of the sun's warmth. Well, it is a really good start, the vigorous undulations and the sun's warmth. But the next clause goes on to say about vibrations in the vessels, which is not quite correct. What we now understand as cohesion tension, tension theory is generally attributed to Dixon Jolie and their seminal paper on the sense of sap in 1896.

So the cohesion, intention theory, essentially states that water or sap more precisely moves down a gradient in water potential. So from a high or less negative to a low more negative water potential. Water potential itself is made up of a number of components. [00:06:00] The most important in the tree, are turgor potential, osmotic potential and gravitational potential. And in soils, something that is a matrix potential is also important. Today I don't want to get too bogged down by the nitty gritty of how those water potentials are calculated. You'll see that I put a few options for further reading on the slide, but if you look at the schematic on the right, you can see that the soil has a higher water potential than the root.

So approximately minus 0.3 megapascals was for example, the root is higher than the, the soil. Sorry. The roots is higher than the trunk, the trunk, then the leaf and the leaf from the air. So this gradient drives the uptake of water from the soil and the transport of water through the tree and into the atmosphere. Thus initiating sap flow.

Interestingly, it's a physical limits of trees and their ability to withstand such high negative pressure that limits the overall height of trees. And that's a really important idea that this negative pressure is limiting to the overall height of trees.

When we think about the soil then the availability of the water from the soil is governed by the soil water potential, that basically the tree needs to be able to generate water potential that is more negative than the soil water potential. If it's to extract water from the soil, however, there will become a point and in temperate trees, it tends to be between minus two and minus four megapascals when the tree reaches its permanent wilting point or the toba loss point. When it can no longer extract water from the soil, the soil just essentially is holding onto the water too tightly at [00:08:00] that point. And when this point's reached in relation to the percentage salt water content depends a great deal on the, on the texture of the soil.

So for example, it might be between 10 and 15% water content in alone, but less than 5% in a sandy soil. So for this reason, it's never really a good idea to rely on the soil water content. If you're looking to evaluate the effect of soil moisture on the drought response. Trees experience, so water potential and not so water content.

Of course, the nature of this, what we call the soil water release curve. Also informs how much water is available to the tree within any given volume of soil. In the right-hand figure, you can see that the water, the available water, the difference between field capacity and the permanent wilting point is only about

7% in a soil, but can in a, in a sort of some soils in a sandy soil, but can be over 20% in the low. So it's important to remember that the properties also have a huge impact on the availability of water to the tree.

Well, in addition to responding to the soil water status, the tree inevitably has to respond to the atmospheric demand for water as well. And this is mostly driven by two variables, air temperature and relative humidity. The data that comes from Northwest England so the temperatures in bay probably look a little disappointing to many of you, but I can assure you this was actually a really nice spring month for us.

We even got over 20 degrees Celsius that 68 Fahrenheit. For those of you, that don't deal in Celsius. The vertical gray bars [00:10:00] shading represents the nighttime. So you can see the temperature and relative humidity tend to mirror each other. With temperature going up during the day and relative humidity decreasing during the day and vice versa at night. When it comes to measuring atmospheric demand for water, though, we tend to integrate these two variables into something called the vapor pressure deficit.

And on the top panel that you can see this vapor pressure deficit, the integration of temperature and relative humid. And as you might expect is it increases during the day and it goes down at night. Quite often to more or less zero but not always, depending if the nights are warm.

Now, when I was first exploring this field, I can never understand why we talk about water potential in the soil and the plant, but then switched to VPD in the air. And to be honest, I, I think the basic reason is it as much tricky to work out the water potential the air, because it has something called the modal volume of water that changes with temperature. I won't bore you with the details, but if we assume that the air temperature is a constant 20 degrees, then I plotted the water potential of the air for the month that we're looking at.

So you can say that the temperature really only represents a, quite a small error in these calculations. The point really is just to show you that the water potential, in the air is always way more negative than that, of the plant or the soil. It regularly gets down to below minus a hundred megapascals. You can see that during periods of rainfall, the water potentially the air is much higher, something around minus 25 megapascals and the corresponding VPD is much lower.

I hope that you can see that there's very, a very good mirror light [00:12:00] relationship between VPD and the water potential of the air. The VPD is much more easily calculated. We tend to present the drying force of the air as VPD, rather than water potential.

Here the upper panel is VPD for the period we've been looking at. And the lower panel is sap velocity of a particular cherry, prunus maackii. And look how closely the driving force of the air matches up with a sap velocity in the tree. In periods of high relative humidity, cool temperatures and rain the sap flow is surpressed. And in dry periods with relative, the low relative humidity, the sat flow reaches its maximum level.

I think you can see that the sap flow is a really powerful tool for monitoring a tree and its function and response to the environment. With data, being able to collect this being collected, something like every 10 minutes you get near continuous dataset. And insensitive to the adaptic as well as the atmospheric conditions. It integrates the root system and the crown. So it's really powerful from that point of view.

Well in these next few slides, the data from the forestry plots at the Morton Arboretum. Samantha is going to talk to you much more about this shortly, but I just wanted to show you how sap flow can represent the period of leaf expansion as well. You can see in this platen the [unknown], essentially expanding its leaves during June so that gradual [00:14:00] increase in sap flow as the crown and the leaves expand.

Data like that probably easier visualize as mean daily values. And so with the exception of some very low VPD days, you can see this steady rise, can't you, in a sap flow throughout the month of June.

And if we just focus in, on kind of region of interest, if you like, the shows, well here, I've just picked a few days that are quite diverse. We can see that how, how rain events can suppress the sap flow trees, either in the middle of the day, like on the 16th and the 21st of July, or they delay sap flow all together where we observed a very wet morning on the 18th of July. You can see that that rain period really delayed sap flow to pretty much halfway through the day when it then started flowing again.

So it's quite sensitive and you can pick up quite a lot of signals through understanding the sap flow. You can see on good sunny days, a, a sort of book-ending this particular periods and the beginning of the end of this particular period. You can see that the sap flow rises very steeply in the morning plateaus during the day, and then declines very sharply in the evening.

I'm going to hand over the Chuck now, but I'm going to speak more about sap flow and how it can be useful to us a bit later. But good. Now let's, let's hand back over to Chuck.

Charles Cannon: I need to unmute myself and start my video. Somebody needs to start my video, I guess. I'll go ahead and start talking. [00:16:00] Thanks a lot, Andy, for that great explanation of the factors that affect sap flow in trees. Now tree ecophysiology is not really my scientific specialty but I see the topic as very central to our ability to help trees adapt to challenging urban environments and in selecting the right tree for the right place.

And so in 2016, I actually attended the ninth international symposium on sap flow. Held at Cal state Fullerton, and that was organized by Dr. Jochen Schenk. I was really looking forward to catching up on all the latest ideas and technology that people are using to measure this important physiological factor.

But during the symposium Jochen introduced the idea of sap flow being a river to the sky. And I was profoundly struck by the beauty and the power of that analogy. And there's a great deal of truth to it as well. As Andy mentioned transpiration, most of the water just passes through the tree and transpiration the loss of water bay from through the leaves of plants in the, into the atmosphere is a major component of the Earth's water cycle.

And it comprises the majority of the terrestrial eco E uh, evapotranspiration that occurs on a global scale. So truly a sap flow in our forest, both natural and urban forests river to the sky that's equivalent in volume to the actual rivers flow into the ocean. And I think that's very clearly highlights the overwhelming importance of plants and their water relations to the global climate and distribution of precipitation and atmospheric community.

So on the next slide, I want to return to the idea of sap flow, being a tree's pulse and dig into some of the details of what that means. This is pretty much the same slide that Andy was just talking about. So he was talking about those factors that affect it. And of course, solar radiation is one of those things, night and day, are very important part of the cycle.

And so trees pulse only happens once a day and comparison to what happens in humans. Our heart beats very [00:18:00] rapidly throughout the day. But the tree pulse is a singular event through the day and it responds very dynamically to what is going on in the environment, whether it's raining, whether it's cloudy and all of those kinds of things.

And so, and there are different parts of that cycle that we can begin to pay attention to and try to learn about. And you can notice, even during the nighttime, how far down the sap flow, how much it declines really, also responds to some extent. So on some days on those bright sunny days, you see it doesn't quite go down as much, but on the wet days, it really goes down to zero.

So there is some kind of hydration that the plant is still trying to achieve even during the night on some sunny days. So there are different parts of the cycle that we can pay attention to and learn different things about what's going on. So this responsiveness is quite remarkable considering the relative simplicity of the anatomy.

So I want to think about on the next slide, kind of how we di, uh, interpret these dynamics in humans, and look briefly at what we think about when we look at human health. So when you go into the doctor's office for your checkup the nurse will take your heart rate and your blood pressure as a very first step.

And this information provides a physician with a quick snapshot of your basic health and can then can look at your medical history and it can make a judgment about your overall health condition and whether you need treatment or whether you need further studies. So each person has a unique combination of heart rate and blood pressure. And but, the cycle of the heart really remains the same for everyone.

So we can look at that those phases of the heartbeat. For example, if there was some irregularity at the doctor detected, he can, she can send you in to look at your EKG and look at these phases in more detail and try to interpret, you know, what is going on. If you're having some kind of a arrhythmia or some issue with your heart beat heart rate.

So we would like to get to this point, and this, this level of knowledge, this level of understanding is built [00:20:00] upon decades, centuries, of detailed measurements. A large number of people in the population. So we need to build up this kind of understanding of trees as well. So trees pulse is really fundamental to its health. And so we need to adopt a similar approach to trying to understand it. So looking at the responsiveness of that sap flow to environmental change, the volume of water conducted over a period of time and how that changes even through the years. So we need to kind of understand how tree progresses through its different stages of maturity and growth, so that can give us a nice insight into the overall health of a tree.

It can be a basic tool for detecting and diagnosing the problems that tree might be having. When, before they manifest themselves as like kind of half dead crowns or major die back is how we often do determine that a tree is declining now.

So in the next slide we need to understand the basic anatomy of a tree, just to kind of as a review, to gain some insight into sap flow. And first I want to just point out the remarkable fact that a tree conducts gallons of water every day up into the leaves that it can be tens of meters above the ground, against gravity, without using any muscles or any kind of pumping action. You know, as Andy pointed out the kind of the first suspicions about how this happened, they really thought there had to be some kind of agent. There had to be some kind of active process that this is occurring through, but it's really just simply through those gradients of, from soil to atmosphere that create this flow.

And so this flow is actually occurring through dead tissue, the xylem, and that's constructed by the tree each year and a careful balance between above and below ground environmental conditions.

To me, the trees are simply the most remarkable living organisms. They link the soil to the sky. They really do integrate those different environmental conditions in a way that's very specific to that location. So as I said about human heart rate and blood pressure, each tree is a different individual and it's adapted to those particular soil conditions, [00:22:00] light availability, and all those things change through time, particularly given the life span of a mature tree, which can be centuries.

And so I really can't get pretty excited about this because I think it's a truly beautiful example of how evolution produced this elegant, very robust, engineering solution over hundreds of millions of years, to a very fundamental problem of conducting water from the ground up to the leaves where they can be, gained solar radiation and conduct photosynthesis.

So I'm sure we all know these basic facts that I'm talking about, but it's really nice to review them again. So the stem of tree has only a thin layer of living tissue just under the bark. And it's really kind of the sandwich between two types of cambium. There's a court cambium, which is on the outside that produces the outer bark. Then you have the vascular cambium on the inside and in between that is the phloem. And so the Cambium layer can be thought of as, as a stem cell, if you kind of thinking kind of anthropomorphic terms or zoological terms, because they're really the cells that are a plural potent, and it can really mature into any kind of tissue.

So that's why you have, you know, different kinds of tissue emerging from this layer that's just under the. So the xylem is formed on the inside of the cambium and the tissue begins to die that reaches maturity and begins to perform its function. So in this xylem, collectively becomes wood most of the sap flow occurs in the newest xylem and the outer portions of the wood are often termed at sapwood.

And we won't get into the details of wood anatomy, but there it is a simple system, but there are many different kinds of tissue that are mixed in here and different types of structures in different species, but this illustration basically captures the, the basic idea. So one thing to note is that the system is larger uni-direction with most of the water traveling up and out into the atmosphere. And only a small portion is returned down through the phloem, but that's a very different process. And so just for clarity sake, as we are talking about sap flow, we're focusing entirely on the xylem and we're not even thinking about [00:24:00] phloem. That's a whole nother issue that we should be studying in more detail as well.

So on the next slide and looking at xylem, there are also different kinds of anatomies. And here I'm showing you three very clear examples of the major types of hardwood or angiosperm wood. So just by looking at these cross sections, you can tell it's sap flow must be very different in these different arrangements of xylem tissue.

As I said, there are clear, these are very clear examples of the differences from the ring porous, where you have very large vessel elements in the early season growth to semi-rigid porous, where they're scattered more scattered and not such clear differentiation between the early and the late growth.

And then you have the diffuse porous where they're just kind of evenly scattered. So you can imagine there are different species that are kind of intermediate between these major types and the arrangement of vessel elements, and tracheids can vary among the major groups. And then you have softwood and gymnosperms species that only have tracheids is we should, they're kind of primitive form of asylum and their anatomy is somewhat more simple than angiosperms.

So I just wanted to point out these details to emphasize that while we're discussing tree sap flow in the general sense. There's a lot of complexity underlying this process and each individual species just as an individual oak tree differs from other oak trees. The oak species are different from maples species.

And so we'll need to develop a database for each one of these in a sense. And so there's no real easy solution rather than just gathering a lot of data through long periods of time.

So on the next slide, the point I'm trying to get across is that the anatomy and physiology of a tree is largely a mechanistic, one directional flow system with a variable water source in one end. And these kinds of finely tuned valves or the stigmata in the leaves on the other end. And we have worked out a lot of the math, I mean, so we've agreed upon the basic principles that are driving the system. So we should be able [00:26:00] to create a predictive model for how much sap flow will occur given a particular tree species in a particular setting, given a particular set of environmental conditions. And this conduit between the uptake in the roots and the release in the leaves, it must be sealed and it must be continuous so that the water column remains unbroken.

So we simply need to gather a lot of set flow data from many different tree species in different environments. Plug in and work out those detailed parameters so that we can make those predictions. And so once we have that kind of robust predictive system of how a tree should be performing, we can understand that when it's not performing as predicted, we can then begin to try to look for various physiological or health factors that might be causing this tree to perform differently than we might expect.

And so now we're finally going to start to get into some data and stop lecturing at you on kind of things you might already know, but it's good to get a refresher. But I'm going to hand it over now to Sam Panock, who will introduce the project and data that we'll be discussing later today from the Morton Arboretum.

Samantha Panock: Thank you Chuck. I will give a brief background on two projects at the Morton Arboretum: the forestry plot project and the tree observatory project, or platform.

So to start the Morton Arboretum in Lisle, Illinois USA is 1700 acres of beautiful land from natural regenerating forest, especially planted collections. It is the perfect place to study trees. One of the earliest aims of the Morton Arboretum was to study timber trees for reforestation purposes. Planted in the late 1920s, some of the early timber and forest restoration model culture trials still exists in our collections. Scientists in the center for tree science, [00:28:00] launched a long-term and multidisciplinary study of these mature monocultures. And that is what we are calling the forestry plot project.

To understand how they both adapt to and transform the site where they were planted. There are monoculture plots of oak, norway spruce, tulip poplar, chinese juniper, american sycamore, and more. We are going to limit our data discussion today on the american sycamores.

Can we advance one more slide? There we go. A sister studies who the forestry plot project is the tree observatory project. The tree observatory project studies, the same species of trees that are in the forestry plot project, but on an individual basis. In other words, these trees are individual open grown trees in the Morton Arboretum collections. They are not in a forest and they are not influenced by any neighboring trees or plants. The species in the tree observatory project are Buckley oak, Norway spruce, chinese juniper, tulip poplar, and of course the american sycamore that we're going to explore data. The main goals of this sister study, this tree observatory project or platform is to one simultaneously collect numerous streams of data from many parts of a plant over many years to create an integrated baseline for physiological, structural and behavioral responses to environmental conditions, to rapidly changing environmental conditions.

Second goal of this study is to create a platform for testing, inventing, and comparing emerging technologies, methodologies, and sensors. To gather this data in aa an efficient and autonomous ways, [00:30:00] particularly early in collaboration with engineers. Third goal is to identify the most effective data collection methods that can be cheaply or affordably and effectively spread much more widely on many trees, in many locations.

And the last goal is to compare tree functions, processes, and adaptations of open grown trees like urban trees, like the ones we're seeing in the tree observatory project to trees in a natural forest, like the trees in the forestry plot project.

We currently have each tree observatory, tree instrumented, and monitored using sap flow sensors for water dynamics. Then durometers for trunk expansion and contraction, several hobo sensors for canopy climate data. Several many risatron tube installations to capture root growth. Collections of soil cores to analyze soil quality. Several tree cores, analyze age and growth history of a tree. We have drone footage for 3d modeling. And we have several leaf litter baskets deployed, analyze carbon and nitrogen relationships.

The forestry plot trees are monitored in a very similar, if not exact same manner. Ideally, we want to expand the tree observatory project, not only on the Arboretum grounds, but across arboreta and gardens around the country and around the world at the Morton Arboretum, we want to add replicates of each tree species to the tree observatory projects.

And then we want to expand the study to different climates and environments around the world.

Just go back to the previous slide for just a second. There we go. So like I previously mentioned, the [00:32:00] fourth goal of the tree observatory project is to compare tree functions, processes, and adapt adaptations of open grown trees, like the ones in the tree observatory project, to trees in a forestry setting, like the forestry plot project tree.

We are very interested in comparing the growth and health of open grown trees with trees growing in closed canopy forest. We often talk of the urban forest and a growing body of work demonstrates that trees compete, communicate and facilitate one another in forests. The open grown tree can act as a control for our understanding of how the dynamics and benefits of a forest emerge.

We have mashed up a small number of tree observatory trees with the same species in the forest plots for longterm comparisons of trees growing in these two major environmental settings. This slide illustrates just the physical observational differences between an open grown tree and a forestry plot tree.

There are clearly some different interactions and processes happening even within the same species that affect how they grow, adapt and survive. We will now hear from Caitlin McBride. As we take a deeper look into one of the major ways that we monitor and compare our trees in these projects, which is measuring sap flow.

Caitlin McBride: All right. Thank you, Sam. So before we get into the data too much, I wanted to give you a little bit more information about the technological side of our measures. So in order to measure the sap flow for the tree observatory plot and tree observatory data, we installed SFM one sap flow monitors, and these automatically took readings every 10 minutes.

The sap flow monitor consists of three probes inserted directly into the sapwood of the tree. The probe in the middle is the heater. The probe above the heater is the downstream temperature probe. And the pro below the heater is the [00:34:00] upstream temperature. The temperature probes are named according to the direction of sat flow in the xylem. The temperature probes, each contain an inner sensor, which is located closer to the heartwood and an outer sensor, which is located closer to the bark.

These allow us to measure the sap velocity at different xylem depths. In order to take a sap velocity reading, the monitor will take the ratio of the temperature increase at the upstream and the downstream probes. This is the origin of the name of the heat ratio method. So the first step of a sap velocity reading involves taking the average temperature at both the upstream and the downstream probes over the course of 80 seconds.

Then the heater emits a heat pulse of known energy. After approximately one minute, the sap flow monitor takes the average temperatures for the upstream and the downstream probes again. The heat ratio is calculated using this temperature increase. For example, if there's no sap movement at the time of the reading. The heat pulls should reach the downstream and the upstream probes at roughly the same time resulting in a ratio of temperature increase of approximately one-to-one. However, if there is a large amount of sap flow, like during the middle of a sunny day, when the rate of transpiration is high, the heat pulse will reach the downstream probe well, before the upstream probe, this will result in a large downstream to upstream heat ratio, which allows us to see that there's a large amount of sap movement happening.

If there is a small amount of sap flow, such as very early in the morning, the heat pulse will still reach the downstream probe before the upstream probe, but the ratio will be closer to one-to-one. By measuring the heat ratio we can gain a precise measure of sap movement as it changes throughout the date and the growing season as a whole.

It's important to remember that the sap flow monitor only measures the sap velocity at one point in the stem. But the values that records are very precise. This precision allows us to use a number of correction factors in order to develop an [00:36:00] accurate estimation of tree level sap flow in overall transpiration for our sycamores.

So with that, I'll hand you back to Chuck to talk about our data a little bit more.

Charles Cannon: Great. Thanks a lot, Cailtyn. Thanks a lot, Sam. Now that you have the kind of context of where this data is coming from, and just want to show you a few examples of the kinds of things we're seeing, again, this is a longterm study. We're building up lots of data surrounding these different plots and trees, but this shows you two different trees at different points in the season.

And I think this is kind of interesting idea because the day length changes right through the growing season, but we can see the solid lines are showing one tree that's tree five there T five there, and then the, the dot the thinner line with the dots is another tree. And the different colors represent the different seasons.

So the July is the reddish line. The August period is the green line. And then the later September period is the blue line. So you can see, even though July is the longest day and it might be the hottest part of the year, the sap flow is actually lower in both of these trees during that period of time than it is later in the season.

And you can even see in September, both of the trees get started quite rapidly after sunrise. And so it's kind of later in the season the tree is really prime and it's, it's really functioning. It may be during those summer months the heat stress might be a little bit more severe. So there are interesting seasonal changes in these trees as they respond to the environment.

So the responses are not consistent throughout the season. We actually need to know what time of year, what phase of the phonology is the tree, to really understand where the sap flow should be. So this is just an illustration of how kind of complicated these dynamics can be. [00:38:00] So on the next slide, just want to show you the synchronization.

So you already saw a slide like this, the same time, the same time period that Andy showed for one tree. But wanted to show you the synchronization among all of these trees and how they all do react very dynamically and in a very similar way to those same events. So you can see that as Andy described it to kind of bookend by sunny days with full sun, but then there are a few rainy days in here in the middle on the.

The second day, there's quite a lot of rain. And then the July 22nd, the July 21st day, there's right in the middle of the day. And you can see, they all responded very quickly and very similarly to these environmental events. And there's some kind of interesting differences. You can see that each individual tree is slightly different in kind of the shape of its curve.

And you can see the pink line is the tree observatory tree. And so the pink line at the bottom, there is the tree that's open grown. And so you can see the shape of that curve is actually quite different than the trees that are growing in the forestry plots. And we probably think this is due to the fact that, you know, because it's standing out in the open, the sun rises, it gets hit immediately by full sun. And that continues through the whole day. So it reaches a maximum very quickly and then kind of continues at that sap flow level and then drops off while the ones that are in the forestry plots are shaded. And so they reached their maximum later on in the day, when the sun gets more overhead, more directly overhead, there's less shading from their neighbors.

And so it takes them longer to really reach that maximum. And they stay at that maximum for shorter period of time. Some, some ways you could imagine the open grown tree, it could be more stressed. If the soil water potential is low, the soil soil water availability is low. That tree could become quite [00:40:00] stressed because it actually doesn't kind of have this buffering of shading of its neighbors.

So this is just a simple demonstration of both the synchronization, how the trees all do respond to these major events in a very similar. But they all each have little idiosyncrasies depending on exactly where they're growing, how much they're shaded by their neighbors and so forth, and the lower magnitude of the, of the tree observatory tree or that pink line is a little bit we're not quite sure exactly why that is, but I can talk about it on the next slide, where we're showing you this is the open grown tree or that pink line over two seasons.

So this is in 2018 and 2019. This is the daily water use for that one tree. And you can see in 2018 of those dark colored bars it was moving a lot of water every day. And so the average water use was over a liter every time and pretty much, and then drops off. And then the next summer you can see it's, it's depressed and there's, it's actually never reaches the same potential, never reaches the same level of, of water you said it did in 2018.

And during the spring of 2019, it was very cool and wet. And actually there was a very bad [[unknown] outbreak particularly in these open grown trees. And we think this, slowness of response. You can see it doesn't really kick off as soon in the year. It's not even until kind of mid July that it really gets going.

So it had to replace all of that tissue that it lost to the [unknown] outbreak. And then it never really reached that same potential. And you can see as well on the lower graph in the daily stem growth, it grew a lot during that 2018 season you know, well over 30 millimeters in size over that season. But in the next season, it didn't even grow 20 [00:42:00] millimeters.

So that, [unknown] outbreak had a huge impact on this tree. And we do think they, that open grown trees seem to experience that worse than the forest replot trees. And so perhaps that affected the magnitude. There could be some wounding impact as well. So as Kaitlin described the, the technique that we've measured, the sap flow in these trees, there is a kind of impact of the the tree recovering from those probes being stuck in. And so kind of it changes the, the measurements and the accuracy of those measurements a little bit and can decline the, the measured magnitude of sap flow. So there are lots of things to keep abreast of and keep on top of, as you're, obviously you're taking these measurements as well.

So, this is just kind of a quick snapshot into some of this data. We'll be presenting these data in the coming years in much more detail and kind of more full analysis, but we're just now getting enough data we can begin to understand and interpret them as they go. And one kind of thing I wanted to point out to you.

I mean, someone who's worked a lot in the tropics. The period of time in which these trees can grow is relatively short as well. The number of months, these trees are actually very actively growing and have sap flow is relatively small compared to the entire year. So it's pretty amazing that these trees can grow so much and become so large, in these climates where the growing season is relatively short.

So I'm going to now go back to Andy and he's going to talk about his research.

Dr. Andy Hirons: Thanks Chuck. Yeah, that was really interesting to hear about those thoughts. So it was great to hear about the long-term monitoring of forestry plots. Plus. Now I'd like to share with you some work that uses sap flow to understand the effect of water logging on trees over a much shorter time. And this is what was [00:44:00] funded by the Highland R. John's grant from the TREE Fund.

No two key hypothesis. I was exploring really. Firstly, that water logging will reduce sap flow in trees. And secondly, that the extent of the decline will be related to the tolerance of the species to water logging. I had a, a basic fields trial set up where I installed a small containerized nursery and, you know, had the series of rows of trees with a range of different species on them.

And then I just really set up some water logging cycles. So where I, I subjected the containerized trees to water logging. And then I recovery phase, where I drained those water logged trees and monitored their response.

And I was really just looking at two key variables, sap flow, as we've been discussing, using exactly the same technique, the SFM one sap flow meters, and then gas exchange. So this is prunus macchia. It's a sensitive species. It shows in the pre-treatment facing you'll see, rather synchronous sap flow between the species and then quite quickly as we entered this water logging phase, you see the departure of the water log tree, that dotted line from the control.

And I should note that is that continued through the water logging cycle. Even at the end of that water logging period, there were no visible symptoms of decline within the crown. They looked exactly the same, the two treatments, and even actually when the, the trees were drained, we didn't really pick up any major recovery.

In the sap flow at [00:46:00] all in those water log trees. And this is just that same sap flow trace on the top plot but you can see the photosynthesis and the stomata conductance data on the, on the middle and lower plots there. And you can see that, you know, that early stage in the water logging the cycle that we picked up the departure of the waterlogged trees from the control trees in the sap flow trace.. We can also see a really highly significant reduction in both of those two key gas exchange variables.

If we take [unknown] and this is the same, the same setup. So again, pretreatment was pretty consistent when those trees were waterlogged. We saw the control treatment you know, continuing to do your thing and the water log trees really declining very, very rapidly.

And interestingly, this species, when we drained the containers, we actually continued to see a decline in the sap flow responses in that previously waterlogged set of trees. And you say, we've n=6. So actually what happened was over the course of that recovery, so-called recovery cycle, it was that the tree totally lost its leaves and it's just, the [unknown] were left on the, on the, on the tree there.

So that was really a very, very significant response. Not only did we seem to have, seem to have this effect of the water logging, but also what we might probably call a [unknown] stress. So where we have perhaps some toxins released by the reoxygenation of the root system that ultimately led to the well, the, the total [00:48:00] [unknown] of the crown.

And you can see, of course, all of that picked up in the, in the sap flow signal. So they're very minor amounts of sap flow a couple of weeks into the drain cycle are probably just going the sap flow, just going through these [unknown] and, and the [shoots, but without any leaves and of course, well, we could measure photosynthesis in the first sort of stage of that stress recovery cycle. But obviously when the leaves were lost we lost those gas exchange values as well. But I think you get the impression that, yeah, very substantive response to water logging there in the [unknown] and the maple.

Okay. So this is a [unknown] white willow, and this is a tolerant species. The date looks a little bit noisy. It was really quite a sort of rainy period, you know, typical similar summer in Northwest England. And you can see the, the waterlogged phases begun there. And actually there's no discernible difference in the sap flow whatsoever. Between the water logged and the control set of trees.

So obviously I was really excited by this because it seemed that we were able to distinguish is quite profound differences in species response, using the sap flow signal. And then just validating that response if you like with the gas exchange.

So again here we see that that sap flow trace with the, with the gas exchange. And you can see that, although actually we were able to pick up some highly significant differences in the photosynthesis and a stamata conductance at peak stress after seven days of water logging in this [00:50:00] case. Within that first week of it being drained, the, there was a return to control values ofgas exchange. And so that the recovery was much, much better, even though we, we were able to pick up some differences the peak stress.

Of course, in willows one of the things that they can do is create these hypertrophied lenses cells. And you can see around the base then of the stem, just underneath the water, you get these hyper hypertrophy lens cells or enlarged lens of cells that were apparent on the water logged trees are not so on the control trees. And that's really just an anatomical or more for anatomical response to the water logging enables much more effective ventilation of the root system.

So the conclusions from, from that sort of first phase of the water logging sap flow response trial, was it yeah, we can, we seem to be able to use sap flows, a tool to evaluate a waterlog interlance. They seem to be, well, at least three, possibly more responses to the sap flow, or of water logging to sap flow.

The first is no response as we saw in the, in the willow. And that's an unsurprising in some senses, but it's nice, nice to see that we don't get a substantive response in something that was known to be a very flood, tolerant species. We can see a decline throughout the water logging period, and then stabilization upon draining. And I don't know actually how long it would have taken for, for those trees to recover, perhaps within the growing season, perhaps it might have taken multiple years for that to recover. And that's the value of having long-term datasets. Like they're doing it Mortum Arboritum, where you [00:52:00] have those stress cycles and then you can follow them through and see how, how long it takes for them to cover, to recover up the pre-stress values.

But and then the third, the third, the third so response I picked out was this declined during a water logging period, and then a continued decline if you like through the drain period. As we saw in the Normway maple, that so alongside sap flow, photosynthesis and stomata conductance are very sensitive to water loggin.. And I think a really important take home message for us arborists who might look at trees visually for much of the time, rather than analyzing them physiologically, is it visual analysis is actually pretty useless for identifying physiological stress.

Okay. I think I'm going to hand back over to Chuck to take us to the end of the presentation. Thanks Chuck.

Charles Cannon: And I am muted. So yeah, I've heard, that's like one of the most common things said these days in the Zoom environments, like you're muted. So yeah. Thanks a lot, Andy. That's a really good wrap, uh, experimental data that indicates kind of short term cycles you can detect that a tree is declining from the sap flow. Even before it becomes a visible physiologically and, you know, decline in the leaves or in the. crown.

So we've been looking at kind of thinking about sap flow as a health indicator and how we might be able to use this in a more applied sense. And so I really kind of want to end up the presentation kind of thinking about how to build tools to measure this fundamental aspect of tree physiology, cheaply.

So we can gather. Large amounts of data, on a large number of trees, across a wide range of species and conditions. [00:54:00] And so one thing that we've been doing at the Mortum Arboritum, working with engineering teams of students and faculty at several universities around the Chicago region to try and solve some of these problems.

We already know how to measure sap flow, and we have high quality automated solar powered sensors that exist from the ICT international, the SF one sensors. But they are pricey. They take, you know, a certain amount of expertise to use. And so we've been challenging senior capstone students and various engineering programs around the region like Northwestern University, to design and build a sort of tree Fitbit for arborists and homeowners.

Okay. One team actually made quite a bit of progress and they gave themselves a rather inappropriate name. I think of team amateur hour. I think they were just being funny about it, but I think they really did a great job of developing a kind of a vision for end to end design from the hardware to the mobile app. Kind of interacting with the homeowner or the arborist.

And they did a really impressive job of thinking through the whole process, how the fitbit function, what benefits provide to the users. And this included the idea of having a health index that was based upon this predictive idea that sap flow should be largely responsive and depend upon both both the species and environmental conditions.

And I really think there's a lot of potential there to to explore. And in the next slide this is kind of a schematic that they developed for the decision process of determining whether the homeowner should seek expert advice or not. Depending on how their trees performing. So imagine you had one of these Fitbits on your tree, you dial in the species in the size, and whether it's in a favorable spot, how much sun it's getting, then you accumulate a baseline sap flow data for that tree in that spot.

And then perhaps the tree is next to a construction site. And the homeowner wants to know whether or not that work is affecting that tree or perhaps damaging the roots of their, you know, their beloved tree. And so you could put that Fitbit on there, you know, before [00:56:00] this construction starts and then monitor it through the process and then provide kind of this immediate, direct evidence about whether there's any kind of damage being done, even perhaps before, you know, it's extensive.

Maybe you could detect small amounts of damage and stop the construction and say, hey, you guys are damaging my tree. So anyway, this is a potential way, you know, an extreme example perhaps, but one that certainly occurs in the urban environment. And when we have big mature trees next to construction areas, but perhaps it's the way the homeowner could know whether their tree is being affected by that work.

And also just to learn to appreciate their tree. How is it, how its performing and whether they're contributing to a larger understanding of trees or how much their tree is, sequestering carbon. All of those kinds of things could kind of be built into this idea.

So on the next slide there's just a couple of semesters, a team of four students were able to put together this kind of comprehensive, comprehensive vision of a tree Fitbit. That could have a great act of the ability. Some reason I can't say that word today. Anyway, the materials needed are relatively cheap and the work will be building upon the database of observation so that reliable predictions can be made.

So, you know, the future directions are kind of looking at some kind of easy to use sensor that people could use widely, uh, on a wide range of tree species in a wide range of conditions. So this idea, I think is not too far away in the future. And we could pull something together over the next several years, I hope and make this more widely available.

So anyway, I think this is a very promising avenue of research and just kind of want to thank you all for your attention. And to recognize the various sponsors, the National Science Foundation, the Morton Arboretum, like the Hamilton Family Trust Foundation has helped us a lot. University of Illinois Urbana-Champaign. University Myerscough, [00:58:00] and the TREE Fund for their continued support of this research.

Dr. Tom Smiley: This concludes Dr. Charles Cannon's talk on measuring trees pulse and its relationship to tree health. This talk was originally presented at the 2020 ISA Virtual Conference. The views and information expressed are those of the presenter. Please join us next month for another presentation in the ISA Science of Arboriculture Podcast series.

Music: In every country, you know, we can work together and learn what we need.