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# The bark side of the water cycle


Edited by
Salli Dymond, Anna Klamerus-Iwan and John T. Van Stan, II


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Frontiers for Young Minds believes that the best way to make cutting-edge science discoveries available to younger audiences is to enable young people and scientists to work together to create articles that are both accurate and exciting. That is why distinguished scientists are invited to write about their cutting-edge discoveries in a language that is accessible for young readers, and it is then up to the kids themselves – with the help of a science mentor – to provide feedback and explain to the authors how to best improve the articles before publication. As a result, Frontiers for Young Minds provides a collection of freely available scientific articles by distinguished scientists that are shaped for younger audiences by the input of their own young peers.

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# The bark side of the water cycle

**Collection editors**
Salli Dymond — Northern Arizona University, United States
Anna Klamerus-Iwan — University of Agriculture in Krakow, Poland
John T. Van Stan, II — Cleveland State University, United States

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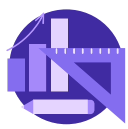

Mathematics and Economics

# About this collection

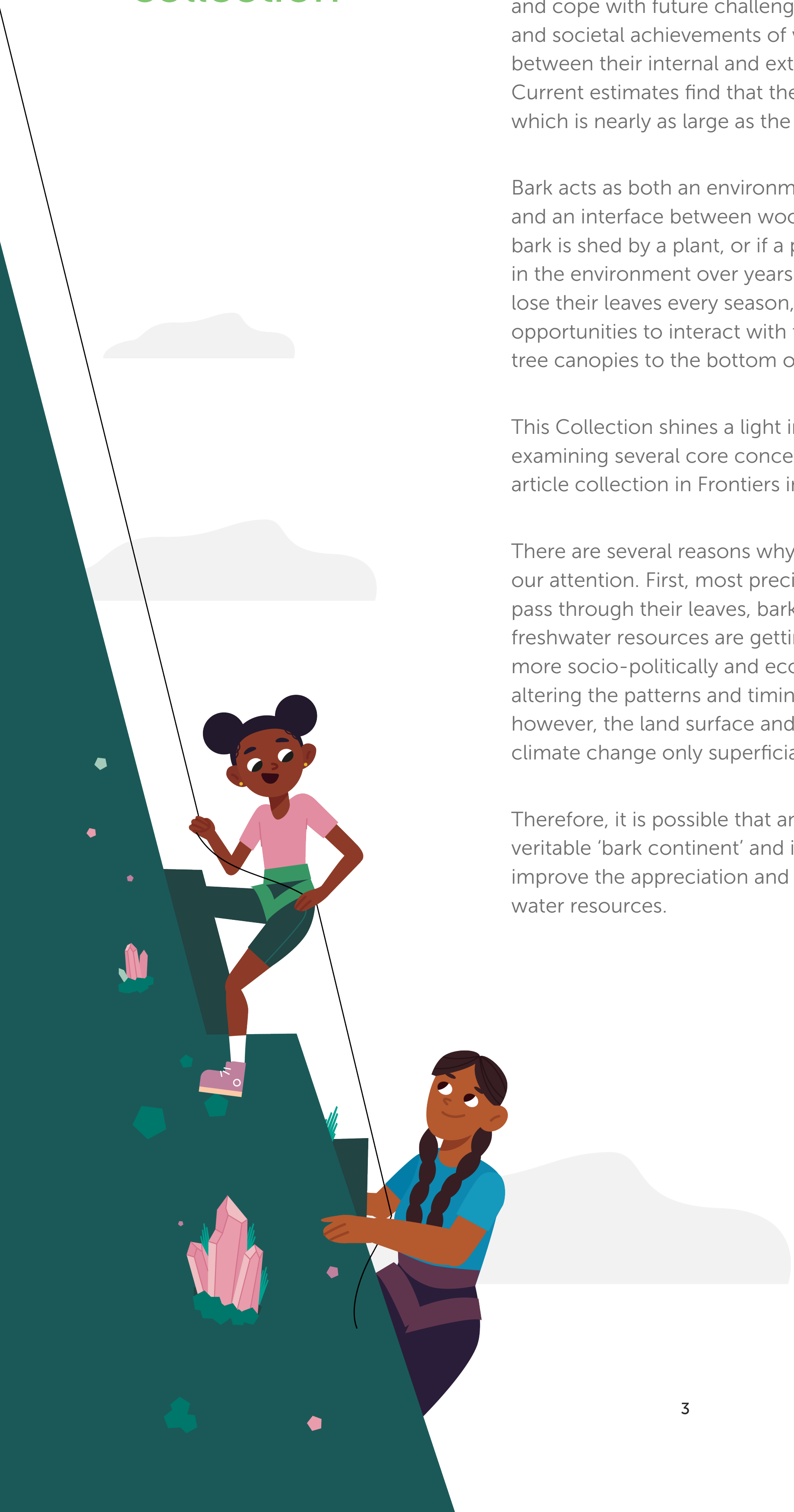
Woody plants are some of the tallest, largest, and longest-lived lifeforms on Earth. Their raw materials have literally framed and supported past human development, continues to do so today, and may aid humanity to combat and cope with future challenges, like climate change. All of the ecological and societal achievements of woody plants are due, in part, to a thin barrier between their internal and external worlds: bark. There is a lot of bark, too. Current estimates find that there is >40 million km2 of bark surface area, which is nearly as large as the entire Asian continent!

Bark acts as both an environmental barrier (to pests and fire, for example) and an interface between woody plants and their environment. Even when bark is shed by a plant, or if a plant dies, bark persists and continues to act in the environment over years-to-decades. In forests where woody plants lose their leaves every season, bark, again, persists. Thus, bark has many opportunities to interact with the water cycle—from the top of live and dead tree canopies to the bottom of the forest floor.

This Collection shines a light into this 'bark side' of the water cycle, examining several core concepts and new discoveries from the companion article collection in Frontiers in Forests and Global Change.

There are several reasons why the 'bark side' of the water cycle requires our attention. First, most precipitation over land falls over forests and must pass through their leaves, bark and litter to reach the surface. At the surface, freshwater resources are getting scarcer and their management is becoming more socio-politically and economically complex. Finally, climate change is altering the patterns and timing of precipitation supplies around the world; however, the land surface and climate models used to predict and adapt to climate change only superficially include bark's roles in the water cycle.

Therefore, it is possible that an increased curiosity and awareness of this veritable 'bark continent' and its importance for our planet's water cycle can improve the appreciation and conservation of forest ecosystems and related water resources.



# Table of contents



EARTH AND ITS RESOURCES
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# HOW TREES MAKE TEA

**_Aron Stubbins[1,2*], Kevin A. Ryan[1] and John Van Stan[3]_**

[1] *Department of Marine and Environmental Sciences, Northeastern University, Boston, MA, United States*

[2] *Departments of Chemistry and Chemical Biology, and Civil and Environmental Engineering, Northeastern University, Boston, MA, United States*

[3] *Department of Biological, Geological, and Environmental Sciences, Cleveland State University, Cleveland, OH, United States*

YOUNG REVIEWER:

LAUREL

AGE: 10

Tea is a mix of natural plant chemicals dissolved in water. You should not drink it, but a weak tea drips through a tree's branches and runs down its trunk when it is raining. The main ingredients in both tea and tree tea are organic molecules. Some, like tannins, are colorful and give tea and tree tea their brownish colors. Others, including sugars, are clear and loaded with energy. Some molecules build up on the tree's surface as it sweats. Other molecules are deposited on the tree by the wind, building up like grime on a car. When it rains, the built up sweat and dirt are washed away as tree tea. Tree tea is an energy drink that bacteria on the forest floor crave! Tree tea is also a flow of carbon from trees to soils that researchers are just beginning to understand.

## THE ROLE OF TREES IN THE CARBON CYCLE AND CLIMATE

Humans are changing the Earth [1]. Our use of fossil fuels has increased the concentration of the greenhouse gas carbon dioxide in the atmosphere, which is warming the planet. Scientists recognized over 100 years ago that global warming would be a side effect of fossil fuel use. This led researchers to study the natural **carbon cycle**, to see how human use of fossil fuel carbon and the natural carbon cycle interact to shape our climate. Today we have a good understanding of how carbon cycles around the world. Trees on land take carbon dioxide out of the atmosphere, using a process called **photosynthesis**. Photosynthesis uses the sun's energy to make sugars and other **organic** carbon molecules from carbon dioxide. Humans, other animals, and bacteria use the organic carbon molecules created by trees for energy. When we eat a sandwich or add sugar to our tea, the energy we gain was originally from the sun. When we and other organisms use the organic carbon and energy in foods, we convert the organic carbon back to carbon dioxide, which is released when we breathe out. Scientists call this process of using organic carbon for energy and releasing carbon dioxide **respiration**. The carbon dioxide produced by respiration goes back into the atmosphere. When scientists study the carbon cycle, they are interested in how much of the carbon taken from the atmosphere by photosynthesis is converted back to carbon dioxide by respiration. To understand this on land, they need to follow organic carbon from where it is created in trees out into the wider world.

**CARBON CYCLE**

The study of how carbon moves around the world and is transformed from one form of molecule to another. Understanding the carbon cycle is critical to predicting our future climate.

**PHOTOSYNTHESIS**

The process by which green plants and some other organisms use sunlight to synthesize organic molecules from carbon dioxide and water.

**ORGANIC**

Containing hydrogen and carbon. This is different from "organic" produce in the supermarket. Examples of organic molecules include sugars, oils, proteins, and wood.

**RESPIRATION**

The use of organic molecules by organisms for energy. When we, trees and most bacteria respire, we use up organic carbon and oxygen, producing carbon dioxide, water and energy.

Often, when trees and forests are in the news, they are mentioned as important carbon stores. To store carbon, trees take carbon dioxide from the air and use it to build their leaves, branches, trunks, and roots. As trees can live a long time and grow to be big, they can store lots of carbon. When forests are burnt by people or wildfires, the carbon the trees worked so long to store is sent back into the atmosphere as carbon dioxide. Adding this carbon dioxide back into the atmosphere adds to climate warming. Although the best way to reduce climate change is to reduce the use of fossil fuels, protecting and regrowing Earth's forests is also important.

Trees are the architects and the architecture of forests. As well as building the forests, trees and other plants provide most of the organic carbon and energy for all the other creatures on the land and in freshwater like rivers, and even for some of the creatures in the ocean. To feed the organisms in these different environments, organic carbon from trees must be transported from the trees to these other places. There is a general flow of organic carbon from trees to the soil, into rivers, and eventually out into the oceans. Most of the organic carbon from trees makes its way to the soil when leaves fall from trees or when trees die. However, there is another way for organic carbon to reach the forest floor: as **tree tea** [2].

**TREE TEA**

The solution made when it rains on trees. Tree tea contains a mix of organic molecules that bacteria consume, but you should not drink.


Figure 1

**Figure 1**

Different trees make different teas. When rainwater runs off a yellow birch tree (left), a yellow tea is formed; while rainwater running off a sugar maple (right) results in a golden, syrup-colored brew. Maple syrup is different from the tree tea in the photo! Syrup comes from inside the tree, while the organics in tree tea are washed from the tree surface.

## PREPARING TO MAKE TREE TEA

When it is dry, trees sweat. The name for this sweat is **evapo-transpiration**. As trees sweat, they get dirty, just like us. Some of this dirt is organic carbon. When it is dry, trees also pick up organic carbon, and other dirt from the air. This is like the grime we might find on our skin after we exercise somewhere dusty or that we find building up on cars and windows. The organisms that live in trees can also add organic substances to the mix. Then, when it rains, all these different types of organic carbon are washed off trees and fall to the forest floor as tree tea: a wonderful molecular mix that fuels forest floor microbial tea parties [3].

**EVAPO-TRANSPIRATION**

The combined loss of water to the air from plants and is the sum of evaporation from and transpiration (sweating) by plants.

## HOW TREES BREW WEAKER AND STRONGER TEAS

There are two main flow paths rain can take to the forest floor, and each creates a different strength of tea. The largest flow is as **throughfall**. Throughfall is the rain that drips through leaves and branches, bouncing from leaf to branch and then falling on your head if you walk under a tree. Throughfall tea is a lightly colored brew. The other, much smaller flow path is called **stemflow**. Stemflow is the rainwater that flows along the tree's branches and then down the trunk of the tree to the forest floor. This water spends more time in contact with the tree's surface. Just like letting a tea bag soak, the long, close contact between stemflow and the tree makes for a rich, dark brown tea (Figure 1). So throughfall makes a light tea and stemflow a dark tea [3]. Although throughfall is a lighter tea, much more rain reaches the forest floor as throughfall compared to stemflow. Thus, throughfall supplies 5–400 times more carbon to the forest floor than stemflow does [2].

**THROUGHFALL**

The portion of rain that makes it to the forest floor by dripping through leaves and branches.

**STEMFLOW**

The portion of rain that makes it to the forest floor by flowing down tree trunks.

Figure 2

**Figure 2**

A storm brings a hot moment at a tree tea hotspot. As a storm brews, (left) the tree tea shop prepares to open for its bacterial consumers under the forest canopy, who have been without rain for days, weeks, or even months! During the storm, (center) bacteria "fuel up" with tree tea that drains from the leaves and bark overhead. Once the storm has passed, (right) the bacteria have had a filling meal and the tree has had a cleansing shower.

## HOW TREES MAKE DIFFERENT TEAS

If we make tea from black tea leaves, we get a brown, caffeinated brew. If we make tea from mint leaves, we get a light green, minty tea. It is the same for tree tea—different trees make different teas. Live oak trees in Savannah, Georgia, USA, are covered in other small plants and mosses called epiphytes. The sweaty limbs of these oak trees result in rich, brown teas when washed clean by rainwater. In Vermont, USA, rain falling on sugar maple trees makes a golden, syrup-colored tea, while a yellower brew washes off yellow birch trees (Figure 1). Although the sugar maple stemflow may look sweet, the molecules that give tree tea its color may not be sweet at all, and you should not drink them. The same way tea, coffee, and orange juice have different colors and chemistries, different tree tea colors are also due to chemical differences in the molecules made and released by different trees [3].

## WHO DRINKS TREE TEA?

You should not drink tree tea because it may contain potentially unhealthy ingredients [4]. So, who *does* drink it? Although other organisms on the forest floor, like fungi and animals, may use the organic carbon in tree tea, bacteria are its most important and voracious consumers. Although we cannot see them, these tiny microbes are critical for the health of forest soils and for carbon cycling. Just like us, bacteria need food and water. Laboratory experiments have shown that bacteria can use the organic carbon in tree tea [2]. When it is dry under the trees, they can survive. But when it rains, they really come alive. Stemflow runs down the tree trunk and throughfall drips from drip points in the branches, piping tree tea energy drinks to fuel hotspots of bacterial activity. While we may like to sip tea in the sunshine, the tea shops of the forest floor open in a downpour (Figure 2).

## BACTERIA, THE TINY CONSUMERS THAT DRIVE THE CARBON CYCLE

As well as being lovers of tree tea, bacteria are one of the most important groups of organisms on Earth. There are about 8 billion people on the Earth today and collectively we add up to about 0.06 billion tons of carbon. Trees are the largest living store of carbon on Earth, totaling 450 billion tons of carbon. Although they are so tiny we cannot see them, bacteria are so numerous that they add up to an estimated 70 billion tons of carbon [5]. So, bacteria are not just numerous, they are a major store of carbon globally and they are one of the main users of organic carbon on Earth. Bacteria have a mixed diet. They can consume almost all forms of organic carbon, including the organics in soils, in sea and fresh water, and in decaying plants and animals. Bacteria in your stomach also help digest what you eat, so both you and they can access the organic carbon in your food.

## HOW WILL TREE TEA SHOPS CHANGE AS THE WORLD WARMS?

Tree tea is important to forest soils, forest bacteria, and to ecosystems downstream of forests, such as rivers and the ocean. Natural patterns drive the delivery of tree tea to the forest floor. Where trees grow and when they lose their leaves influence when and where organic carbon is available to make tree tea. Patterns in rainfall influence when and where rain washes trees clean and carries tree tea to the forest floor. People are changing when and where tree tea is made. Deforestation, agriculture, and urbanization have altered the distribution of trees across the planet. Climate change is altering where certain trees can live, as well as when trees grow their leaves in spring, when they flower, and when they lose their leaves in fall. Climate change is also altering when, where, and how strongly it rains. All these factors need to be understood to predict how the delivery of tree tea will change in the future and whether changes in the amount and flavors of tree tea available will affect how downstream ecosystems function. There is plenty still to discover about tree tea. Grab a coat and a cup, and help make the next breakthrough in understanding forest brewing.

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## YOUNG REVIEWER

**LAUREL, AGE: 10**
Hello, I like mechanical engineering and Lego. I like making things and tinkering. I like learning English and science.

## AUTHORS

**ARON STUBBINS**
Aron Stubbins is a biogeochemist interested in how people and other organisms interact to shape Earth's climate and environment. He studies the natural organic carbon in trees, rivers, glaciers, soils, and the oceans, plus how plastics move around the Earth and whether plastics have harmful environmental effects. He is a professor at Northeastern University in Boston, USA. *aron.stubbins@northeastern.edu

**KEVIN A. RYAN**

Kevin A. Ryan studies how humans and climate influence the freshwater we all rely on. He has worked in rivers impacted by the mountain coal mines of West Virginia and the salmon aquaculture industry in southern Chile. He is a Ph.D., student at Northeastern University in Boston, USA.

**JOHN VAN STAN**

John Van Stan is an ecohydrologist interested in what happens when plants and water meet during storms—rain, snow, sleet, or otherwise. He enjoys researching the roles that wet plants play in our Earth's energy balance, nutrient cycles, and landscape ecology. He is currently an associate professor at Cleveland State University, where he leads the Wet Plant Lab.

BIODIVERSITY
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# KOALAS GIVE TREE BARK A LICKING

*Valentina S. A. Mella*[1*] *and John T. Van Stan II*[2,3*]

[1] School of Life and Environmental Sciences, The University of Sydney, Sydney, NSW, Australia
[2] Applied Coastal Research Laboratory, Georgia Southern University, Savannah, GA, United States
[3] Department of Geology & Geography, Georgia Southern University, Savannah, GA, United States

YOUNG REVIEWER:

JASON
AGE: 9

All animals need water to live, but not all of them need to drink it from their surroundings. Drinking free water from rivers or puddles is just one of many ways that animals get the water they need. Until recently, koalas were thought to get most of their water from the leaves that they eat. But, after years of koala watchers getting caught in the rain, the scientists and volunteers began sharing similar, strange stories. These sleepy animals were waking up during storms and giving the tree bark a lively licking! Surprisingly, koalas appear to drink a type of free water rarely studied: stemflow. This is rainwater that drains down tree bark, and it is not just water. Stemflow picks up all types of things from the bark as it drains, from nutrients and pollutants to bacteria and fungi, raising many new questions for koala scientists.

## INTRODUCING THE KOALA'S DIET

If Mother Nature opened a koala café in the trees of Eastern Australia, the menu would be very simple: leaves. Because of this leafy diet,

**FOLIVORE**

An animal that only eats leaves—like a koala.

koalas are called **folivores**. Any appetizers on this folivore menu, you ask? None. What about a drink menu? Probably not—especially if the weather has been nice (and rainy). Well, what kind of leaves would be on the menu? Mostly eucalyptus leaves. This menu would certainly not appeal to many other animals on Earth, and not just because of its simplicity. First off, eucalyptus leaves are toxic to most other animals! The eucalyptus trees fill their leaves with toxins to prevent animals from biting them—leaves are the tree's lungs after all. Koalas do not get sick from these leaves because they have evolved special gut bacteria that can detoxify the toxins found in the leaves, so those toxins are digested and expelled quickly. Second, eucalyptus leaves have very little nutritional value. As a result, it is believed that koalas literally eat themselves sick. They stuff their bellies with as many leaves as they can, usually around 500 g each day—that is three burgers worth!

**FREE WATER**

Water that is naturally sitting in, or flowing through, an area, such as water from a river, lake, creek or rainwater in a puddle.

Finally, most other animals would need at least a glass of water to wash down this toxic meal. But koalas rarely need a glass of water from Mother Nature. Scientists who study animal behavior call the water that is naturally sitting in or flowing through an area **free water**, and they originally thought that koalas did not need much. While eucalyptus leaves are toxic and not very nutritious, they do store a decent amount of water. Koalas also lose less water than other animals through their skin, through their mouths when they breathe, and even when they pee! Because of this, eucalyptus leaves can meet all the koala's water needs…or, so we thought. It turns out that koalas may drink free water, just not from the usual places like puddles, ponds or rivers. They prefer to wait in their trees until a storm turns the trunk into a tap.

## HOW DO SCIENTISTS WATCH KOALA BEHAVIOR?

**SYSTEMATIC**

Doing something in a planned way, so it can be repeated accurately.

We must be careful, consistent, and persistent in studying the ways wild animals interact with other animals and their environments. To do this, scientists prefer to watch wild animals in a **systematic**, or carefully planned, way. This is because we want other scientists who are not there watching with us to be able to see the same behavior, by doing the same things we did. Thus, in Eastern Australia, scientists plan systematic visits to the koala cafés. The scientists do not order anything, since the food is toxic anyway. Instead, they sit outside the cafés and watch the koalas eat or do whatever the koalas want to do (mostly sleep!). The scientists also do not take a seat in the café. Rather, they sit 10 m outside with binoculars. Like private eyes, they write down koala behaviors as they happen. Sometimes scientists systematically plan to watch the koalas a bit closer and for longer times, such as overnight. To do this, they set up cameras in the koalas' favorite trees.

Sometimes these systematic visits to the koala café get interrupted by something that was not planned. Storms are a common interruption, and they can be dangerous. Storms can bring lightning, unsafe winds, or just curtains of rain that can block or blur the scientists' view. The

Figure 1

**Figure 1**

Koalas drinking stemflow in their natural habitat. Photos provided by Echidna Walkabout and Koala Clancy Foundation.

water can also damage the expensive science gear. Most of the time when it rains, koala scientists pack up their gear and plan to come back another time. But some koala scientists and volunteers refused to let rain completely ruin their plans—they kept watching. The watchers who withstood the storm were rewarded with a rainy view of an odd koala behavior.

## WHAT DO KOALAS DO WHEN IT RAINS?

During and after the storm, wet scientists with ruined plans saw koalas drinking free water in trees! The free water was reaching the koalas in an unusual way: by draining down the bark of tree trunks. A portion of the rainwater that hit the leaves and branches was caught by the tree and then drained down the bark, as what is called **stemflow**. Stemflow can flow down tree trunks for hours. The branches of the koala café acted like waiters, delivering a drink of water right to the koalas at the trunk. Koalas did not just lick the bark for a quick taste. They lapped up stemflow for long periods of time, from 15 to 30 min. One observation counted the number of licks per second, and for these slow animals, two licks every second is a real frenzy of activity. After 34 min straight of steady stemflow sipping, the koala that was being watched took a 2-min break to catch its breath, then began again! Every time that a wet scientist was watching the koala café in the rain, the koalas were drinking this free water. This was a lot of observations (46) over a long period of time (from 2006 to 2019) from different parts of Australia! The number of observations across koala communities over more than a decade suggest that this drinking behavior is a natural behavior of koalas, not just an occasional odd occurrence (Figure 1).

**STEMFLOW**

Rainwater that is collected by a tree canopy and drained down the bark of the trunk. A type of free water.

Many important aspects of koala drinking behavior remain unseen. Sure, videos and photographs are great for documenting that this behavior occurs. To see a koala giving tree bark a licking, check out the video below.

Video 1. A koala giving tree bark a licking. Video credit: George Madani and Lachlan Hall.

**Figure 2**

Not all stemflow is the same. The darker the stemflow, the more ingredients are typically dissolved and suspended within it. These substances come from within the tree bark but also from the surrounding environment, like pollutants generated by car exhausts, and might be helpful, such as nutrients, or harmful, such as disease-causing bacteria and viruses. Photo credits: top left—Forest and Kim Starr from Wikicommons Media; top middle, right—Emilian Robert Vicol from Pixabay; bottom—Julie Schooling.

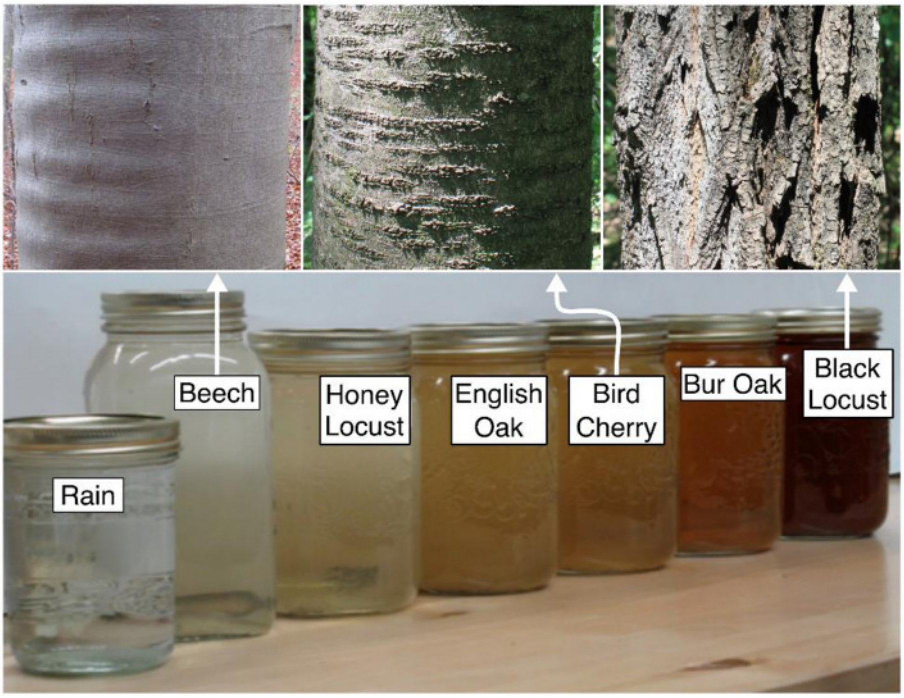


Figure 2

However, standard videos do not provide answers to many important questions. For example, how effective are these animals' tongues at lapping up this thin layer of water streaming down tree bark? To answer questions like this, special high-speed video cameras must be used to catch every little detail of the koala's tongue as it licks. Careful experiments may also be done to calculate the exact amount of stemflow that koala tongues can lap up with a single lick!

## WHY DOES IT MATTER THAT KOALAS DRINK FREE WATER?

Free water is never just water. Water that is flowing and pooling around the environment picks up stuff that could be healthy or cause disease. Although the free water that koalas are drinking comes from rain, its path down the tree branches and trunk adds a few ingredients from the tree bark to the water. In fact, stemflow may contain more ingredients than other types of free water in the natural environment—even more than river and lake water! Stemflow picks up all types of things from the bark as it drains, from nutrients and pollutants to bacteria and fungi. Scientists know very little about stemflow. We do not know much about the bacteria and fungi in stemflow or the potential viruses it might contain. To complicate matters more, different types of trees, and even different trees of the same species, can make different flavors of stemflow (Figure 2). So, do koalas choose to drink cleaner, clearer stemflow? Or do they prefer a murkier, tea-like stemflow? Can the ingredients that the bark gives stemflow be healthy or harmful to the koalas? Finally, could trees with high-quality and/or abundant stemflow play some part in koalas' territoriality?

Our research, and all these unanswered questions, are important because the successful conservation of koalas, or any other animal, depends on our understanding of their behavior. Behaviors related to where, how, when, and what kind of water a species drinks can be crucial to that species' survival and if we observe carefully, animals can really tell us what they need. For koalas, continuing this research may help ensure that human activities do not turn off, or taint, the taps flowing down the trunks of their canopy cafés.

## ORIGINAL SOURCE ARTICLE

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## YOUNG REVIEWER

**JASON, AGE: 9**
Jason is fascinated by animals and the many ways that humans rely on other animals. He loves having a pet snake whose behaviors he can watch up close. He also enjoys the challenge of searching for and finding wild animals in their natural habitats (including fishing!).

## AUTHORS

**VALENTINA S. A. MELLA**

Valentina Mella is a zoologist interested in wildlife ecology, animal behavior, fauna management, and conservation. She currently leads a project investigating the how water availability in the environment affects koala behavior and health. The study plays a pivotal role in the conservation of koala populations, providing practical management solutions to help wild koalas through climate change-driven heatwaves and droughts. *valentina.mella@sydney.edu.au

**JOHN T. VAN STAN II**

John Van Stan is an ecohydrologist interested in what happens when plants and water meet during storms—rain, snow, sleet, or otherwise. He currently directs the Applied Coastal Research Laboratory in Savannah, Georgia, USA, leading projects on how wet plants affect coastal soils, shorelines, and society. *professor.vanstan@gmail.com.

frontiers FOR YOUNG MINDS

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# LUNG LICHENS FACE CHALLENGES FROM CLIMATE CHANGE

***Paolo Giordani*** [1*]***, Renato Benesperi*** [2] ***and Juri Nascimbene*** [3]

[1] *Department of Pharmacy, University of Genova, Genoa, Italy*

[2] *Department of Biology, University of Florence, Florence, Italy*

[3] *BIOME Lab, Department of Biological, Geological and Environmental Sciences, Alma Mater Studiorum, University of Bologna, Bologna, Italy*

YOUNG REVIEWER:

ADIA-MAE

AGE: 13

Lichens are a type of fungi that live in close relationships with algae or bacteria. Unfortunately, the future is not looking very bright for these organisms, because they have no protective structures and are sensitive to environmental change. The lung lichen is a large species that, in the upcoming years, will find itself in trouble. Climate change will reduce the amount of available water and increase air temperatures. Global warming is also expected to change the environments where the lung lichen lives. One of the main threats will be the expansion of some very competitive trees. Among them, the black locust has become invasive, forming dense woods that will replace the native tree species. Even though it seems like the situation is bad, there is still hope! Lichen scientists are trying to figure out how to prepare suitable shelters to save lung lichen from climate change.

## A QUEEN IN THE FOREST

On a walk in a forest, even just outside the city, you may have seen strange organisms of various shapes and colors dwelling on the trees or rocks. Most likely these were **lichens**. Lichens are fungi that live in a close, mutually beneficial relationship, called a **symbiosis**, with single-celled green **algae** and/or a type of bacteria called **cyanobacteria**. Lichens have no protective tissues and therefore have no way of regulating the amount of water inside themselves. For this reason, they are extremely sensitive to any environmental changes. As with all groups of organisms, lichens include tough, hardy species, as well as species that are more delicate and sensitive. One of the more delicate species is called the lung lichen (*Lobaria pulmonaria)*, a very noticeable and rather rare species that lives on the bark of trees (Figure 1). It can only be found in older forests that have been preserved from over-use and that have ideal moisture and light conditions. Many lichenologists (people who study lichens) consider the lung lichen to be the "queen of the woods." But life is difficult, even if you are a queen. Others may be trying to steal your crown! Scientists think things will get even more difficult for the lung lichen soon.

**LICHEN**

A fungus living in symbiosis with a population of green algae and/or cyanobacteria.

**SYMBIOSIS**

An interaction between two different organisms (in the case of lichens, between a fungus and an alga or a cyanobacterium) that usually benefits both organisms.

**ALGAE**

A group of photosynthetic organisms that can form a lichen symbiosis with fungi.

**CYANOBACTERIA**

A group of bacteria that can perform photosynthesis and extract nitrogen directly from the atmosphere.

## A DANGEROUS FUTURE

The biggest danger that lung lichen face is invisible, but unfortunately very real: climate change. Researchers have been trying to find out how climate change will affect the lung lichen on the Italian peninsula, from the warm Mediterranean coast to the cool forests of the Alps in the north. In Italy, between now and 2070, it is expected that temperatures will increase considerably and that there will be a drastic decrease in precipitation, as well as a general increase in extreme periods of weather such as chilly and/or very rainy days and long, dry heat waves. These are not exactly the ideal conditions for a species that likes to live quietly in a continuously humid atmosphere with moderate temperatures. Researchers' models predict that the areas with climate conditions that are ideal for lung lichens will almost completely disappear.

But the news gets even worse for the lung lichen. In addition to the direct effects of climate change, researchers predict that the lung lichen will also suffer other, indirect damage. The increase in temperature and the decrease in precipitation will make Italy a less hospitable environment for the trees on which lung lichens grow, which include mainly oaks, chestnuts, and beeches. So, it seems that the lung lichen may have fewer trees available to grow on in the future.

## A NEW QUEEN?

As if the situation of the lung lichen is not bad enough, it is possible that an alien and invasive species might soon be battling the lung lichen for

**Figure 1**

The lung lichen (*Lobaria pulmonaria*) growing on mosses in a Mediterranean forest. The scientific name *Lobaria pulmonaria* and the common name (lung lichen) come from the fact that these lichens are shaped like the lobes of the lungs. Shining like gems, the orange spots are the reproductive structures of the lichens, called fruiting bodies, which are not frequently observed.


Figure 1

the crown of forest queen. An alien species is not an extraterrestrial of course! It is a species introduced, either accidentally or deliberately, into a natural environment where it is not normally found. Not all alien species are invasive, but all invasive species are dangerous to native plants and animals. Invasive species are tough. They grow quickly and spread rapidly and efficiently, over long distances. They can easily take over new environments and outcompete the native species, causing those native plants or animals to die off.

The invasive alien in question here is called the black locust (*Robinia pseudoacacia*). It is a tree of North American origin that has become invasive in Europe, where it poses a major problem for conservation of our native biodiversity. We have recently been trying to better understand the damage locust trees may cause to lung lichen. Will lung lichen be able to grow on black locust bark? Early results suggest that perhaps it could. But another problem could be the structure of the black locust woodlands. The black locust forms dense thickets, which do not give other tree species room to grow (Figure 2A). Black locust forests are extremely inhospitable to lung lichen because, being very dense, they greatly reduce the amount of light available to the lichens.


Figure 2

**Figure 2**

**(A)** A black locust grove in the Po Valley, Northern Italy. The dense, fast-growing black locust is replacing native forest species. (photo credit: Juri Nascimbene) **(B)** A possible micro refuge for the lung lichen in a shady Mediterranean forest, called "the dripping oaks," is an ideal place to find water and shade. (photo credit: Paolo Giordani).

## SAFETY IN THE HIDDEN, FORGOTTEN CORNERS OF THE FOREST?

Although they are small organisms, lichens have important roles in the forest. For example, they are often used as shelter, food, or hunting grounds for small insects. Lichens are also used by small forest birds to build their nests. They also help to retain water and regulate the humidity of the forest. Additionally, since lichens are very sensitive to air pollution, they can give us an indication of the quality of the air around us. Despite all these important roles, lichens are not well-known to many people, so we risk not understanding what we are about to lose forever.

Is there any hope for the future of the lung lichen? We cannot know for sure. The ecologists who calculated the predictions sincerely hope they are wrong, but the numbers leave little doubt that these lichens are in danger. As with other species, we still do not know whether we can somehow protect lung lichens from the negative effects of climate change. But perhaps there is a way! The solution may lie in what are called microrefugia. Microrefugia are locations that, due to special favorable conditions such as dense forests or narrow valleys, can maintain a milder climate and serve as a home to fragile species (Figure 2B). Microrefugia might provide small, hidden corners of the forest where the right climatic conditions for lung lichens are maintained, even if the surrounding forest turns into an arid, desolate wasteland. Even a scanty group of trees, a few gnarled and shady oaks, perhaps covered with a sleeve of damp moss, might be enough for the lung lichen. Perhaps microrefugia will help lung lichens to hang on until we can prepare a better future for them!

## ORIGINAL SOURCE ARTICLE

Nascimbene J., Benesperi R., Casazza G., Chiarucci A., and Giordani P. 2020. Range shifts of native and invasive trees exacerbate the impact of climate change on epiphyte distribution: the case of lung lichen and black locust in Italy. *Sci. Total Environ.* 735:139537. doi: 10.1016/j.scitotenv.2020.139537

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## YOUNG REVIEWER

**ADIA-MAE, AGE: 13**

I love learning, reading, creative arts, helping others, coding, and school. I am passionate about conservation, social issues, all types of science, and all academic things. When I am not lost in a book, I participate in a variety of extra-curricular activities involving STEM, problem-solving, leadership, and sports. I find the teamwork, challenges, and camaraderie of group activities to be the most fun and fulfilling parts. I hope to positively impact others, animals, and the environment.

## AUTHORS

**PAOLO GIORDANI**

Paolo Giordani is an associate professor of botany at the University of Genoa, Italy. Since his thesis and doctorate at the University of Trieste, Italy, has been studying different aspects of lichen life to try to understand how organisms from two different kingdoms (a fungus and an alga) can form a new organism and live successfully in any terrestrial ecosystem. *giordani@difar.unige.it

**RENATO BENESPERI**

Renato Benesperi works at the University of Florence, Italy as an associate professor of botany. Since his Ph.D. he has been working on lichens. In particular, Renato's work concerns the study of lichens in forest ecosystems and, in particular, the effects of invasive tree species in natural habitats. Renato studies how these species modify the structure of natural habitats and can lead to changes in the short and long term.

**JURI NASCIMBENE**

Juri Nascimbene is a professor of botany at the University of Bologna, Italy. Juri holds a Ph.D. from the University of Trieste and has transferred his passion for the mountains of the Alps into the topics of his work on lichen ecology along altitudinal gradients in the perspective of climate change. He is currently president of the Italian Lichenological Society.

BIODIVERSITY
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# DO LICHENS AND MOSSES DRINK FROM TREE BARK?

*Philipp Porada*[1*] and *Paolo Giordani*[2]

[1] *Ecological Modeling, Institute of Plant Science and Microbiology, Department of Biology, Universität Hamburg, Hamburg, Germany*

[2] *Dipartimento di Farmacia—University of Genova, Genoa, Italy*

YOUNG REVIEWERS:

ANSHUL
AGE: 11

PRANATEE
AGE: 14

Lichens and mosses often live on tree branches in the forest canopy. They store large amounts of rain, fog, or dew, because they cannot reach water in the soil. However, we do not know what their most important source of water actually is. For example, is water uptake from wet bark important? This is hard to answer, because these lichens and mosses live high above us, so it is difficult to make direct measurements. Computer mathematical simulations can be useful to answer this question. We used a computer model of lichens and mosses to calculate how much water these organisms may take up from bark. We found that water from bark supports about 20% of the growth of lichens and mosses per year, so it *is* important for their survival. We also found that lichens and mosses are well adapted to taking up water from bark.

## WHAT ARE LICHENS AND MOSSES?

Lichens and mosses are small organisms that live almost everywhere, all over the world. They not only cover the surfaces of rocks or the forest floor, but they also often live on the trunks and branches of trees. Plants that live on other plants are called **epiphytes**, and epiphytic lichens and mosses grow in many forests, in all climate zones.

**EPIPHYTES**

Plants that live on other plants.

Mosses are plants, but they do not have roots like grasses or trees. Lichens, however, are *not* plants—they are composed of a fungus and a green alga (or a type of photosynthesizing bacteria) that live together as one organism. Without roots, lichens and mosses must take up water by collecting rainfall or the moisture from dew or fog. Rainfall, dew, and fog are not available all the time, but this is not a big problem for the epiphytes—they simply dry out and become inactive. When water is available again, they "wake up." This is the main difference between lichens/mosses and plants like grasses or trees, which die when they dry out.

## ARE LICHENS AND MOSSES IMPORTANT FOR THE FOREST?

Even without roots, lichens, and mosses can have large impacts on the **water cycle** in forests. Like sponges, they soak up the water that collects on their surfaces. Since they are often bushy and have a large surface area, lichens and mosses can take up a lot of water. The water evaporates from their bodies back into the atmosphere. This means that the water does not enter the soil, so trees have less water available. However, the sponge effect of the epiphytes can also help trees: it cools the forest, because energy from warm air goes into the water, to turn it from liquid into vapor. This energy is then transported into the atmosphere as water vapor. Cooling of forest air can reduce heat stress for trees.

**WATER CYCLE**

The movement of water between several storage locations, including the oceans, soil, rivers, and lakes, and the atmosphere (as water vapor and clouds).

It is still not entirely understood how important lichens and mosses really are for water availability and temperature regulation in forests, because relatively little research has been done on this subject.

## DO LICHENS AND MOSSES GET ENOUGH WATER?

If we want to better understand how epiphytic lichens and mosses affect forests, we need to know how many there are and how much they can grow in a given forest. In other words, how big is the "sponge"? To answer this question, we first need to know how much water is available for the epiphytes. Even though they may cope well with drying out, they need to be active to grow, and to be active they need water.

We want to shed some light on a source of water that may have been overlooked until now, and that may be important to sustain the growth of epiphytic lichens and mosses: tree bark.

## THE OVERLOOKED ROLE OF BARK WATER

Rain, dew, and fog are not the only sources of water for epiphytes living in the forest canopy. After it rains, water runs down the branches and stems of trees. This water is called **stemflow**. Some of the stemflow is stored in the cracks and pores of tree bark. Maybe the epiphytes can use this water for their growth.

**STEMFLOW**

Water that runs down the trunks of trees during and after rainfall.

We say "maybe" because we do not yet know how important water uptake from the bark is for epiphytic lichens and mosses—it is certainly possible, but rain, dew, and fog could be much more important for these organisms; not enough research has been done. Also, individual species of lichens and mosses could differ a lot in their ability to take up water from bark, but we have no idea how important these differences are for the water cycle of the forest.

## IS BARK WATER IMPORTANT?

In our study, we wanted to find out how important bark water is for epiphytic lichens and mosses [1]. We also wanted to know if there are differences between species in this regard. Unfortunately, it is very difficult to measure bark water uptake, because we cannot simply switch it off to see how that affects the organisms.

**COMPUTER SIMULATION MODEL**

A simplified "copy" of a process or an organism, in form of a computer program. It can be used for tests that cannot be conducted in the real world.

**CLIMATE DATA**

Numerical information that describes climate, such as temperatures or rainfall for a certain time period and location.

A **computer simulation model** is a good tool to answer these kinds of questions, because a computer model can be changed much more easily than real ecosystems or organisms can. Our computer model is called LiBry, short for lichen and bryophyte computer model (bryophytes are mosses). The computer model works like a complicated pocket calculator: when we input certain **climate data**, such as temperature or the amounts of rainfall or light, the model calculates how much the epiphytic lichens and mosses can grow. The computer model can do this for many species of lichens and mosses.

Calculating the growth of lichens and mosses based on climate conditions is relatively complicated, because these organisms carry out many processes, like photosynthesis or respiration, that are affected by climate factors. The LiBry computer model calculates many of those important processes using dozens of mathematical equations (Figure 1). The equations usually have the form:

flow of carbon or water $=$ some climatic condition $\times$ the state of the organism $\times$ additional factors

In the computer model, the equations are all connected, similar to what happens in a real organism. You can imagine the carbon or water flows as arrows between boxes, with the boxes representing pools of carbon or water. A small part of these flows and pools is shown below in Figure 2.

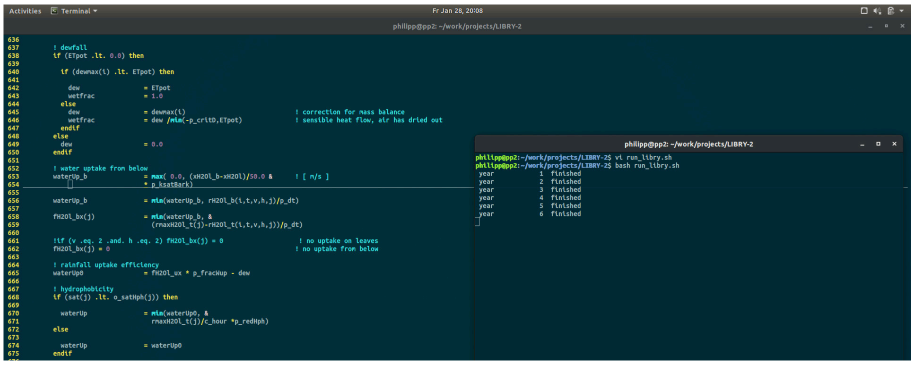

Figure 1

**Figure 1**

Screenshot of the LiBry computer model. Since the model is made of a bunch of equations coupled together, it does not have a user interface. It is a collection of text files that contain the equations. Some of the equations are shown on the left, in the programming language Fortran95. The gray line is where bark water uptake is calculated. The inset window on the right shows the run command and the output of the computer model, which lists how many years of epiphytes growing have been simulated so far.

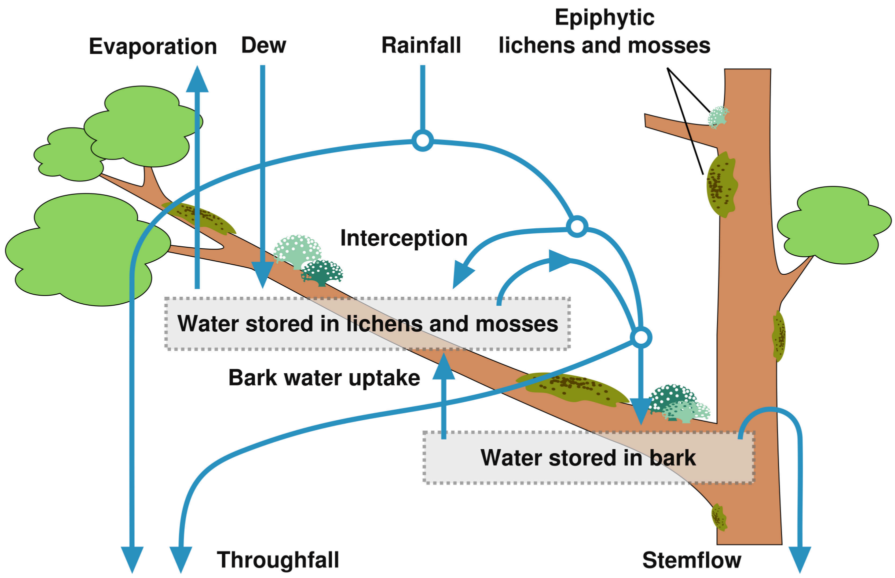


Figure 2

**Figure 2**

Part of the water cycle in a forest. Water can enter the canopy in the form of rainfall, dew, or fog. That water is then either intercepted by trees and their epiphytes or falls/drips to the forest floor as throughfall. Water intercepted by trees can be stored in the bark or flow down the bark as stemflow. Water stored in epiphytes like lichens and mosses can be used by those organisms to grow before it evaporates back into the atmosphere.

To test if the computer model works, we selected a **field site** in Sardinia, an island in the Mediterranean Sea close to Italy. In the forests and woodlands of Sardinia, many species of epiphytic lichens and mosses can be found (Figure 3).

**FIELD SITE**

An outdoor location (in a forest, for instance) where measurements are taken and experiments are carried out.

## SWITCHING WATER FLOWS ON AND OFF

With the LiBry computer model, we simulated 3,000 species of epiphytic lichens and mosses for a location in Sardinia. This means that

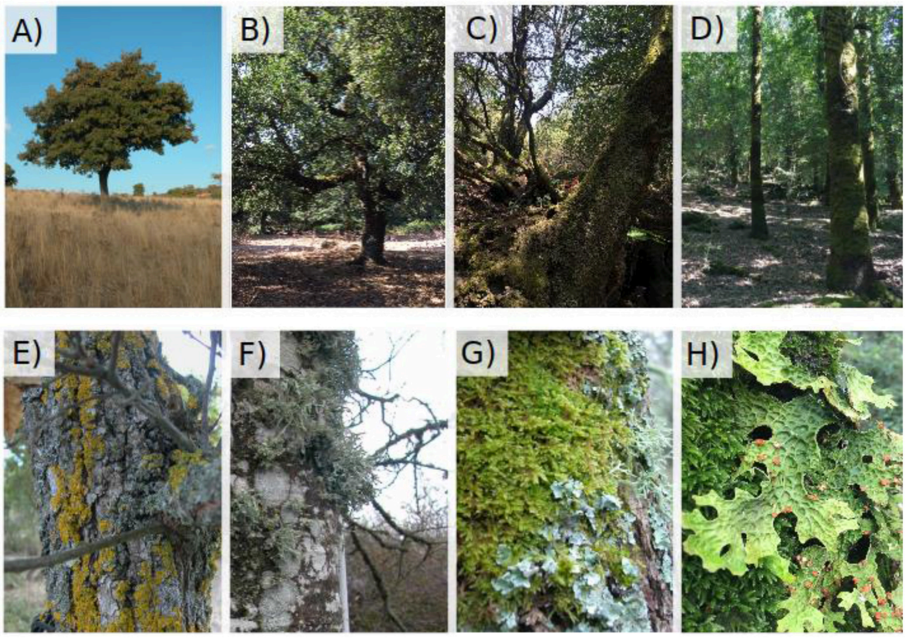

Figure 3

**Figure 3**

Many types of mosses and lichens can be found in the forests of Sardinia, and the types growing in an area often depend on how dense the forest is. **(A,B)** Some grow on isolated trees. **(C,D)** Some grow in shady forests composed of old trees. **(E,F)** Some mosses and lichens can grow as thin sheets. **(G,H)** Other mosses and lichens can form larger bodies.

we used climate data for this region from the last 40 years and, for each hour, LiBry calculated how much each species could grow.

Sounds simple, but we must admit, it is a bit more complicated: the species in the computer model were not the actual species that live at the field site in Sardinia. It is not possible to collect enough samples and make all the measurements that would be needed to represent all the real species. Instead, the 3,000 simulated species are examples of all species that could *potentially* occur there. The computer model then checks whether each species would be able to survive in the climate of the field site. Usually, many species "die out" in the computer model, and the "surviving" ones are those that are adapted to the climate of the field site. This is helpful, because we do not have to measure the properties of all the real species in the field site—instead, we simply see which species "survive" the computer model simulation.

Back to the bark water: water fluxes are important for the growth of the lichens and mosses in the LiBry computer model. The more water that is available, the longer the organisms can stay active and grow. Figure 2 shows the routes by which water can flow from the atmosphere through the canopy to the ground. Rainfall that is captured by the canopy surfaces (a process called **interception**) can leave the canopy as stemflow or drip off leaves and other surfaces to the ground, as **throughfall**. Water can be stored in epiphytes, on leaf surfaces, or in the bark.

**INTERCEPTION**

Rainfall that is captured by the canopy surfaces (leaves, bark, epiphytes) and evaporates from there instead of falling to the ground.

**THROUGHFALL**

Rainfall that is not intercepted by the canopy, but hits the ground, or drips from leaves to the ground.

Since we wanted to find out how important bark water uptake is for epiphytic lichens and mosses, we used the LiBry computer model for an experiment. In one simulation, we simulated the growth of lichens and mosses using all the "normal" climate conditions of the field site. In a second computer model simulation, we set the size of the bark water storage to zero, so the simulated organisms could not take up water from the bark. Then we compared the results of these two computer model simulations.

## THE BARK MAKES A DIFFERENCE

We found that bark water had a large influence on epiphytic lichens and mosses in Sardinia, all thanks to the LiBry computer model. In the "normal" computer model simulation, the organisms could grow around 20% more than they could in the simulation without bark water uptake. The effect was strongest in spring. In winter and fall, water was likely not limiting growth, because rainfall was sufficient and temperatures were lower, so bark water did not matter as much. In summer, rainfall and dew were so low that bark-water storage also did not make a difference—the lichens and mosses were inactive most of the time.

Without bark water uptake, not only did the epiphytes grow less, but fewer species survived the whole computer model simulation. The species that *did* survive without bark water were slightly different from those in the "normal" simulation: they were more resistant to water evaporation, which helped them to store more water in their tissues. They were also adapted to higher temperatures, which makes sense if you remember the cooling effect that we explained earlier. With no bark water, there was less water to evaporate, so the temperature in the canopy would be higher, favoring those species that could tolerate warmer conditions.

In conclusion, in our computer model experiment we found that bark water storage is important for the growth of epiphytic lichens and mosses in Sardinia, and it can influence which species will be successful in an ecosystem. These findings are important because Earth's climate is changing. Changes in bark water uptake due to climate change could affect the survival of the epiphytes—not only in Sardinia, but also in other locations around the world. So, our research can be used to predict which epiphytic lichen and moss species are threatened by climate change, and these predictions will become more accurate by including the role of bark water.

## ORIGINAL SOURCE ARTICLE

Porada, P., and Giordani, P. 2021. Bark water storage plays key role for growth of Mediterranean epiphytic lichens. *Front. For. Glob. Change*. 4:668682. doi: 10.3389/ffgc.2021.668682

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1. Porada, P., and Giordani, P. 2021. Bark water storage plays key role for growth of Mediterranean epiphytic lichens. *Front. For. Glob. Change*. 4:668682. doi: 10.3389/ffgc.2021.668682

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## YOUNG REVIEWERS

**ANSHUL, AGE: 11**
Hello! My name is Anshul and I am a sixth grader at Germantown Academy, which is close to Philadelphia. I am very interested in Biology and Entomology. I am an active member of the Johns Hopkins CTY program, and my favorite hobby is to read.

**PRANATEE, AGE: 14**
Hello! I love to bake, especially around the holidays. In school, my favorite subjects are English and lunch. I like spending time outdoors and going hiking. I am a creative person who loves painting in my free time, and live off of music. In the future, I would like to study science, especially psychology.

## AUTHORS

**PHILIPP PORADA**
Philipp Porada is a junior professor of ecological modeling at the University of Hamburg, Germany. He studied geo-ecology, which lies at the intersection of geosciences and biology. He conducted his Ph.D. project at the Max-Planck-Institute

for biogeochemistry in Jena, Germany, and then went to Stockholm University in Sweden for a postdoctoral fellowship. He returned to Germany to focus on process-based modeling of vegetation, and he aims to unite concepts from ecology and biogeochemistry. He has extensive experience in computer modeling of mosses and lichens and their effects on global biogeochemical cycles.
*philipp.porada@uni-hamburg.de

**PAOLO GIORDANI**

Paolo Giordani is a professor of botany at the University of Genoa, Italy. Since his thesis and doctorate at the University of Trieste, Italy, he has been studying various aspects of lichen life, to try to understand how organisms from two different kingdoms (a fungus and an alga) can form a new organism and live successfully in any terrestrial ecosystem.

EARTH AND ITS RESOURCES
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# THE WORLD'S TALLEST TREES CAN "DRINK" FOG!

***Salli F. Dymond****

*Department of Earth and Environmental Sciences, University of Minnesota Duluth, Duluth, MN, United States*

YOUNG REVIEWERS:

AVIV

AGE: 9

ISAAC

AGE: 14

The world's tallest tree, the coast redwood, can reach heights $>$115 meters. Its ability to reach such staggering heights is due to many interconnected factors—traits unique to the tree itself and favorable growing conditions. One of the unique coast redwood characteristics is the ability to absorb coastal fog water via its leaves and bark. These two processes (called foliar and bark uptake) replenish some of the water lost during the day when plants are acquiring carbon dioxide via transpiration. The coast redwood's ability to exploit its foggy growing conditions allows it to thrive and reach unthinkable heights.

## THE REDWOOD FOREST

Close your eyes and imagine you are standing at the base of the tallest tree on Earth. Would you be able to see the top? Could you wrap your arms all the way around its trunk? The answer? Definitely not! Hyperion, the world's tallest tree, is 115.6 m tall and almost 5 m in diameter [1]—that is taller than most large buildings and more than double the wingspan of a bald eagle! Hyperion is a coast redwood (*Sequoia sempervirens*), which are the world's tallest trees (Figure 1A). Despite their colossal stature, coast redwoods occupy only a small

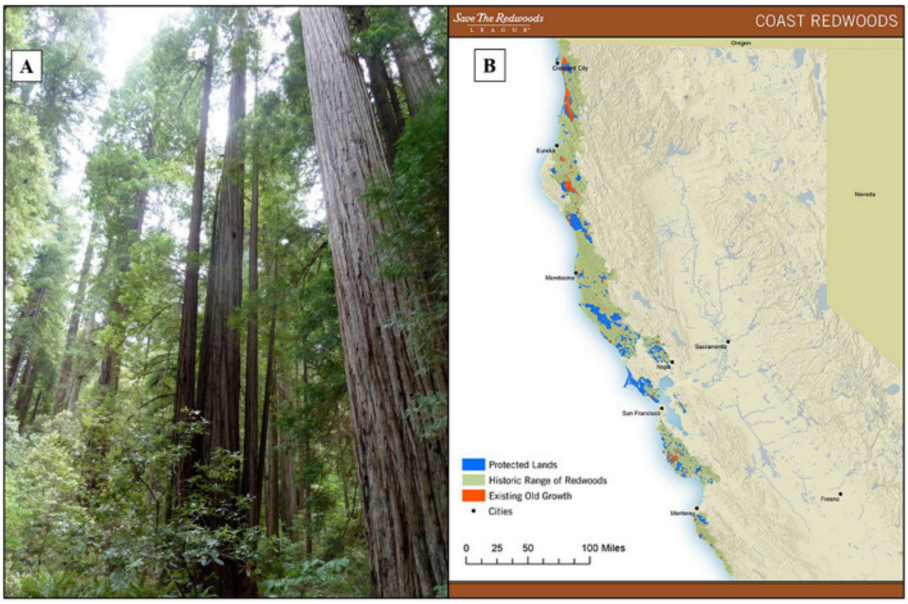


Figure 1

**Figure 1**

**(A)** Coast redwoods are found along a 450-mile stretch of coastal Oregon and California. **(B)** These trees are the tallest in the world [Photograph Credits: **(A)** S.F. Dymond; **(B)** Save the Redwoods League www.savetheredwoods.org].

portion of the world. They span a narrow, 450-mile-long strip of the Pacific coast of the United States, from southern Oregon to northern California, covering an area close to 81,000 hectares—which is only slightly bigger than New York City (Figure 1B).

Coast redwood trees are **conifers**, which means they are cone-bearing trees. Despite their giant size, the cones of coast redwood trees are small and measure only about 2.5 cm in length—slightly larger than a peanut [1]. While baby redwoods can sprout from the seeds present in these cones, coast redwoods are also prolific stump sprouters. This means that the tree will actually grow new plants around a cut or damaged stump. After a coast redwood tree is cut down, one stump can produce as many as 100 baby trees! These baby trees will be genetically identical to the original plant. Think of them as identical twins of the original tree. Eventually, the sprouts will develop their own root systems independent of their parent stump. This often results in circles of redwood trees, sometimes called fairy rings, which surround the old, rotting stump.

**CONIFER**

A cone-bearing tree, like a pine or a spruce.

Coast redwood trees are a remarkably long-lived species and, if left undisturbed, can live over 1,000 years. They have also been present on Earth for a long time—fossil records indicate that coast redwoods existed on Earth during the Jurassic period, over 200 million years ago [1]. These unique forests are also home to rare plants and animals, such as banana slugs (yes—these are slugs that look like bananas!), Northern spotted owls, and redwood violets.

## WATER MOVEMENT IN PLANTS

Like humans, plants need energy (which they get from the sun), air (only carbon dioxide instead of the oxygen that animals need), nutrients (which they get from soil), and water. Most trees get water from the soil beneath their trunks, pulling it from their roots up through their trunks, to where it finally escapes through their leaves. When trees lose water from their leaves, the process is called **transpiration**. Trees do not want to lose this water—they need it to make food—yet some water escapes as they take in carbon dioxide, which is used to make the sugar needed for growth, defense, and reproduction.

**TRANSPIRATION**

The process of water movement through a plant and its evaporation *via* leaves, stems, and flowers.

**XYLEM**

The vascular tissue in plants that moves water and dissolved nutrients upward from the roots.

**ATMOSPHERIC PRESSURE**

The pressure (or force) exerted by the weight of the atmosphere.

Trees can move water upward, against the force of gravity, through small vessels in their trunks called **xylem**. Think of xylem as the veins of the tree. The small diameter of the xylem, as well as **atmospheric pressure** and other built-up pressures in the leaves all contribute to a tree's ability to pull water vertically against the force of gravity. In this case, the atmosphere has a negative water potential compared to the plant, so the atmospheric pressure works to pull water up the plant instead of pushing it down. This is very similar to moving water up through a straw: the straw is like the plant's xylem, and the suction from drinking is similar to the pull from the atmosphere. Yet the massive height of coast redwood trees has made scientists wonder if something else might help them move water vertically for such long distances. The key to this riddle lies in the very location in which coast redwoods live and thrive—the coastal California fog belt.

## OCCULT PRECIPITATION

Fog is basically a cloud that forms low in the sky, near the ground or a body of water. Fog occurs when water vapor (the gas form of water) changes into a liquid. For this to occur, a few things must happen: (1) there must be a lot of water in the air; (2) the air must cool, allowing water to condense from water vapor to liquid water droplets; and (3) these water droplets must contact very tiny particles called **cloud condensation nuclei** (1/10,000 the size of a rain drop!) to change from vapor to liquid. Fog is different from normal rain because the droplets are too small to fall to the ground due to gravity. Because of this, it is extremely hard to measure the amount of water in fog using a normal rain gauge, which is why it is often call it **occult precipitation** (occult means magical or mystical). However, while scientists cannot totally measure the amount of water that fog provides to an ecosystem, we can certainly see its profound effects on the landscape, such as in coast redwood forests.

**CLOUD CONDENSATION NUCLEI**

Small particles 1/100th the size of a cloud droplet on which water vapor condenses.

**OCCULT PRECIPITATION**

Precipitation that is unrecorded by a standard rain gauge, such as fog or dew.

In the climate of north-central California, fog events are a vital source of water during the summer, when ecosystems are otherwise quite thirsty. In this region, almost all of the rainfall occurs during the rainy season, from approximately October–May. This rainy season

**Figure 2**

**(A)** Morning fog rolls inland from the Pacific Ocean in northern California. **(B)** Fog water condensing on the leaves of a coast redwood tree. **(C,D)** The deep, furrowed bark of coast redwoods allows them to trap and store large volumes of water [Photograph Credits: **(A,B)** J. Petreshen; **(C,D)** S.F. Dymond].

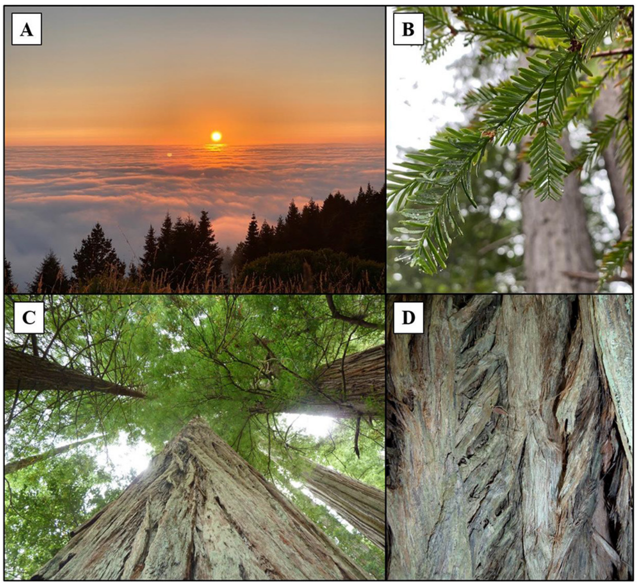


Figure 2

also happens to be the time when most of the vegetation is not transpiring due to the lack of sunlight. Thus, during the summertime growing season, plants in this region must rely on water that was stored up in the soil during the rainy season. Once this water is gone, it might be months before it is replenished. The key to the survival and amazing growth of coast redwoods lies in their exceptional ability to use occult precipitation.

## LEAVES AND BARK HELP WITH WATER UPTAKE

In the coastal California fog belt, fog generally occurs during the summer season (Figure 2A). It rolls onto land off the Pacific Ocean in the evening and dissipates during the morning after the sun comes out. Coast redwood trees trap this fog water in their feathery leaves (Figure 2B). These leaves have a high surface area, which means they can capture a lot of water. This water then drips down to the soil, where it is taken up by plant roots (Figure 3). This dripping water, called fog drip, sometimes sounds like it is raining in the forest, while no actual rain is occurring! Yet this is not the only way that trees in these ecosystems can acquire water. Coast redwoods, unlike most other trees, can absorb water directly through their leaves in a process called **foliar uptake** [2]. This means that they can sip in the water from occult precipitation during the evening and early morning, to replenish any water that they lost from daytime transpiration. Only a few tree species on the planet are known to do this! Additionally, coast redwoods can even store water on their leaves, saving up for future dry periods [3].

**FOLIAR UPTAKE**

The transfer of water from the outside of leaves and stems into a plant.

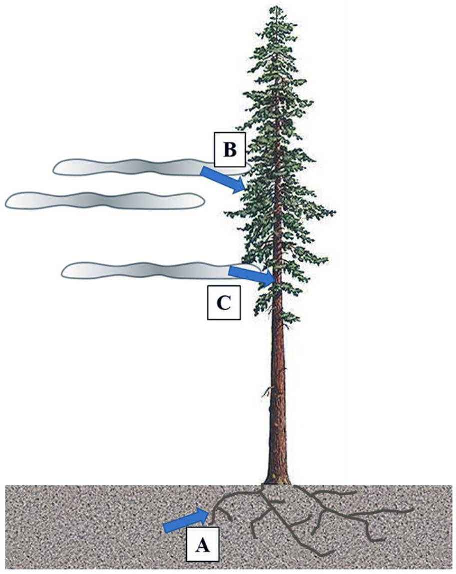


Figure 3

**Figure 3**

**(A)** Coast redwood trees can take up soil water through their roots. **(B,C)** These trees can also get water from precipitation or fog via their leaves or bark. Water moves up the tree (blue arrows) before it is lost back into the atmosphere via transpiration (green arrow).

Foliar uptake is not the only trick that redwood trees have up their trunks. Redwood twigs and bark also play a critical role in quenching the thirst of these colossal trees (Figures 2C,D). The deep, tough, fibrous bark of coast redwood trees allow them to store large amounts of water during rain events. Sometimes, these trees grow so much in diameter during fog events and rainstorms that they have broken the equipment used to track their annual growth! Scientists have discovered that coast redwoods can take in water directly through their bark and transfer it to the xylem (Figure 3), where it can help these trees to grow [4]. It turns out that staying constantly hydrated allows coast redwoods to achieve their enormous size and live for thousands of years. It is not occult magic—rather, redwood trees have adapted and evolved over millions of years to make the most out of their foggy living conditions.

## HOW DO COAST REDWOOD TREES GET SO TALL?

Just how do the tallest trees on Earth reach their staggering heights? It is a combination of many factors, but the summertime fog that replaces water lost by the trees during transpiration plays a big role. Other reasons include the relatively moderate climate in which they grow, high annual rainfall in the region, nutrient-rich soils, and few insects or diseases that can harm the trees. While the coast redwood forests may be some of the oldest on the planet, their future is increasingly uncertain. Scientists estimate that climate change has already resulted in a 33% decrease in the number of foggy days in coastal California since the early 1900's [5]. Decreased fog could result in an increasing number of dehydrated and stressed coast redwood trees. It is uncertain how redwood trees will adapt to live in drier, warmer climates and what the resulting impacts to the redwood ecosystem might be. If history has taught us anything, it is that these ancient trees are capable of finding creative ways to adapt to unique living conditions; it might just take a little while.

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## YOUNG REVIEWERS

**AVIV, AGE: 9**

A huge Harry Potter fan! I love reading books! I spend many hours reading on my Kindle, especially Harry Potter—I have read the entire series 20 times! I also love jamming on my electric piano, jump-roping and skipping when I am happy. I like eating salads and home cooked meals, but I also have a big sweet tooth—chocolate is yummy! As a vegetarian, I love nature—learning about it, protecting it, and enjoying it!

**ISAAC, AGE: 14**

Hello, my name is Isaac and I live with my parents and my dog, Themis! I enjoy reading and biking, and I swim, and play badminton and golf as well. My favorite subject in school is math.

## AUTHOR

**SALLI F. DYMOND**

Salli Dymond is a forest hydrologist, which means she studies the interactions between trees and water. She is particularly interested in how forests and streams respond to climate change and disturbance events such as logging, fires, and insect outbreaks. Dr. Dymond is primarily a field scientist and loves to tromp in the woods, climb trees, or dig in the soil on sunny, snowy, or rainy days. She is an Assistant Professor at the University of Minnesota Duluth in Duluth, Minnesota, USA, which overlooks Lake Superior—one of the world's largest lakes. *sdymond@d.umn.edu

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# FUNGI OF THE "BARK SIDE"

***Donát Magyar*[1*], *John T. Van Stan II*[2] and *Kandikere R. Sridhar*[3,4]**

[1] *National Public Health Center, Budapest, Hungary*
[2] *Biological, Geological, and Environmental Sciences, Cleveland State University, Cleveland, OH, United States*
[3] *Biosciences, Mangalore University, Mangalore, India*
[4] *Centre for Environmental Studies, Yenepoya University, Mangalore, India*

YOUNG REVIEWERS:

NATHAN
AGE: 15

OLIVER
AGE: 11

SAMUEL
AGE: 8

You may not pay much attention to fungi growing on the bark of trees in your neighborhood, but there are many fungal species that scientists know have joined the "bark side." The fungi living on bark do many interesting and surprising things. For example, bark fungi may prowl the bark in search of resources or new habitats. Fungi create tiny versions of themselves, called spores, which can use "the force" (of nature, like blowing wind, or flowing water) to move from one place to another on the bark. In this article, we introduce the microscopic war waging on the bark of your neighborhood trees, and present some of the fungi warriors of the bark side. We describe how some fungal spores use the force to stalk the bark (and beyond) during storms and discuss why fungi-bark interactions are another important reason to preserve and protect our trees.

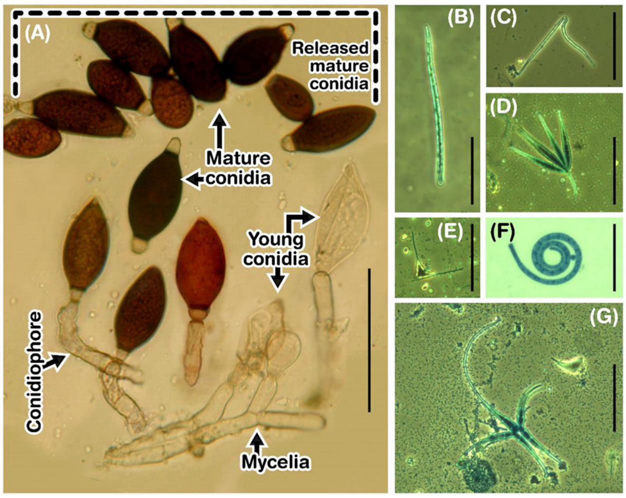


Figure 1

**Figure 1**

Microscope photographs of fungi and their spores. **(A)** The hyphae of a fungus, its conidia and the arms that sprout conidia, called conidiophores. Conidia come in many forms depending on the species of fungus, including: **(B)** an eel form, **(C)** a caterpillar form, **(D)** a broomstick form, **(E)** a mustache form, **(F)** a spiral form, and **(G)** a many-armed form (Note that the colors result from the different stains used to view the fungi more easily through the microscope). Scale bar = 50 μm. One micrometer is 1,000 times smaller than 1 mm.

**PATHOGEN**

A microbe, including a fungus, that can cause disease or death.

**SAPROTROPH**

An organism that feeds on dead or decaying materials.

**SPORE**

Microscopic living particles that fungi produce to spread and reproduce themselves.

**HYPHAE**

Fine, thread-like, noodley arms that fungi use to search for resources nearby.

**CONIDIUM**

A type of spore that fungi create to clone (or asexually reproduce) themselves. Fungi can produce both sexual and asexual spores, but this article focuses on the asexual spores.

## FUNGI'S CLONE WAR ON THE BARK SIDE OF TREES

A long time ago in a canopy far, far away....or, more precisely, about 25 million years ago on some tree bark....it was a dark time for a termite, for it had been killed by a fungus. While the fungus feasted on its victim, a tide of tree sap engulfed both fungus and termite, dried into amber, and froze this fungal feast in time. This amber, when found by scientists millions of years later, became the first historical record of any insect-eating fungus [1]. These fungi are still prowling around the bark of forests (or the "bark side") all around you, hunting insects to this day. Tree bark hosts many types of fungi that feast on various sorts of living and dead organisms. Whether a fungus is **pathogenic** (targets living things) or **saprotrophic** (targets dead and decaying things), it must prowl the bark in search of its target, or perish. One way that many fungi search for food or a new habitat is to create a tinier version of themselves, called **spores**, that can use "the force" (a natural force, like wind, or water) to get around.

Fungi can only reach so far with their noodley arms, which are called **hyphae** (Figure 1), so spores that can be swept up by the wind or by some flowing water can help fungi explore new habitats beyond the reach of their hyphal hands. Some spores are genetically identical clones of their fungal parents! These special spores, called **conidia**, not only help their fungal parent to explore, but they can also settle into a new location and reproduce there asexually, meaning without the need for a partner. In this way, conidia help fungi wage their own "clone war" to spread and grow more quickly than other lifeforms that need to reproduce sexually. On the other hand, because conidia cannot control where the winds or waters take them, they can end up anywhere! But the clone army is so numerous that some loss is acceptable. So, if fungal spores end up on the "bark side" of a tree, maybe stuck deep in a crack of the bark, what do they do next?

## WHY DO FUNGI JOIN THE "BARK SIDE"?

Fungi mostly end up stuck in tree bark because the bark is very sticky. Most of a tree's surfaces are sticky to fungal spores. Trees are so sticky that several hundred kilograms of particles from the air can get stuck in a single city tree each year—that is the weight of a buffalo! The number of particles stuck to the bark can be much greater than the number that sticks to leaves. A recent study in Beijing, China found that one square centimeter of bark captured 50 times more particles (by weight) than the same area of leaf surface [2]. Bark on trunks also captured nearly 90% of all the larger particles (the size of fungal spores or larger) found on the tree. So, it appears that bark is not only a great particle trapper, but it is especially good at trapping particles the size of conidia.

A crack in the bark surface may not seem like a cozy place to us, but it may be a very nice habitat for fungal conidia. We would probably not like how dark it is, for instance. The sun's rays may never fully penetrate to the crack's depths, leaving it frequently damp. Conidia, however, might find the dampness perfect for germinating and beginning to grow hyphae. Even the tiny creatures crawling around the crack may be a welcome sight to fungal conidia. As conidia become fully functioning (pathogenic) fungi, they may welcome their neighbors—by extending hyphal hands to capture and consume them! Bark cracks may also contain dead or decaying matter. In that case, any conidium with saprotrophic tendencies may find this bark graveyard…appetizing.

## WHO HAVE WE SEEN ON THE BARK SIDE?

There are many fungi that have been found on the bark side (see some examples in Figure 2), and some of these species are not interested in eating creatures, living, or dead. Instead, they prefer pollen grains, which are loaded with nutrients. Luckily, bark is a great pollen trap! To eat pollen grains, fungal conidia from some species, like *Mycoceros*, use horn-like limbs. Others, like *Retiarius,* can spear pollen grains with a structure resembling a Roman gladiator's trident weapon. Other species, like *Lecophagus*, can capture worms called nematodes, which are 10–100 times longer than a germinating conidium, as these worms squirm across the bark surface. Even celebrities of the fungal world—species starring in popular YouTube videos, for instance—dwell on the bark side. These include *Ophiocordiceps* species, which sneak inside insects, take control of their minds, and then burst through their exoskeletons when the fungus fruits (makes a mushroom)! Thousands of fungus species are known to burst through the exoskeletons of many types of insects, from ants to wasps to grasshoppers. There are also many fungi operating on the bark side in ways that are currently unknown to scientists, like the two *Oncopodiella* species in Figure 2. Perhaps, one day, you will discover what they are up to!

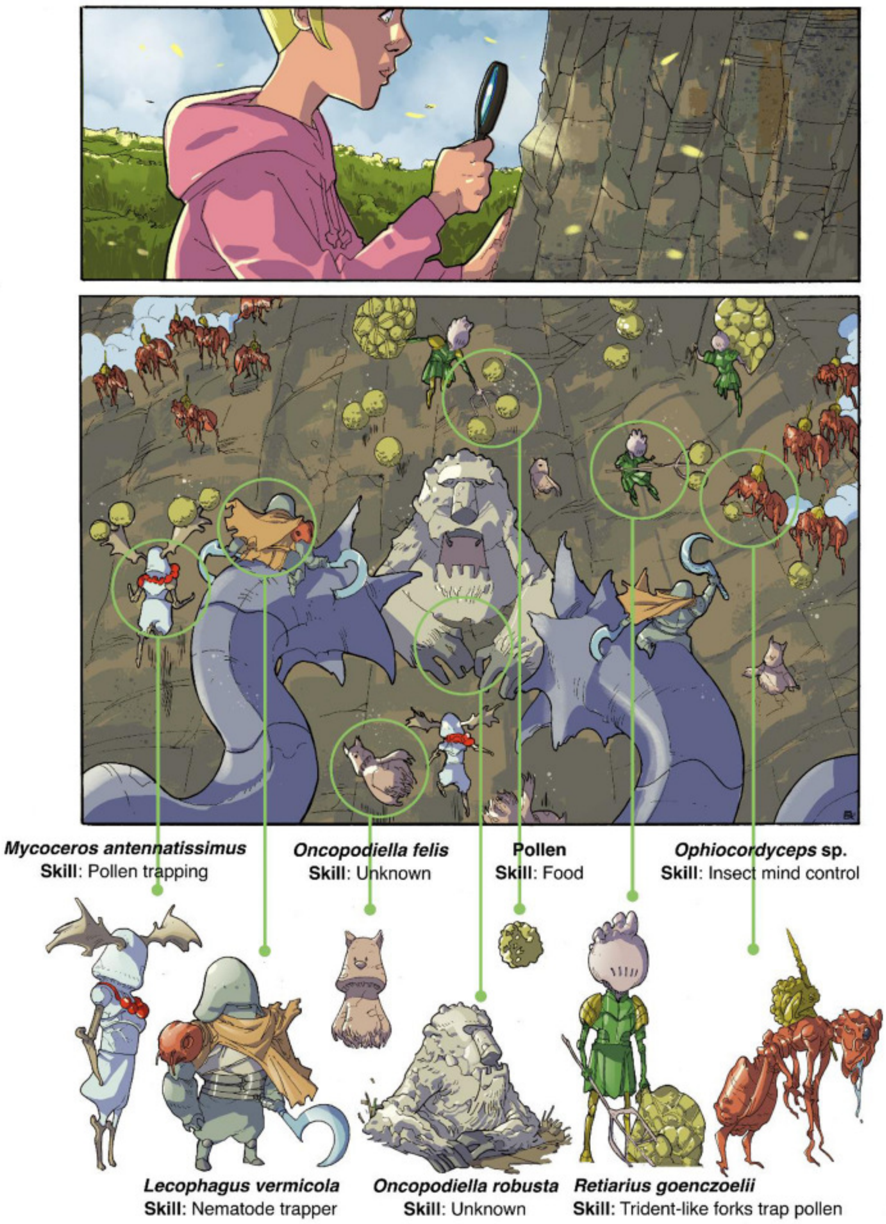


Figure 2

**Figure 2**

Cartoon representations of fungi engaged in the war on the "bark side" of trees. If you look closely at the bark surface—like, really, microscopically close—you will see fungi competing to consume resources including pollen, nematodes, and insects!

## WHY SHOULD WE KEEP AN EYE ON THESE FUNGI?

Generally, scientists keep an eye on fungi because fungi play important roles throughout the natural and human environment, such as breaking down dead stuff or creating medicines. In forests, fungi can help or hurt trees. For example, some fungi can partner with roots to help plants find resources in the soils, but other fungi attack and eat leaves. Scientists would like to better understand the role the bark side plays in the life cycle of fungi. For example, many spores from bark fungi can surf on rainwater as it flows down the bark in a process called stemflow. Is riding this bark-side water slide an important step in how these fungi roam the forest in search of resources?

Healthy trees are important for our neighborhoods to cycle water, shelter animals and even our mental and physical health [3]. Scientists are interested in how bark fungi affect tree health. Some scientists have found that the bark water slide, loaded up with insect-eating fungal spores, may help trees to control pests [4]! The tree's bark also provides the first line of defense against pathogens, much like our skin does. Many fungi of the bark side help keep trees healthy by eating tiny nematodes or pathogenic fungi that could penetrate or infect the "tree skin" and cause disease. On the other hand, not all bark fungi are friendly to trees. So, it is important for scientists to identify which bark fungi can become pathogenic to a tree if its bark is broken by human activities, such as a car accident or someone carving their name. These human activities not only damage the bark, but also give potential pathogens an opportunity to attack the tree! Thus, keeping an eye on the fungi of the bark side and how they use the force (of nature), can help us keep trees healthy.

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## YOUNG REVIEWERS

### NATHAN, AGE: 15
I am a passionate learner in science, especially in biology. I also love to explore different topics and enrich myself. I work to become a doctor in the future.

### OLIVER, AGE: 11
I enjoying being out in nature and playing with my friends. My favorite hobbies are bike riding and fossil hunting. I also like learning about science and how things work. When I am older I want to either be an ecological designer or paleontologist and hopefully help save the planet!

### SAMUEL, AGE: 8
I enjoying being out in nature and playing with my friends. My favorite hobbies are bike riding and learning about airplanes. In school my favorite subject is maths. I am also on the school eco council. I think it is really important to look after our planet.

## AUTHORS


### DONÁT MAGYAR
Donát Magyar is an aerobiologist researcher at Hungary's National Public Health Center. He studies the ways that fungi (and pollen) are dispersed, trapped, and re-dispersed by natural and human processes. *magyar.donat@gmail.com



### JOHN T. VAN STAN II
John Van Stan is an ecohydrologist interested in what happens when plants and water meet during storms - rain, snow, sleet, or otherwise. He enjoys researching the roles that wet plants play in our Earth's energy balance, nutrient cycles, and landscape ecology. He is currently an Associate Professor at Cleveland State University, where he leads the Wet Plant Lab.



### KANDIKERE R. SRIDHAR
Kandikere Sridhar is a senior professor at Mangalore University, Karnataka, India, where he researches the ecology of freshwater fungi. His work particularly focuses on a type of fungi (hyphomycetes) in the Western Ghats and mangrove/marine habitats along India's west coast.

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# BRANCHFLOWS: UPSIDE-DOWN RIVERS CLINGING TO THE BARK ABOVE OUR HEADS

***John T. Van Stan II[1*] and Alexandra G. Ponette-González[2]***

*[1]Department of Biological, Geological and Environmental Sciences, Cleveland State University, Cleveland, OH, United States*
*[2]Department of Geography & the Environment, University of North Texas, Denton, TX, United States*

YOUNG REVIEWERS

LICEO CLASSICO PAOLO SARPI

AGES: 15–17

If you look up during a storm or when it is foggy, you may see little rivers flowing down the tree branches above your head. These are called branchflows, and they play an important part in moving water along trees and through forests. For scientists who study water, branchflows are really weird! They do not flow on top of something, like rivers that flow over the ground. Instead, they flow *underneath* branches, clinging to the bark, the same way you might cling to monkey bars at the park. Branchflows can also disappear before making it to the ground, because the water gets stuck inside of tree holes. Branchflows transport important stuff through the forest and to the forest floor, from life-saving meals to life-ending predators! Please join us as we explore what branchflows are, where they flow, what they carry, and why we need to know more about them.

## WHY SHOULD WE LOOK UP DURING STORMS?

Looking up during a storm can be just as unpleasant as looking up on a clear, sunny day: instead of receiving an eyeful of sunlight, you might get a face full of water! If you are in a forest during a storm and you look down, you may notice dry spots here and there. What keeps these spots dry? The leaves and branches above your head, which are called the forest **canopy**, do this. When it starts to rain, a dry canopy keeps the surface below dry, simply by catching raindrops and snowflakes before they can reach the ground. Like a drinking glass, leaves and bark can only hold so much water, and eventually they will overflow. When leaves overflow, they begin to drip (Figure 1a) and the area below them gets wet. On the other hand, when bark on the top (upper) side of a branch is soaked, water drains down the bark to the bottom (underside) of the branch (Figure 1b), but it may not drip to the ground. Instead, this water flows along the branch bottom, hanging from the bark, defying gravity all the while (Figure 1c, Video 1).

**CANOPY**

The above-ground leaves, branches, and plants growing on them, in any ecosystem, like a forest.

**VIDEO 1**

After enough water drains to the branch bottom, branchflow paths can be seen.

The flow of water along branches is called **branchflow**, and it can transport liters (bucketsful!) of water from one area to another in a storm [1]. In this way, branchflows can keep some areas of the forest floor dry while making the area where the branchflow ends wet. We humans may prefer to wait out the storm in one of the drier spots. However, there are many thirsty ground-dwelling plants and microbes that may not have had a drink of water since the last storm. These organisms might prefer to make their homes in the wetter places at the ends of these upside-down rivers. In other words, understanding branchflows in the canopy can help us understand what is happening on the forest floor, particularly what grows and thrives where, and why.

**BRANCHFLOW**

Rain, fog, dew, or melting snow water that drains down the bottom of a branch of a tree or shrub.


Figure 1

**Figure 1**

Wet leaves and wet branches. **(a)** When leaves are soaked, they will usually begin to drip. **(b)** When the tops of branches get soaked, water drains to the bottom of the branches. **(c)** After enough water drains to the branch bottom, branchflow paths can be seen [Photograph credits: **(a)** John Van Stan; **(b)**, **(c)** David Dunkerley].

So, where can branchflows end up? And importantly, what can these branchflows carry and deliver to the places they travel?

## WHERE DO BRANCHFLOWS GO?

Branches come in many shapes and sizes and can be covered in many different types of bark. As a result, branchflows can run into, or over, many obstacles as they drain to a bigger branch or to a tree trunk. These obstacles can force water off of its path. For example, if a branchflow hits a sharp bend in the branch, or a bark ridge that is too tall, water can lose its grip on the bark surface and drain to the ground below. This can create a **drip point** that can deliver 10 times more rainwater to a small spot on the forest floor [2]! Just as smaller rivers flow into larger ones, branchflows come together at bigger and bigger branches, gathering larger and larger amounts of rainwater. Scientists have observed some of the largest canopy water flows at the trunk, where branchflows from all over the tree unite and become what is called **stemflow**.

**DRIP POINT**

An area, usually at the bend of a branch, where lots of branchflow falls off the branch.

**STEMFLOW**

Branchflows that come together at the trunk and drain to the forest floor.

Given the right conditions, stemflow can drain hundreds of liters of rainwater to a small area around a tree! One of the conditions that affects stemflow is the type of bark. Smooth bark (like that in Figure 1) and bark with channels in it tend to drain the most stemflow, while flaky or spongey bark drains less due to the water getting sucked up, or splashed off. In some forests, stemflow can be so large and powerful that it rips away soil particles at the base of the tree trunk. At one site, stemflow carried away several centimeters of the soil surface (about the thickness of a juice box) in a single year [3]! In other forests, stemflow enters the soil easily by traveling along the roots. So, the story for stemflow does not end at the forest floor. In fact, scientists are still puzzling over why stemflow goes in different directions (into the soil or over it) at different sites.

In fact, some stemflow may not reach the forest floor at all. After all, tree trunks can have just as many obstacles as branches do. In addition to the extreme bends and rough bark, trunks often have holes in them. These tree holes can capture stemflow water, becoming what are called **dendrotelma**. Dendrotelma can store many liters of water before they overflow and let the stemflow continue down the trunk (Video 2). There are also many tree-dwelling animals that have been seen to give the bark quite a licking. For example, wild koalas have recently been caught drinking stemflow [4].

**DENDROTELMA**

A hole in a tree that fills up with water during a storm.

**VIDEO 2**

Here we see a small tree hole filled with stemflow water (called a "dendrotelma") and overflowing, permitting the stemflow to pass further down the trunk.

## WHAT IS IN THESE UPSIDE-DOWN RIVERS?

Branchflows, like rivers, can carry a lot of stuff—from life-saving meals to life-ending predators [5]. Scientists call all these very tiny things particles. Many of these particles are made of elements (like carbon,

**Figure 2**

Creatures found in branchflows can include nightmarish nematodes, cute tardigrades, orchid seeds, lots of bacteria, and many fungal spores. Illustration by Tyasseta.

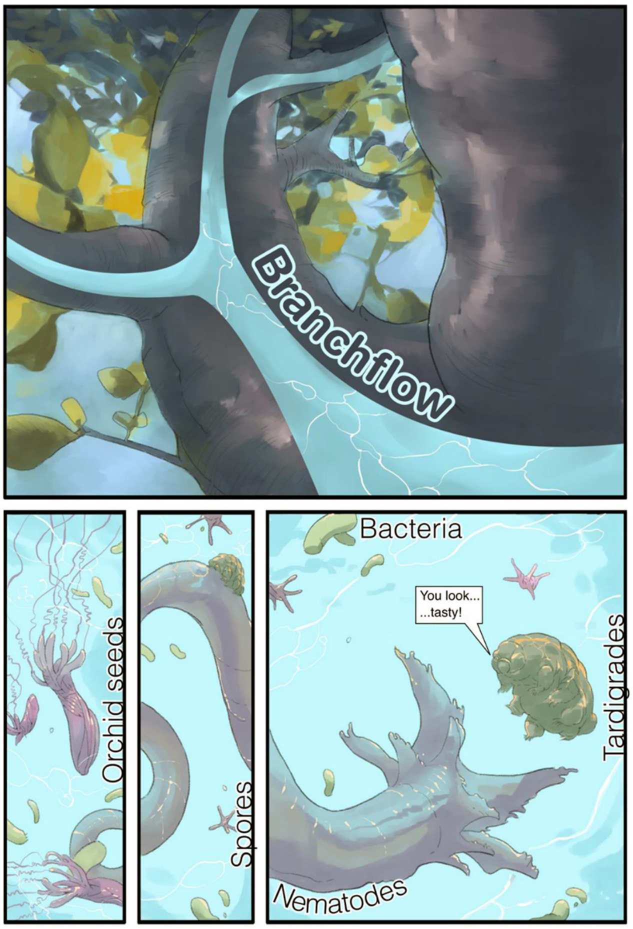


Figure 2

nitrogen, and phosphorus) or compounds (like sugars, proteins, and fats). Tiny creatures in the soil eat these nutritious particles to survive. Soil creatures like some of the particles delivered by branchflows more than others. You see, before these particles were picked up by branchflows, they were baked in various types of ovens...sort of. One type of oven might be a car engine, for example, while another could be the belly of a bug. Both ovens bake carbon-rich particles that can end up on bark and in branchflows. But it is much harder for creatures in the soil to digest the meal baked in a car engine (basically soot) than the meal baked in the belly of a bug (basically sugar). Which would you prefer?

Some of the particles in branchflows are alive (Figure 2). The tiny creatures that hitch a ride on branchflows may look like they came from a horror movie. For example, wormlike creatures called **nematodes** not only look scary, but also can be a real horror to the bacteria they eat. Luckily for nematodes, branchflow waters can carry hundreds of thousands of bacteria in a single drop of water. Other tiny beasts in branchflows are considered by many to be Disney-level cute—cute enough to earn "meme" status—like the **tardigrade**. Some of the larger tardigrades do not see nematodes as nightmarish at all,

**NEMATODES**

A small worm, often called "roundworms."

**TARDIGRADE**

A small animal with eight legs that is commonly called a "waterbear."

but as lunch. Branchflows can also be a major way for certain plants and fungi to disperse their seeds and spores (Figure 2). For example, one type of orchid seed can put out octopus-like tentacles when it gets into branchflows. These tentacles help the seed to stick to a nice spot on the branch and grow. Many fungal spores do not want to stick to the branch at all—instead, they have multiple "fins" that help them ride branchflows out of the canopy. Loaded with snacks, microbes, animals, and plants, branchflows have the same types of particles that bigger water flows, like rivers, have. They are just a lot smaller.

## SO WHAT? WHY "BARK UP" THIS BRANCH?

What brought attention to branchflows in the first place? The same thing that, according to the story popularized by Voltaire, led Isaac Newton to investigate why apples fall from a tree straight into the ground—but, in reverse! Scientists did *not* see falling droplets hit their rainfall collectors under a tree on rainy days. Of course, they wondered where the droplets went. This is when, according to known records, a young poet, forester, and scientist named Carl Eduard Ney saw stemflow and branchflow, when wandering the Bavarian forests in search of the "missing" rain [6].

We need to study branchflows because they contain important information about how forests work. Because branchflows are formed by rainwater draining from all over the tree canopy, they can represent a meaningful amount of the total rainwater that reaches forest soils. Branchflows can also result in intense rainwater supplies to small areas, in the case of drip points and stemflow, which can increase how deeply the water penetrates into soils and can also reduce the amount of soil around trees. Thus, branchflows may be important for "recharging" a forest's soil and ground waters and for transporting soil to other spots. It is just as important to take note of the elements, compounds, and creatures delivered by branchflows to dendrotelma, animal bellies, and the soils. In fact, the materials that branchflows deliver to a dendrotelma are more important than they appear at first glance. For example, if you investigate a dendrotelma, you will notice that it provides a comfy nursery for mosquitos—and for the diseases they can spread. In summary, from the health of plant roots to human diseases, there are many reasons why scientists in forests should continue gazing upward during storms.

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## ORIGINAL SOURCE ARTICLE

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## YOUNG REVIEWERS

### LICEO CLASSICO PAOLO SARPI, AGES: 15–17

We are the best school in the world, because we are the tallest and the cleverest, and we have the best teachers. But specifically we are the best class of the school because we have a lot of different type of people and we are very funny. We love science because we have a very good teacher.

## AUTHORS

### JOHN T. VAN STAN

John T. Van Stan is an ecohydrologist interested in what happens when plants and water meet during storms – rain, snow, sleet, or otherwise. He enjoys researching the roles that wet plants play in our Earth's energy balance, nutrient cycles, and landscape ecology. He is currently an Associate Professor at Cleveland State University, where he leads the Wet Plant Lab. *professor.vanstan@gmail.com

### ALEXANDRA G. PONETTE-GONZÁLEZ

Alexandra G. Ponette-González is an ecosystem geographer who studies interactions between humans and the environment. She is interested in the many materials that enter the atmosphere (what goes up) and other materials that fall out of the atmosphere onto trees and forests (what comes down). She is currently an associate professor in the Department of Geography and the Environment at the University of North Texas.

BIODIVERSITY
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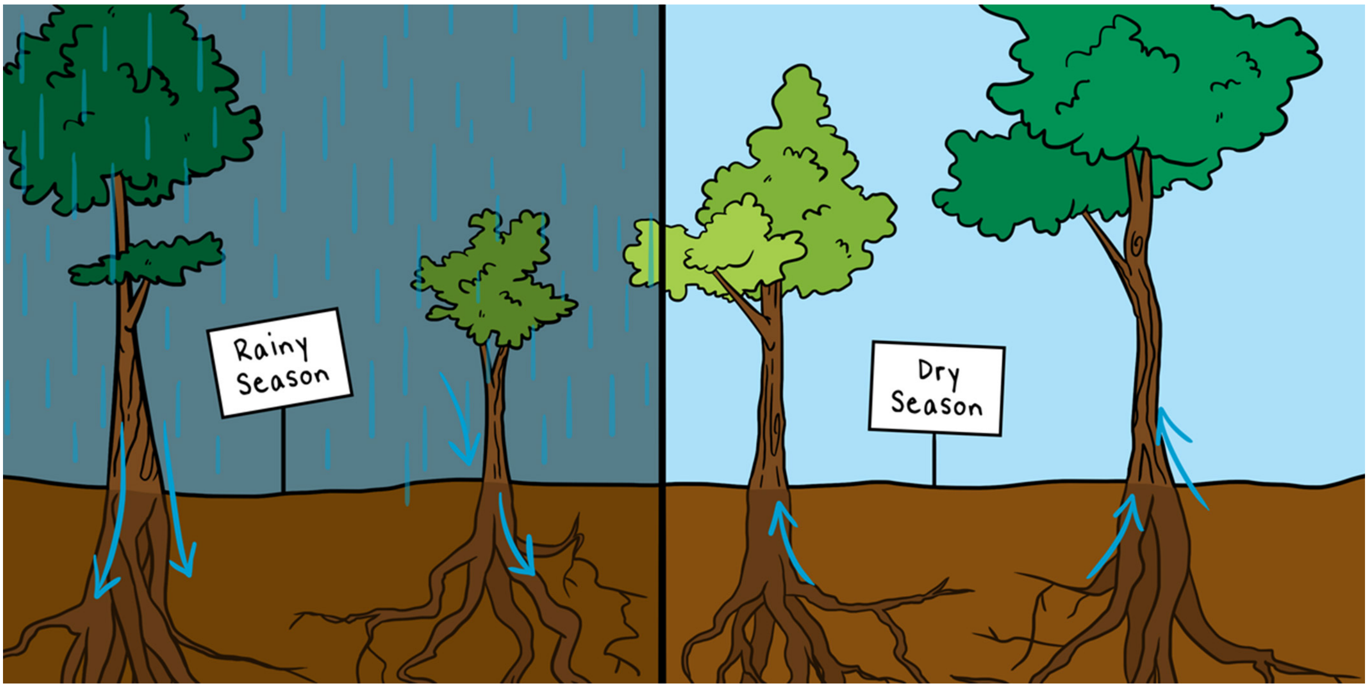


# CAN TREES HELP PUT WATER *BACK INTO* THE SOIL?

***Kelly Cristina Tonello*[1*] *and Julieta Bramorski*[2]**

[1] *Research Group of Forest Hydrology Ecosystems, Department of Environmental Science, Federal University of São Carlos, Sorocaba, Brazil*

[2] *Research Group of Forest Hydrology Ecosystems, Department of Environmental Science, Federal University of Amapá, Macapá, Brazil*

YOUNG REVIEWER:

ANNA-MARIE
AGE: 16

Just to the south of the Amazon, there is a vast and biodiverse savanna that scientists believe is under even greater threat, called the Cerrado. Scientists want to understand how the plants that live in the Cerrado affect the rainfall that enters the ground to recharge the aquifer. Many of these plants are trees that capture rainwater and drain it down their bark-covered branches and trunks. This water, called stemflow, may be one way to recharge the aquifer, if the branches and bark of the trees are the right size and shape. This article will introduce the common plant species of the Cerrado, describe how they affect the way rainfall enters the ground, and discuss how bark and branches may help conserve water.

## DO YOU KNOW THE CERRADO?

The Cerrado originated at least 40 million years ago, making it one of the oldest **biomes** on Earth. The Cerrado is huge, originally covering 22% of Brazil, and it contains the highest biodiversity of any biome in

**BIOME**

They are types of ecosystems, habitats or biological communities with a certain level of homogeneity.

**Figure 1**

The Cerrado forest is also called the "upside-down" forest. Notice how the tree roots go much deeper into the soil than their canopies reach to the sky! Figure credit: Dr. John Toland Van Stan, II.

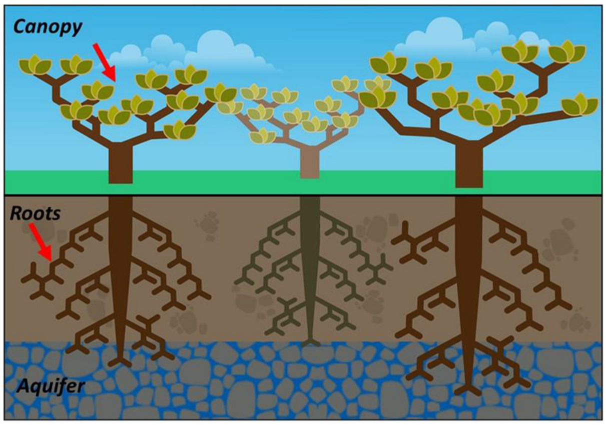


Figure 1

Brazil. The Cerrado isn't the same over its entire area; instead, it is a patchwork made of different types of land cover, including cerradão ("big cerrado"), typical cerrado, campo cerrado, dirty cerrado field, and clean cerrado field. The cerradão is the only type of land in the Cerrado with large forests. There is a great diversity of plants in the Cerrado, including palm, fruit, and timber trees, plus a wide variety of grasses, bromeliads (like mini pineapples), orchids, and other smaller plants. Some species, like timber trees, have twisty and thick trunks reaching up to 20 meters in height. Other **woody plants** are shorter and more like bushes, like the strawberry guava.

**WOODY PLANTS**

Forest species providing products such as wood.

This diversity of plant life is surprising because the Cerrado has a dry season every year that can last from April to September and the soils are generally low in nutrients. Scientists believe that many trees survive the long dry seasons in poor soils due to their deep root systems: some roots can reach up to 15 meters in depth. This allows them to capture water from natural water storage areas called **aquifers**, deep below the surface. The rainwater that flows through this huge savanna contributes water to the Guarani aquifer, which is important to many countries in South America. Many measurements and estimates suggest that the height of the tree canopy above the ground is only a third of distance that the roots extend into the soil. Because its root system can be more extensive than its treetops, the Cerrado is also called the "upside-down forest." So, the Cerrado's upside-down forest is strongly rooted into the aquifers below it (Figure 1).

**AQUIFER**

An area that can store or transmit water underneath the ground.

## HOW TREES HELP TO RECHARGE AQUIFERS

Plant roots take up lots of water from the Cerrado's aquifers during the dry season. But they also help to put lots of water *back into* these aquifers later. You see, the climate of the Cerrado also has a rainy season, which generally occurs between October and February. The aquifers are recharged by this rain, but they depend on plants to get the rainwater down into them. The same plant roots that remove groundwater from the aquifers during the dry season provide drainage pathways for rainwater into and through soils during the rainy season. These root pathways can help rainwater to drain into and recharge the aquifers. In fact, if we looked closely at one of these plants, we could count thousands or even millions of roots—that's thousands to millions of pathways for rainwater to travel along to recharge the aquifers! And, if we look for *tiny* roots with our microscopes, we will see countless other mini-root water pathways that intertwine with the roots of other plants [1]. So, the Cerrado's complex root system can promote water movement from the soil surface to the aquifers in the wet season, while also nourishing the plants in the dry season.

## RAIN MUST OVERCOME LEAFY AND BARKY OBSTACLES

The story of roots and aquifers is a little more complicated though, because a lot happens to rainwater between the Cerrado's treetops and the soil surface. When the rain reaches the forest's leaves and bark, it is forced along one of three paths… and not all of them lead to the soil surface! First, some water will be stored on leaves and bark and will eventually evaporate back into the air. Second, some water will drip to the surface, as if a branch has become a leaky faucet. Finally, some rain will stick to the bark, branches, and stems and will drain all the way down to the soil surface at the bottom of the tree trunk. This last process is called **stemflow**. Stemflow comes from many branches all draining down to one spot at the surface right next to the trunk, so it can result in a very concentrated flow of water to the soil in that location. Stemflow does not just come from rain. In fact, in some **arid and semi-arid regions** where there is little rainfall, water vapor from the air condenses into liquid water when it contacts the plant and drains to the soil via stemflow.

**STEMFLOW**

Water that is captured by plant leaves and branches and drained down their stems.

**ARID AND SEMI-ARID REGIONS**

Regions where the rain is usually short-lived but very intense.

Many researchers are now trying to understand what factors affect the production of stemflow in the Cerrado and in many other regions around the world. Stemflow depends on how the forest is structured, such as the number of trees in a certain area and the types of plant species present. For example, forests with a larger density of trees and a greater area of leaves and bark tend to catch a greater amount of rainfall that becomes stemflow. Sometimes, the structure of a plant's leaves can reduce the amount of stemflow, for example if they are hairy. In those cases, the leaves may retain the water, which will eventually evaporate and not make it to the soil. The way a tree species' bark is shaped is also important. There are many types of bark in the Cerrado. A thicker bark (Figures 2A–C) could reduce stemflow by acting like a sponge and sucking up all the water draining down the trunk. A thinner bark (Figures 2D–F) would not absorb as much water, allowing more stemflow to reach the ground.

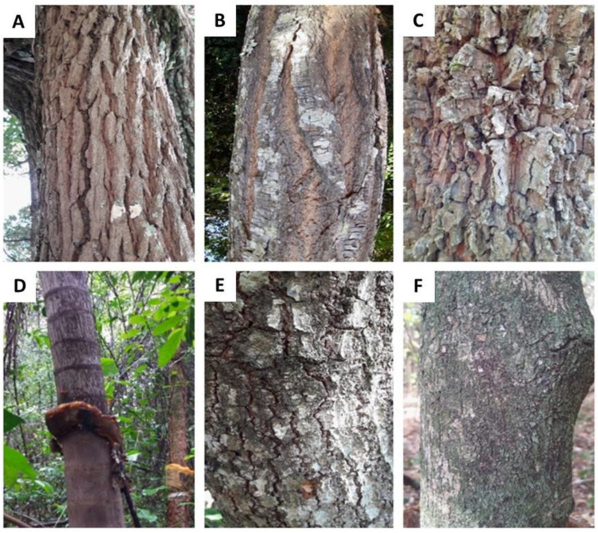


Figure 2

**Figure 2**

Examples of bark types from the Cerrado. Notice how the top row of trees has thick bark that can absorb some of the stemflow, while those in the bottom row have thinner bark that would allow more stemflow to reach the soil. **(A)** candeia, **(B)** cedro, **(C)** angico, **(D)** palm, **(E)** pata de vaca, **(F)** ipê amarelo.

## THE FINAL HURDLE: CROSSING THE LITTER

Upon reaching the bottom of the trunk, stemflow may still not meet the soil quite yet...it might instead meet the **litter**, a thick layer of fallen leaves, branches, insects, flowers, fruits, and even fallen tree bark, too! This litter can protect the water that makes it into the soils below, blocking soil water from the wind and sun that could cause it to evaporate. Some researchers have found that stemflow can pass right by the litter layer and into the soils. If this is common, then stemflow may make it to the soils and the protection of the litter layer by riding the bark straight into the soils. In the Cerrado, more water has been found in soils that lie beneath the forest litter. So, maybe the bark does a double duty! First, it helps to drain rainwater along stems and into the soils. Then, perhaps the fallen bark in the litter helps protect the water that makes it to soils, allowing it to infiltrate and recharge the aquifers!

**LITTER**

Is the layer composed by the deposition of plant remains (leaves, branches) and the accumulation of organic material in different stages of decomposition that superficially covers the soil.

## THE MAGNIFICENT UPSIDE-DOWN FOREST

The upside-down forests of the Cerrado, with their large roots and trees with thick and rugged bark, have been fittingly called a "cradle of waters." We hope that you now have a better understanding of forest and water relation. It is important for researchers to continue to study forest hydrology because we have a lot of specific interactions among biomes, their structure, soil properties and hydrology. Further research will help us to understand and protect Cerrado forests in South America. So, we wish someday we can count on your help to study and protect this magnificent biome!

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## YOUNG REVIEWER

**ANNA-MARIE, AGE: 16**
My favorite subject is biology, I like bionics. In the future I would like to work on new materials, new substances. I am curious about the mysteries of the universe, there is so much to discover!

## AUTHORS

**KELLY CRISTINA TONELLO**
I am an Associate Professor at the Federal University of São Carlos and a head of the Research Group of Forest Hydrology Ecosystems - Sorocaba Core (Hidrolef-Sorocaba). My research focuses on how forests are linked with the water

cycle and soil water content. Besides research, I also enjoy being out in nature, doing adventure tourism, climbing mountains, and visiting places that I have never been before. *kellytonello@ufscar.br

**JULIETA BRAMORSKI**

I am an Associate Professor at the Federal University of Amapá and the head of the Research Group of Forest Hydrology Ecosystems - Macapá Core (Hidrolef-Macapá). My research focuses on understanding how the presence of the forest acts in the conservation of ecosystems. Besides research, I also enjoy to listening a music and watching movies.

EARTH AND ITS RESOURCES
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# TREE BARK: A SURPRISING AND DIVERSE RESERVOIR FOR WATER

***Courtney M. Siegert*** [1*] ***and Anna Ilek*** [2]

[1] *Department of Forestry, Forest and Wildlife Research Center, Mississippi State University, Starkville, MS, United States*

[2] *Department of Botany and Forest Habitats, Faculty of Forestry and Wood Technology, Poznań University of Life Sciences, Poznań, Poland*

YOUNG REVIEWERS:

AVIV
AGE: 9

EVAN
AGE: 8

Bark is the outside layer of wood that all trees have. Bark protects trees from harsh environmental conditions including weather, pests, disease, and damage from hungry animals. Just like leaves, bark is different across species. Some trees have thick, rough bark while others have thin, smooth bark. When it rains, bark acts like a sponge and absorbs water. Some trees have bark with large pore spaces that make it easy to absorb rain water quickly. Other trees have bark with smaller pore spaces, which absorb water slowly. Each tree species has a maximum storage capacity of water that can be held in the bark. In fact, some mature trees can store more than 100 L of water in their bark—that is about as much water as you would use in a 10-min shower! In this way, bark influences the water cycle of individual trees and entire forests.

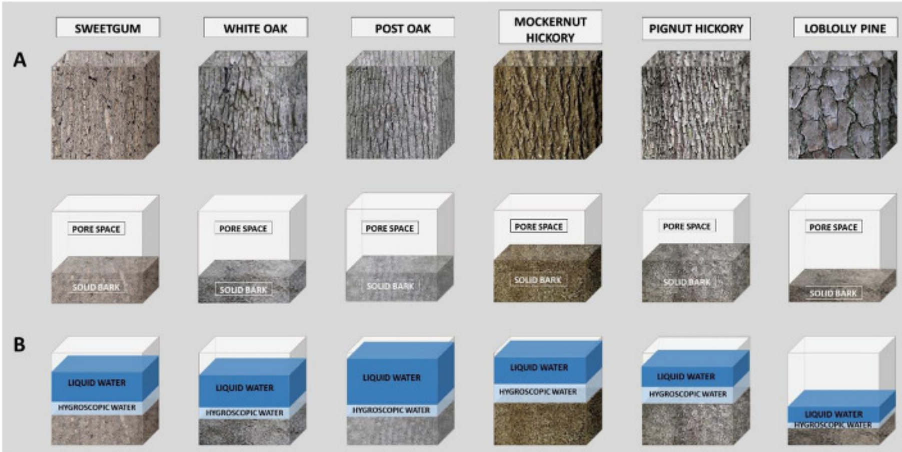


Figure 1

**Figure 1**

The barks of different tree species absorb different amounts of water. **(A)** The barks of various tree species are shown in the top row. If we squeeze all the solid bark together and separate it from the open pore space, we can see that some species have more open pore space and some have less. **(B)** Some of this pore space is always occupied by hygroscopic water, which is water absorbed from the atmosphere, and whatever pore space is left over determines the amount of additional water the tree bark can store from rain storms.

## THE WATER CYCLE IN THE FOREST

Have you ever thought about where rain goes when it falls from the sky? There are scientists called hydrologists who do just this. They study the **water cycle** as water moves through our environment, and this area of study is called **hydrology**. Rain is just one small part of the water cycle. The water cycle describes the movement of water on Earth and includes rain and snow, rivers and oceans, groundwater below our feet, and water that evaporates from soil, lakes, and leaves [1]. If we look closely at a forest, even more parts of the water cycle can be found. Some water lands on the leaves of trees and drops to the ground—this is called **throughfall**. Some water lands on leaves and flows down branches to the tree trunk and then to the soil—this is called **stemflow**. And some water lands on leaves and bark and is held there before being evaporated back into the atmosphere—this is called **interception**. Hydrologists care about how much water reaches the forest floor by throughfall and stemflow. We also care about how much water is "lost" to interception because that water cannot be used by the trees or animals in the forests, or by humans who might rely on the forests for drinking water.

## WHAT IS BARK'S ROLE IN THE WATER CYCLE?

Bark is the outside layer of wood that all trees have. Bark protects trees from harsh environmental conditions including weather, pests, disease, and physical damage from hungry animals. Bark is an important component of the water cycle because it acts like a sponge during storms. That means some of the rainwater is absorbed into the bark and does not make it to the forest floor. The amount of water that can be absorbed by bark depends on the tree species and its physical structure [2]. For example, if we compare the same amount (or volume) of bark among six different tree species, loblolly pine bark is about 18% solid bark and the rest of bark volume is open **pore space** (Figure 1A,

**WATER CYCLE**

Movement of water between the Earth and the atmosphere.

**HYDROLOGY**

The scientific study of water and its movement on Earth.

**THROUGHFALL**

Rainwater that falls through forest canopies to the forest floor.

**STEMFLOW**

Rainwater that runs down tree trunks.

**INTERCEPTION**

Rainwater that is captured by forest canopies and evaporated back to the atmosphere.

**PORE SPACE**

Open voids that can be filled with water or air.

Figure 2

**Figure 2**

Sometimes bark must be removed from trees so experiments can be performed on that bark in the lab. This is called destructive sampling. In this picture, a piece of bark was pried from a loblolly pine tree in the Bankhead National Forest in northern Alabama. Don't worry, the tree will be ok!

far right). Pores inside bark are spaces that can be filled up by water during rain events. In contrast, mockernut and pignut hickory bark are about 38% solid bark and the rest is open pore space. So when it rains, loblolly pine has a lot more open pore space to absorb water!

## HOW DO WE STUDY BARK?

Measuring surface characteristics of bark is pretty easy. We can poke and prod the tree and measure how deep the bark is, down to the underlying wood. But sometimes, we need to take the bark off of the tree and bring it back to the laboratory to perform more experiments. Using chisels and hammers, we isolate a square patch of bark and gently pry the bark sample off of the tree. When we remove a piece of a tree to study it, we call this **destructive sampling** (Figure 2). Some of the experiments we might conduct on tree bark in the lab are listed in Table 1.

**DESTRUCTIVE SAMPLING**

Removal of sample from the object of interest.

## SOME PORES HOLD MORE WATER THAN OTHERS

Just like leaves, bark is very different depending on the tree species [3]. Some trees have thick, rough bark while others have thin, smooth bark (Figure 1A). Bark consists of two layers, the outer layer and the inner layer. The outer layer is composed of dead cells while the inner layer is living. Does bark with more pore space retain more water than bark with less pore space? Not exactly!

Loblolly pine has the most pore space but, despite this, it absorbs the lowest amount of water (Figure 1B). The pore space in post oak is very

**Table 1**

Experiments we conduct on tree bark to understand how water is stored.

| Experiment Name | What Is It? | How Do We Do It? |
|---|---|---|
| Bulk density | How much mass of solid bark is in a certain volume of bark. | Submerge bark quickly in water in a graduated cylinder, to see how much the volume increases. The increase in water volume is the volume of the bark. Then dry bark in the oven for several hours and weigh bark on a scale to get dry mass. Calculate bark density as the ratio of dry mass to bark volume. |
| Bark porosity | How much of the bark is open pore space. | To calculate bark porosity, the bulk density and specific density of bark are needed. Specific density describes how much mass of bark is in the volume of solid bark measured without the volume of pore space. |
| Bark saturation | How much water it takes to fill all the open pore space in bark. | Submerge bark in water for several days. Weigh bark every day until it stops gaining weight. The difference between initial and final weight is the weight of the water absorbed into the bark. |
| Hygroscopicity | How much water vapor can be absorbed into bark at 100% relative humidity of the air. | Place bark in a sealed chamber on a raised platform above some water. This water will make the relative humidity of the air inside the chamber equal 100%. Weigh bark every day until it stops gaining weight. The difference between initial and final weight is the weight of the water vapor absorbed into the bark. |

Table 1

similar to sweetgum and white oak, but post oak can absorb much more water than the other two species because these barks have pores of different sizes. And even though mockernut hickory bark has much less pore space than loblolly pine, mockernut hickory can absorb a lot more water. These differences tell us that water absorption into the bark is a complex process and depends on many factors. We are trying to identify these factors through our research.

Some species have larger pores and some have smaller pores, and pore size also influences how much moisture the bark can absorb directly from the atmosphere, even when it is not raining! This characteristic is call **hygroscopicity** (Figure 1B). When we account for hygroscopicity, the pore space that can absorb additional rainwater diminishes and the capacity of our "sponge" is smaller. Bark hygroscopicity may reach up to 60% of the total amount of water absorbed by bark.

**HYGROSCOPICITY**

The ability of a substance to absorb moisture from the environment.

## CONCLUSION

Now you know that bark is a reservoir for rainwater and that different tree species can have very different bark. Managing water resources is important because forests provide more than 75% of the world's water for drinking and growing food [4]. If we want to be good managers of water resources [5], then we need to know exactly how much rainwater will make it to the forest floor and how much might be caught by leaves and absorbed into bark. By studying these topics, hydrologists help to understand the important role that trees and forests play in the water cycle.

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## YOUNG REVIEWERS

**AVIV, AGE: 9**

A huge Harry Potter fan! I love reading books! I spend many hours reading on my Kindle, especially Harry Potter—I have read the entire series 20 times! I also love jamming on my electric piano, jump-roping and skipping when I am happy. I like eating salads and home cooked meals, but I also have a big sweet tooth—chocolate is yummy! As a vegetarian, I love nature - learning about it, protecting it, and enjoying it!

**EVAN, AGE: 8**

Evan has a passion for science from coding, to designing robots, to learning about planets and volcanoes, to understanding how viruses work (thanks to corona virus) and learning about different animals and their habitats. Evan is also a talented artist and loves to draw and design robots when he is not at school. His favorite activity is playing with his young brother and dad. He enjoys his mother's home baked cakes, and his favorite fruit is banana.

## AUTHORS

**COURTNEY M. SIEGERT**

Courtney Siegert is a forest hydrologist and biogeochemist. She studies diverse forest ecosystems across the southeastern United States and around the world to understand how disturbances like fire, insect outbreaks, and climate change influence the ways water and nutrients move through trees and soils. *courtney.siegert@msstate.edu

**ANNA ILEK**

Anna Ilek is a forest hydrologist interested in plant-water interactions. She studies how bark characteristics impact the movement of water down tree trunks and into soils.

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# THE FOREST GRAVEYARD: THE IMPORTANCE OF DEAD TREES, BARK, AND WATER

***Anna Klamerus-Iwan*** [1*], ***Ewa Błońska*** [2], ***Jarosław Lasota*** [2] ***and John T. Van Stan*** [3]

[1] *Department of Forest Utilization, Engineering and Forest Technology, Faculty of Forestry, University of Agriculture, Krakow, Poland*

[2] *Department of Ecology and Silviculture, Faculty of Forestry, University of Agriculture, Krakow, Poland*

[3] *Department of Biological, Geological, and Environmental Sciences, Cleveland State University, Cleveland, OH, United States*

YOUNG REVIEWER:

SILAS
AGE: 11

The forest floor is the forest's graveyard. There, broken branches and fallen trunks are laid to rest. However, this deadwood still has an important role to play. New deadwood is still covered in bark—a tissue that protects a living tree's insides from the outside world. The bark makes it difficult for water to enter the dead tree. It repels the rain and dew, as if the dead tree still needs this protection. Since deadwood cannot rebuild its bark, the bark slowly breaks down over time. As the bark decomposes, rain and dew are no longer repelled, and the deadwood begins to store more and more water. Recent findings show that, as its bark disappears, the amount of water that can be stored by deadwood changes significantly. This role of deadwood on the forest's water cycle has consequences for soils and the organisms living in deadwood.

## WELCOME TO THE FOREST'S GRAVEYARD

**DEADWOOD**

Wood lying on the forest floor, including dead roots and stumps ≥10 cm in diameter.

**DECOMPOSITION**

The process of "rotting," in which dead materials are broken down to become soils.

**WATER CYCLE**

The continuous movement of water on, above and below the surface of the Earth.

When you go hiking in the woods, you probably stick to the trail. After all, the trail is very well trimmed, there are few leaves or branches to walk through, and there are no fallen trunks to climb over (hopefully)! Let us walk off the trail for now, and wade through the fallen leaves, branches, and trunks. Here, we find ourselves in the forest's graveyard, where the branchy skeletons of dead trees poke their limbs through the decaying leaves. Forest scientists call these tree skeletons **deadwood**, and they have long been interested in understanding how deadwood decomposes. During **decomposition**, deadwood is eaten by microbes and insects and eventually becomes soil [1]. Before deadwood can become a true feast for the forest graveyard organisms, the bark that protected the trees during their lives must be broken down. This is no easy task for these wood-hungry critters, as bark can contain chemical compounds that protect living trees from some of the same organisms now trying to digest it [2]. These compounds can also make it hard for water to enter the deadwood—a beverage that wood-hungry critters crave as they eat. Recent research is looking into how deadwood affects the **water cycle**, and the consequences for forest soils.

## DEADWOOD IN THE FOREST'S GRAVEYARD

Deadwood is an important part of forests. It affects the cycling of nutrients, including the capture and long-term storage of carbon. Natural forests can have between 40 and 120 cubic meters of deadwood in a single hectare (10,000 square meters, or an area roughly the size of a rugby field). But forests managed by humans can have much less—as little as 5 cubic meters of deadwood in a hectare—because forest managers typically remove a lot of deadwood. For comparison, a single elephant's volume is about 5 cubic meters, making these deadwood volumes equal to approximately 1–24 elephants-worth in a single hectare of forest! Not all deadwood is the same. Different tree species tend to decompose differently, because their deadwood can have unique physical and chemical traits that affect its durability. So, deadwood can be as diverse as the living trees of the forest! The structure of deadwood also changes as bark and wood decompose, which can change the deadwood's water-absorbing properties (Figure 1).

The nature and timing of these decomposition changes appear to depend on the hardness of the wood. For example, fir and aspen are soft (and therefore easy to decompose), but harder woods (like hornbeam and oak) resist decomposition and are well-suited for building structures or outdoor furniture. Softer woods lose their bark relatively quickly, in approximately 10 years, while harder woods can keep their bark for up to 100 years. Rainwater must pass through the forest graveyard to recharge the soils and groundwater from

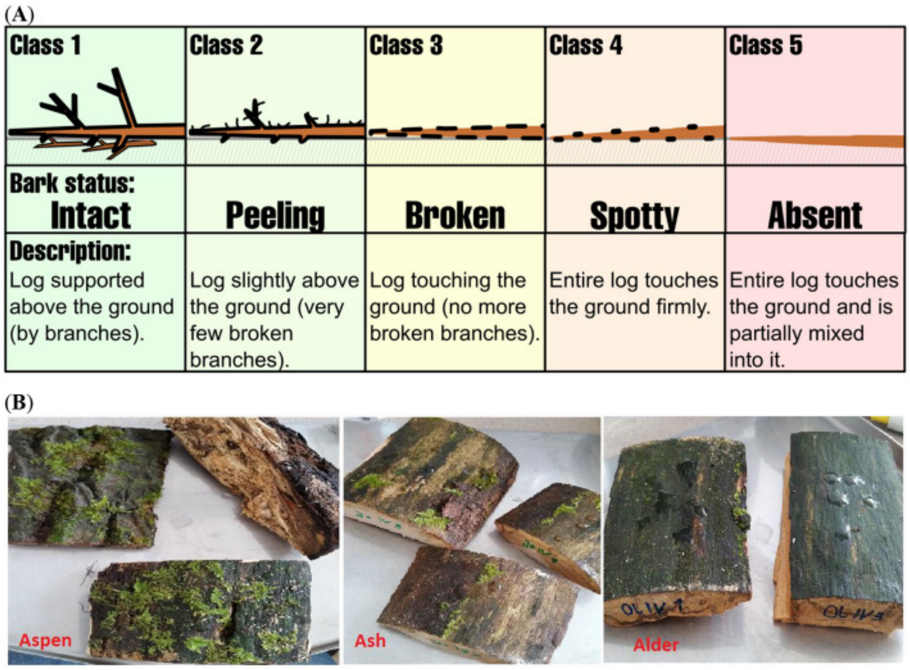


Figure 1

**Figure 1**

**(A)** The five classes of decomposition for deadwood. The status of the bark and of the wood is different for each class (Figure credit [3]). **(B)** Examples of wood of different hardness, all in the fourth stage of decomposition. Different types of wood differ significantly in porosity, which affects the amount of water they can hold.

which living plants drink. Given the amount, diversity, and types of deadwood, it is important for forest scientists to see if water-related properties (like the amount of water deadwood can absorb and store) change meaningfully for deadwood of different tree species as they decompose.

## WHAT HAVE WE DONE SO FAR?

So far, we have studied the water properties of deadwood from a forest in central Poland, the Czarna Rózga Forest Reserve, and we have examined diverse species including silver fir, European hornbeam, ash, alder, and aspen. The samples that were tested represent the final three decomposition classes shown in Figure 1A. Measuring the amount of water that a log in the woods can absorb from the rain would be very challenging! For example, if you wanted to weigh a long chunk of deadwood multiple times during a storm, how would you get a scale underneath? How would you power that scale in the woods, under the forest canopy where even solar panels have a tough time generating energy? Finally, how would you keep the deadwood intact, since most deadwood over class 3 can fall apart when lifted?

We tried to avoid these and other challenges by exposing samples of deadwood to simulated rainfall in a laboratory in Krakow, Poland (Figure 2). This way, the **water-storage capacity** of a small chunk of deadwood could be estimated as the difference between the amount of water used to simulate rainfall over the wood sample and the water that is recovered, meaning not absorbed by the deadwood. We also

**WATER-STORAGE CAPACITY**

The largest amount of water a surface or material can hold.


Figure 2

**Figure 2**

**(A)** A scale with a mesh platform is used to analyse the amount of water taken up by deadwood samples. **(B)** Water is sprinkled over the deadwood sample to simulate rainfall (Photo credit: Anna Klamerus-Iwan).

investigated how much water could soak into the wood, by soaking deadwood in water and measuring its weight change over 66 h, until the weight no longer increased. With these data, the **absorbability** was estimated as the difference in weight between a deadwood sample saturated with water and a dry sample.

**ABSORBABILITY**

The ability of a material to take up water.

## HOW DOES WATER STORAGE CHANGE AS THE BARK ON DEADWOOD DISAPPEARS?

Our research suggests that: (1) deadwood is an important, large, water-storage container in forests; and (2) the water-storage capacity and absorbability of deadwood depends both on the species and the degree of wood decomposition [3, 4]. For the forest we studied, a single cubic meter of deadwood could hold approximately 55 L of rainwater—that is about 240 juice boxes! Since natural forests can have 40–120 cubic meters of deadwood in a single hectare, that is 9,600–28,800 juice boxes of rainwater storage over an area the size of a rugby field! This means that the deadwood in the forest's graveyard can suck up more water in a single storm than your class typically drinks in a week. We found that different species' deadwood stores different amounts of water, showing that forest biodiversity has an impact on a forest's precipitation water storage and humidity, even after tree death! The low-density deadwood of fir trees was the thirstiest, while dense deadwood of the hardy hornbeam was the least thirsty.

As all deadwood decomposes, the number of holes throughout—called **porosity**—can increase as the graveyard residents find ways to enter and eat (Figure 1B). As porosity increases, there is more potential space into which water can penetrate, resulting in higher water-storage capacity and absorbability. Thus, most deadwood in the final class of decomposition, regardless of the tree species, has a great potential to store water. For deadwood with a bark "lid" still clinging on (class 3 deadwood), the bark surface reduced the water-storage capacity. For example, deadwood with just a partial bark lid, for any species studied, could store only three-fifths of what class 5 deadwood could store,

**POROSITY**

A measure of the "empty" spaces in a material.

**Figure 3**

Forests with different deadwood density (Photo credits: Ewa Błońska and Jarosław Lasota).

Figure 3

on average [5]. After a long, dry period, when the bark gets very dry, bark's effect on decreasing the water-storage capacity of deadwood becomes even greater. For all study species, the average water-storage capacity for deadwood with some very dry bark was only one-quarter of what deadwood could store without bark! So, the biodiversity of the forest's deadwood, its porosity, the presence of bark, and how dry this bark gets all contribute to the amount of rainwater the forest graveyard can store (Figure 3).

## WHY DOES THE WATER IN DEADWOOD MATTER?

Forest scientists are very interested in how deadwood and its bark interact with the water cycle. This is because the deadwood that rests within forest graveyards appears to be an important water-storage container. The presence of bark can act like a lid that covers these containers. With or without bark, a single deadwood log can store hundreds of liters of water each year.

**RUNOFF**

Rainwater that flows over the land as surface, rather than being absorbed into the ground or evaporating.

Deadwood water storage matters because it keeps a portion of rainfall from becoming **runoff**. Since stormwater runoff is good at picking up soil particles and carrying them away, the water storage in deadwood may also help prevent local soil erosion. Deadwood is as diverse as the living forest itself. Therefore, any new-fallen log or branch will bring its species' unique bark features to the forest floor with it—affecting how much water can be stored. This means that the biodiversity of a forest could affect the graveyard's water storage. As the diverse deadwood decomposes and the logs lose their lids, however, diversity ceases to matter as much in terms of water absorption and retention. These findings indicate that, by regulating the quantity and species composition of deadwood, we can actively influence the way stormwaters are stored and drained through forest ecosystems. Managing deadwood may also be useful to create local "micro" habitats where moisture can be maintained. Moist micro-habitats are particularly important in times when water becomes scarce. Overall, deadwood is an essential element of forest ecosystems that is a source of nutrients and serves a very important role in the maintenance of biodiversity. Deadwood are microhabitats which, thanks to the combination of shapes, wood species and degrees of decomposition, enable rain waters to persist and be available to multiple organisms even when it is not raining.

## ORIGINAL SOURCE ARTICLE

Klamerus-Iwan, A., Błońska, E., and Lasota, J. 2020. Interspecific variability of water storage capacity and absorbability of deadwood. *Forests*. 11:575. doi: 10.3390/f11050575

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## YOUNG REVIEWER

**SILAS, AGE: 11**

My name is Silas. I like to draw, build with LEGOs, and do stop-motion. I am reading Calvin and Hobbes. My favorite video game is Minecraft. My favorite art mediums are pencil and pastel. I have a brother and sister. My favorite Star Wars movie is The Empire Strikes Back. When I grow up, I want to be a filmmaker. My favorite song is Eleanor Rigby by The Beatles. I hope that we can end this pandemic so we can visit our friends and family.

## AUTHORS

**ANNA KLAMERUS-IWAN**

Anna Klamerus-Iwan works at the Faculty of Forestry at the University of Agriculture in Krakow, Poland. She is an ecohydrologist investigating how living and non-living factors affect water-storage capacity of tree crowns, bark, and topsoil. *annaklamerus.iwan@gmail.com

**EWA BŁOŃSKA**

Ewa Błońska works at the Faculty of Forestry at the University of Agriculture in Krakow, Poland. Ewa is a soil scientist investigating soil microbial activity and the deadwood-soil relationship.

**JAROSŁAW LASOTA**

Jarosław Lasota works at the Faculty of Forestry at the University of Agriculture in Krakow, Poland. He is a soil scientist investigating the soil-plant relationship and the effects of pollution on the soil.

**JOHN T. VAN STAN**
John Van Stan is an ecohydrologist interested in what happens when plants and water meet during storms—rain, snow, sleet, or otherwise. He enjoys researching the roles that wet plants play in our Earth's energy balance, nutrient cycles, and landscape ecology. He is currently an associate professor at Cleveland State University, where he leads the Wet Plant Lab.

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# FISHING FOR RIVER CRITTERS: THE IMPORTANCE OF WOOD AS BAIT

*Kelsey Wilbanks*[1], *Damon L. Mullis*[2] *and Checo Colón-Gaud*[3*]

[1] *Department of Entomology, University of Georgia, Athens, GA, United States*
[2] *Ogeechee Riverkeeper, Savannah, GA, United States*
[3] *Department of Biology, Georgia Southern University, Statesboro, GA, United States*

YOUNG REVIEWER:

MEHA
AGE: 15

A river's residents can tell us a lot about the health of their home. Groups of small insects and other river critters, called macroinvertebrates, can change if pollutants are affecting the river. We used snags in bags (basically pouches of wood and bark) as a new method for collecting critters in larger rivers in the southeast US. We compared the types and numbers of critters collected with snags to those collected with two other commonly used methods. We found snags to be a suitable method for collecting macroinvertebrates in large rivers, as these resemble an important habitat for river critters.

## WHY STUDY CRITTERS IN RIVERS?

As the world fills with more and more humans, it becomes important to understand the freshwater systems that humans live near (and live off of). We humans, for example, produce waste—from our industries, farms, lawns, and even our toilets—that eventually enters streams. Since this waste can be hard to see with the naked eye, scientists have found that they can (literally) look at the river's residents for clues! Studies of this kind are called **bioassessments**. Specifically, scientists like to look at the small critters called **macroinvertebrates**, for clues about the extent that human activities have affected rivers. Macroinvertebrates are animals that lack a backbone and you can see with your naked eye. The macroinvertebrate community can be very good at giving scientists clues [1]. After all, macroinvertebrates are diverse, they pretty much stay in one area, they live a long time in that area compared to other river critters, and they each have unique and specific survival needs.

**BIOASSESSMENT**

An evaluation of the conditions of a waterbody based on the types or number of organisms living within it.

**MACRO-INVERTEBRATE**

An animal that lacks a backbone and you can see without the aid of a microscope.

One big factor that determines which macroinvertebrates can live in which stream is the amount of oxygen dissolved in the water, which many macroinvertebrates need to breathe. Human pollution can decrease the amount of dissolved oxygen levels in water. Some macroinvertebrates have gills that take the dissolved oxygen directly from the water and, thus, are more sensitive to lower oxygen levels. Other macroinvertebrates can hold a bubble (called a plastron) of air close to their bodies, and still others have special cells (called hemoglobin cells) that help them survive on lower levels of dissolved oxygen—making them more tolerant to pollution. Of course, we cannot see how much oxygen is in the water with our eyes, but researchers have determined the oxygen needs of many common macroinvertebrates and they use this information as clues about the river's water quality. In bioassessments, the numbers of the different types of critters (**taxa**) found tell scientists the relative health of the river system in which they live.

**TAXA**

A group of organisms of any rank, such as species, family, or class.

## HOW DO SCIENTISTS CATCH RIVER CRITTERS?

Several methods have been developed for catching (also called sampling) macroinvertebrates from their river communities [2]. Methods include active and passive sampling. **Active sampling** typically means using something that a scientist moves around, like a net or a scraper, to collect wood, rocks, or leaves from the river. The wood, rocks, or leaves that are netted or scraped up are **habitats**, or neighborhoods, where certain macroinvertebrates prefer to live. The critters that get netted or scraped are then brought back to the lab and identified. **Passive sampling** involves leaving some sort of artificial habitat in the stream or river for a period of time, to allow macroinvertebrates to "move in" to the newest neighborhood created by that artificial habitat device (Figure 1). Once the macroinvertebrates have moved in, the entire neighborhood (by this we mean "device") is removed and taken back to the laboratory. Both passive and active types of sampling are good at capturing a community of macroinvertebrates, but passive sampling methods are easier to use in large rivers.

**ACTIVE SAMPLING**

A method for sampling macroinvertebrates in which scientists use nets to scrape or scoop a range of materials—containing various habitats—from the study location.

**HABITAT**

The place where an organism lives and grows.

**PASSIVE SAMPLING**

A method for sampling macroinvertebrates in which scientists deploy a device and allow organisms to colonize the device before it is retrieved after a set period of time.

Figure 1

**Figure 1**

Macroinvertebrate sampling devices for bioassessments include artificial habitats such as (from left to right) a wood bag, a leaf bag, and a Hester-Dendy sampler (photo credit: Checo Colón-Gaud).

**HESTER-DENDY**

A device made of stacked plates of artificial substrates that is commonly used to collect macroinvertebrates from rivers and lakes.

There are many different passive sampling devices that can be used to collect critter communities from rivers. One of these is called a **Hester-Dendy** sampler and it is made from square pieces of a hard board (called Masonite), spaced with plastic washers [3]. The Hester-Dendy sampler is easily made by scientists, which allows scientists anywhere to compare their results. Leaf litter is a habitat and a food source for macroinvertebrates, so researchers use mesh bags filled with leaves as a common passive sampling device. Wood is also an important habitat and food source for macroinvertebrates [4]! Because of this, there are probably a lot of macroinvertebrates who would like to move into a wood sampling device, but scientists do not often use these. Although we do not know exactly why wood samplers have not been used frequently by scientists, it is possible that the other types of sampling devices are more easily available, or maybe it is difficult for scientists to create wood sampling devices to resemble natural conditions.

After macroinvertebrates are captured, they are brought to the lab, identified, and counted (Figure 2). Researchers use many clues from the community of critters collected to estimate the health of the river, including which creatures are present, their known oxygen needs, and their known habitat preferences.

In our study, we compared three types of passive sampling devices: sacks filled with sticks (wood bag), sacks filled with leaves (leaf bag), and Hester-Dendy samplers. Because macroinvertebrates may have different habitat preferences and feeding strategies, we expected to see different taxa collected using each of the different sampler types.

Figure 2

**Figure 2**

Macroinvertebrate sample in the laboratory. Samples consist of a variety of insects from many different taxa (photo credit: Benjamin Hutton).

## WHAT WAS SEEN?

We found that different samplers collected certain taxa better than other samplers. The wood samplers (the ones rarely used in past research) actually captured the greatest number of organisms! We theorized that this happened because wood provides a complex habitat, with lots of nooks and crannies in which smaller insects can hide. Additionally, wood is a food resource for many river critters. Some macroinvertebrates, like snails and crustaceans, were found in larger proportions on the bags filled with leaves. This probably happened because these types of macroinvertebrates prefer to eat leaves. We also found higher numbers of the types of animals that burrow into wood in wood samplers and in Hester-Dendy samplers. All samplers collected similar types of critters, but in different proportions. This told us that using any of the three samplers would be suitable for collecting macroinvertebrates for bioassessment purposes, and all three would likely provide similar results.

## WHY DOES BIOASSESSMENT MATTER?

Since wood or snags are major habitats for macroinvertebrates in many rivers, our study provides a new sampling option that uses wood as a habitat for these critters to move into. Learning which types of critters are more likely to move into a specific habitat type can help scientists to understand bioassessment results. Bioassessments provide managers, policymakers, and scientists a tool to make informed decisions for our water resources that are based on visible clues. Bioassessments can be used in situations when chemical or physical tests would otherwise be needed to assess river health.

Bioassessment research can also help us understand what a healthy macroinvertebrate community looks like in the large rivers of the southeastern USA. If macroinvertebrates can no longer live in a freshwater system, this would eliminate the critical functions that these organisms perform. For example, macroinvertebrates can help with the process of decomposition, by turning larger particles into smaller pieces. They can also control the excess growth of algae, and they provide an important food source for larger consumers, like fish, amphibians, reptiles, and even birds!

Rivers provide humans with drinking water, recreation, agriculture, industries, and many other benefits! Increased amounts of pollution in rivers and other bodies of freshwater could compromise the resources and services that humans obtain from these ecosystems. Clearly, the continued use of these water resources is important to us. Higher levels of pollution in aquatic ecosystems will not only impact their ability to function but will also impact our own quality of life. Thus, it is important to monitor rivers using bioassessment and other methods, so that we can keep our waterbodies, the organisms that live there, and ourselves, healthy.

## ORIGINAL SOURCE ARTICLE

Wilbanks, K.A., Mullis, D. L., and Colón-Gaud, J.C. 2020. Comparison of a wood sampler for macroinvertebrate bioassessment of non-wadeable streams in the southeastern coastal plain. *J. Freshw. Ecol.* 35:429–48. doi: 10.1080/02705060.2020.1852122

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## YOUNG REVIEWER

**MEHA, AGE: 15**

Hey, I am a sophomore in high school, and looking forward to a career in medicine. My hobbies include drawing, tennis, and just hanging out with friends! I also love to volunteer and give back to my community. I am excited to be a part of Frontiers for Young Minds, as I want my peers and other students to be able to access these great scientific accomplishments made every day.

## AUTHORS

**KELSEY WILBANKS**

Kelsey Wilbanks is an ecologist interested in aquatic insects living in large rivers and floodplains. She is a student at the University of Georgia where she studies insects in major rivers of Georgia.

**DAMON L. MULLIS**

Damon Mullis is an ecologist and environmental advocate interested in protecting water resources. He is the executive director of the Ogeechee Riverkeeper, a not-for-profit organization committed to protecting, preserving, and restoring water quality in the Ogeechee River Basin.

**CHECO COLÓN-GAUD**

Checo Colón-Gaud is an ecologist and biology professor in Statesboro, Georgia. Checo is interested in learning how changes in climate affect aquatic insects and other invertebrates in coastal Georgia rivers and wetlands.
*jccolongaud@georgiasouthern.edu

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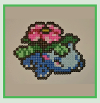
# PLANT LITTER CAN BE IMPORTANT FOOD FOR STREAM BUGS

*Checo Colón-Gaud[1*], Keysa G. Rosas[1], José Sánchez-Ruiz[2], Pablo E. Gutiérrez-Fonseca[3] and Alonso Ramírez[4]*

[1] Department of Biology, Georgia Southern University, Statesboro, GA, United States
[2] Department of Ecology, Montana State University, Bozeman, MT, United States
[3] Department of Biology and Center for Research in Marine Science and Limnology, University of Costa Rica, San Jose, Costa Rica
[4] Department of Applied Ecology, North Carolina State University, Raleigh, NC, United States

YOUNG REVIEWERS:

VIKTOR
AGE: 15



VINCENT
AGE: 9

Plant parts from the land can be important energy sources and habitats for small plant-eating animals that live in water. Animals in forested streams depend on energy from plant parts because the shade limits the amount of light needed for photosynthesis. One group of animals that benefits from these resources are water critters called macroinvertebrates. Macroinvertebrates are small, but most of them are visible to the naked eye. Examples include insects and worms. Macroinvertebrates can influence the amounts of materials floating in streams by helping to break down plant litter that falls into the water. These tiny water critters play an important role in making energy available to stream animals like fish and shrimp.

## ONE COMMUNITY'S LITTER IS ANOTHER'S DINNER

Many rivers and streams depend on nearby forests for energy [1]. For example, a small stream surrounded by forest may receive enough shade to block sunlight from reaching the stream bottom (Figure 1). This reduced sunlight limits the process of **photosynthesis**, which some stream plants and algae use to obtain energy and building blocks from sunlight. Forests can provide streams with lots of outside-the-stream, or "external" energy when they shed their dead leaves, branches, and other plant parts [2]. As these dead plant parts, called plant litter, fall to the stream bottom, they become **detritus**. Detritus in streams provides shelter for many small aquatic organisms. For example, insects hide in detritus to escape from predators like fish or shrimp, but these insects can also use detritus as food.

**PHOTOSYNTHESIS**

The process by which green plants and other organisms use sunlight to create food from carbon dioxide and water.

**DETRITUS**

Dead and decaying plant materials (plant litter), such as leaves, bark, needles, and twigs that have fallen to the ground or into the water.

Figure 1

**Figure 1**

A forested stream on the island of Puerto Rico (photo credit: Pablo E. Gutiérrez-Fonseca).

Detritus in a stream quickly becomes covered by **microorganisms**. Microorganisms, like bacteria and fungi, help break down detritus through the process of decomposition [3]. Bacteria and fungi remove nutrients from the detritus and, by hanging out on the plant materials, they make the detritus tastier to other organisms, like bugs. Scientists compare this to spreading peanut butter on a cracker. In other words, the microbes act like the peanut butter, or the tasty stuff, and the detritus acts like the cracker that simply holds the tasty stuff. Aquatic insects help break down detritus by eating it. However, because they are messy eaters, aquatic insects can break up larger pieces of detritus, turning them into smaller pieces that can be eaten by even smaller organisms, as these pieces sink to the bottom or float downstream.

**MICROORGANISMS**

Organisms that are of microscopic size or too small to see without using a microscope. Examples of microorganisms include bacteria and fungi.

## HOW DO SCIENTISTS STUDY AQUATIC INSECTS AND THEIR DIETS?

Insects are the most diverse group of organisms on the planet. There are close to one million species of insects, which represents about 80% of all the species in the world. Many of these insects live in

**NYMPHS**

The immature forms of some invertebrates, particularly insects, which undergo gradual transformation before reaching its adult stage.

**LARVAE**

The juvenile form of many insects before undergoing the process of transformation into adults.

rivers or streams when they are young. These immature forms are called **nymphs** or **larvae**. As aquatic insects mature and transform into adults, many transition to living on the nearby land. You have probably seen some of these insects—large swarms of mayflies coming out of streams, dragonflies and damselflies flying close to your home, or stoneflies and dobsonflies when you go fishing. In streams, you can find young aquatic insects living under rocks, amongst roots and leaves, or buried in the sand and mud.

Stream ecologists (scientists who study stream life) are often interested in discovering which species—and how many of them—live in streams or rivers. To collect aquatic insects, ecologists use nets or cores, depending on the type of stream (Figure 2). The insects collected in streams are then taken to the laboratory, where they are identified, counted, and measured with a microscope, a magnifying lens, or other tools.


Figure 2

**Figure 2**

Two types of devices used for sampling **macroinvertebrates** in streams. A Surber sampler **(A)** uses a net fastened around a square frame which permits the user to isolate a known area of stream bed for sampling. A core sampler **(B)** is a cylindrical device used in shallow waters to collect sediments containing organisms (photo credits: Pablo E. Gutiérrez-Fonseca and Sean Kelly).

**MACRO-INVERTEBRATES**

Small animals without backbones that are large enough to be seen with the naked eye or without a microscope (like insects and worms).

**FOOD WEB**

A series of links describing "who eats whom" in an ecosystem.

Researchers may also be interested in studying what the insects eat. This allows them to collect details on "who eats whom" in the stream, and tells them where the insects are getting the energy to grow. This information is used to build **food webs**, which help ecologists understand the feeding relationships of stream animals. To examine what insects are eating, researchers make small cuts to remove their stomachs. Then, the stomach contents are examined with a microscope to identify and count the various food particles found. This entire process is repeated until many organisms are obtained from each stream.

In our study, we examined the stomach contents of aquatic insects from two streams on the island of Puerto Rico. We classified the food particles found in their stomachs as fungi, detritus, animals, or algae. We also measured the growth of insects over an entire year. We then used this information to identify the major food sources that aquatic insects use in these tropical island streams.

## WHAT WAS SEEN?

Similar to what happens to us when we are young and are growing really quickly, we found that small insects grow much faster than large ones of the same kind. While small insects use their energy to grow, larger insects use their energy to emerge from the streams as adults, to produce eggs, and to develop strategies that help them cope with life on land. Of all the insects we studied, we found that a group called the non-biting midges, which are flies commonly found in slow-moving waters, grew the fastest. Growing very quickly allows midges to have many offspring in a shorter time, which helps the survival of the species.

Although the diets of aquatic insects can be variable and are usually based on the availability of food in the stream, we found that most insects eat detritus in these forested island streams. In fact, dead plant materials accounted for about one-third of the insects' diets. Other food types such as algae, fungi, and animals were less common in the insect stomachs that we studied. Insect growth is the result of turning food items into body tissues or mass. We found that detritus contributed the most to the formation of insect mass in these streams (Figure 3).

## WHY DOES IT MATTER?

Streams and the nearby land are closely connected by the exchange of materials and by the movement of insects. Forested streams have limited growth of algae, due to being shaded by surrounding trees, and most rely on outside sources of energy from the land. Therefore, learning more about what various types of aquatic animals eat (bark, leaves, wood, and algae) and why they eat it helps stream ecologists to understand the foundations of the food webs that keep streams (and their fish, birds, and other animals) healthy.

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**Figure 3**

A simplified food web of a forested stream on a tropical island. Aquatic insects include mayflies, midges, and caddisflies. Food items include terrestrial plant parts (e.g., leaves, stems) and animals (e.g., spiders and terrestrial insects) from the nearby land that fall in the stream, and fungi and algae from within the stream. The arrows indicate what is eaten by whom (image credit: José Sánchez-Ruiz).

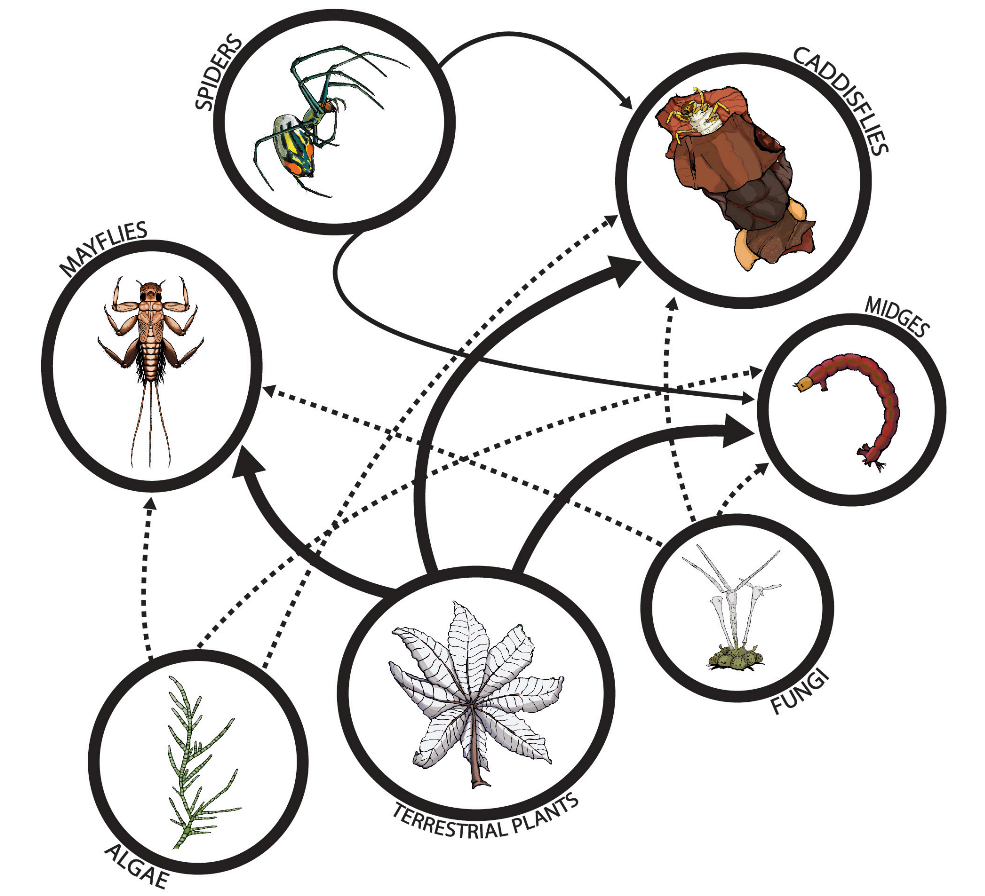


Figure 3

## ORIGINAL SOURCE ARTICLE

Rosas, K. G., Colón-Gaud, C., and Ramirez, A. 2020. Trophic basis of production in tropical headwater streams, Puerto Rico: an assessment of the importance of allochthonous resources in fueling food webs. *Hydrobiologia* 847:1961–75. doi: 10.1007/s10750-020-04224-y

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## YOUNG REVIEWERS

**VIKTOR, AGE: 15**

I am 15 years old and love natural sciences, with a specific interest in ornithology. I am an avid birdwatcher, and in my spare time I like to look for new birds. I like traveling, and my interest has taken me all around the globe. I have seen all the continents except Antarctica, which I hope to visit soon.

**VINCENT, AGE: 9**

I am 9 years old and my favorite pokemon is Lucario. I love playing piano and my favorite piece is "Jingle Bells." I love playing football. I have traveled widely and my best memory is of Queensland, Australia. We were staying as a homestay guest and had set out in the night to see some flying squirrels. It was pitch dark and we saw a huge carpet python lying across the tarmac road. It was thrilling and scary at the same time.

## AUTHORS

**CHECO COLÓN-GAUD**

Checo Colón-Gaud is an ecologist interested in the role of animals living in streams, rivers, and wetlands. He is a biology professor in Statesboro, Georgia and studies how changes in climate affect aquatic insects. *jccolongaud@georgiasouthern.edu

**KEYSA G. ROSAS**

Keysa G. Rosas is an ecologist studying how human activities affect ecosystem services. She is a biology lecturer in Athens, Georgia and is mainly interested in tropical streams and the cute bugs that live in them.

**JOSÉ SÁNCHEZ-RUIZ**

José Sánchez-Ruiz is an ecologist with experience working in streams, rivers, and wetlands. He is a graduate student in Bozeman, Montana and is studying how natural and human-caused disturbances influence food webs and ecosystem services.

**PABLO E. GUTIÉRREZ-FONSECA**

Pablo E. Gutiérrez-Fonseca is an ecologist studying tropical stream ecosystems. He is a professor and researcher in Costa Rica, and he greatly enjoys sitting by the riverside and wondering about the creatures that live there.

**ALONSO RAMÍREZ**

Alonso Ramírez is an ecologist studying stream ecosystems in tropical and urban environments. He is a professor in Raleigh, North Carolina, where he studies the effects of climate change on stream ecosystems, with a focus on macroinvertebrates.

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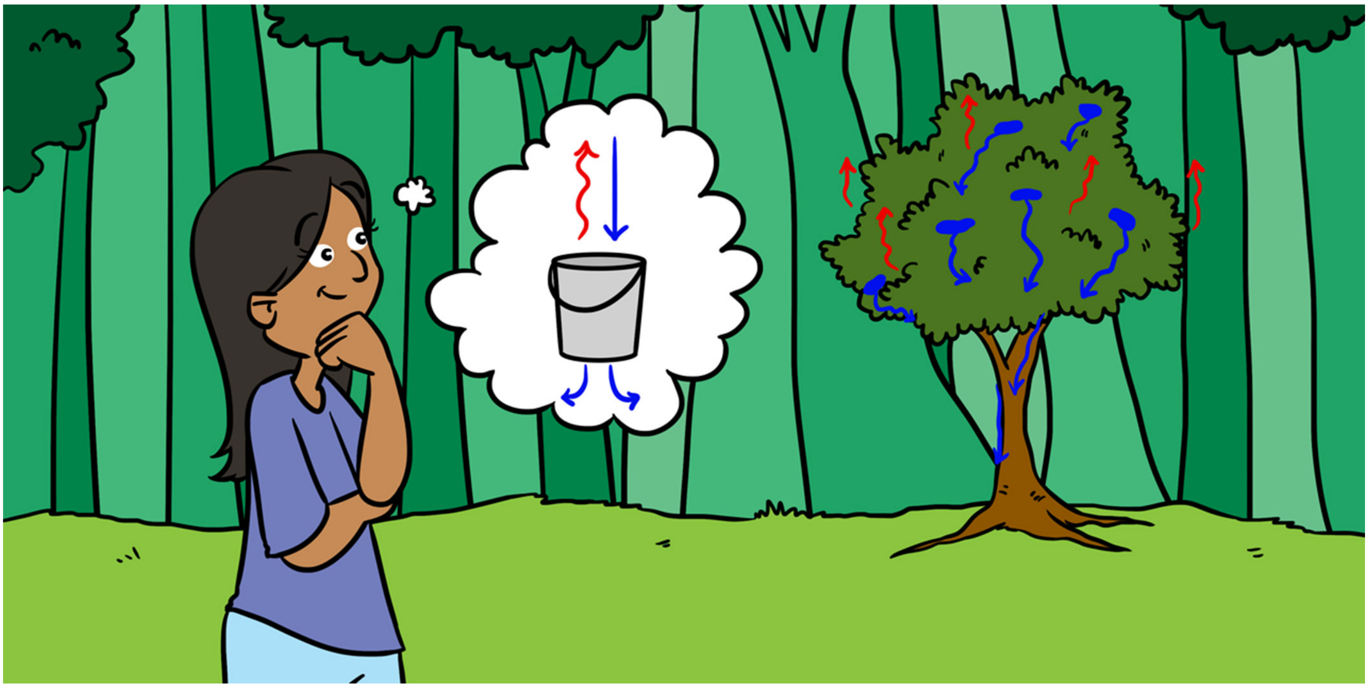

# HOW MATH HELPS US PREDICT WATER FLOWS IN FORESTS

***Katarina Zabret*** [1,2*]***, Mojca Šraj*** [1] ***and John T. Van Stan II*** [3]

[1] *Faculty of Civil and Geodetic Engineering, University of Ljubljana, Ljubljana, Slovenia*

[2] *Institute for Water of the Republic of Slovenia, Ljubljana, Slovenia*

[3] *Department of Biological, Geological, and Environmental Science, Cleveland State University, Cleveland, OH, United States*

YOUNG REVIEWERS:


ELI, ELLA, JACK
AGE: 13


ELLE
AGE: 12


JOSI
AGE: 9


MANVI
AGE: 13


SAHANA
AGE: 13

Water flows through forests in many ways, so it is difficult to understand and predict where and when it will flow. Understanding how water flows through forests is important, as it affects many of the services that forests offer to people, like lumber for houses and cleaner air. Water scientists (called hydrologists) have a way to reduce the complex water flow of a forest into something we can explain with simple math: they turn forests into buckets! In this article, we describe a forest "water park," where leafy and bark buckets fill and empty into each other or onto the forest floor. These buckets help us describe and predict water flows in forests using simple arithmetic and statistics. We focus on the flow of rainwater as it drains through the canopy to the ground, contributing water needed for tree growth and filling the groundwater that we drink.

## WATER SCIENTISTS AND THEIR LOVE OF BUCKETS

**HYDROLOGIST**

Scientist, who studies water and its movement around the planet.

**EVAPORATION**

A major process in the water cycle that happens when liquid water turns into a gas.

Water is an important part of nature, our societies, and our individual lives. It is cycling all the time—from land to the clouds; returning as precipitation; filling rivers, lakes, and seas; recharging groundwater aquifers; forming surface runoff; wetting fields and forests; and watering plants and trees. This movement of water is called the water cycle and it is studied by scientists called **hydrologists**. Hydrologists observe the various water processes in nature, trying to understand and predict them. Some water flows are hard to follow—for example, it is hard to watch liquid water become an invisible gas through **evaporation**. This makes the water cycle difficult to understand and even more difficult to explain or predict. To think about these complex processes, hydrologists imagine that all these processes act as one big water park full of interconnected buckets. Some buckets are being filled with rainfall, others with snow, and some are already full of water, which starts to overflow.

**REDUCTIONISM**

Analyzing and describing a complex process in a simple way, so that humans can better understand a process and make predictions.

**RAINFALL INTERCEPTION**

The part of rain (or snow) that does not make it to the ground beneath plants, because some of it evaporates while passing through plants' leaves and branches.

This mental "model" of nature may sound crazy, but it is actually quite useful in helping us understand and manage water. How? Well, let us begin by admitting something obvious: nature is very complex, so it can be hard to understand and predict. Even when we focus on one important piece of the water cycle—like, "how does rain recharge the soil in a forest?"—a lot of complexity remains [1]. For example, to reach the soil, rainwater must pass through the forest's canopy, which has leaves and branches that stick out in all directions and angles (Figure 1A). At any point during a storm, rainwater could be stuck or moving or splashing anywhere throughout that forest canopy! How can we keep track of all the water—at all times during the storm and at all places in the canopy—to understand how much rain reaches the soil (Figure 1B)? We *cannot*, at least not without enormous expense and difficulty. But hydrologists using the "water park" approach investigate this complex process using a scientific technique called **reductionism**, which is a way to describe something complex in a simple way. All those branches and leaves can be thought of as buckets (Figure 1C)! No matter where the rainwater is sitting in the forest's canopy, it is now simply sitting in a bucket. When a canopy bucket fills up, the extra rainwater empties out onto the soil below. Another benefit of this reduction (turning a canopy into a bucket) is that we can now use math to describe the evaporation (E) process, called **rainfall interception**, with some simple arithmetic:

$$E = R - R_T - R_S$$

**THROUGHFALL**

Rainwater that falls through gaps in the forest and that drips from leaves and branches to the ground.

In this equation, evaporation from rainfall interception (E) is really hard to measure (in fact, hydrologists still have not figured out how to measure this consistently [2]), but each of the letters on the right side of the equation represent something we *can* measure directly. If we measure the rain (R) falling in an open area next to trees, the rain that drips to the ground beneath the trees as **throughfall** ($R_T$), and the

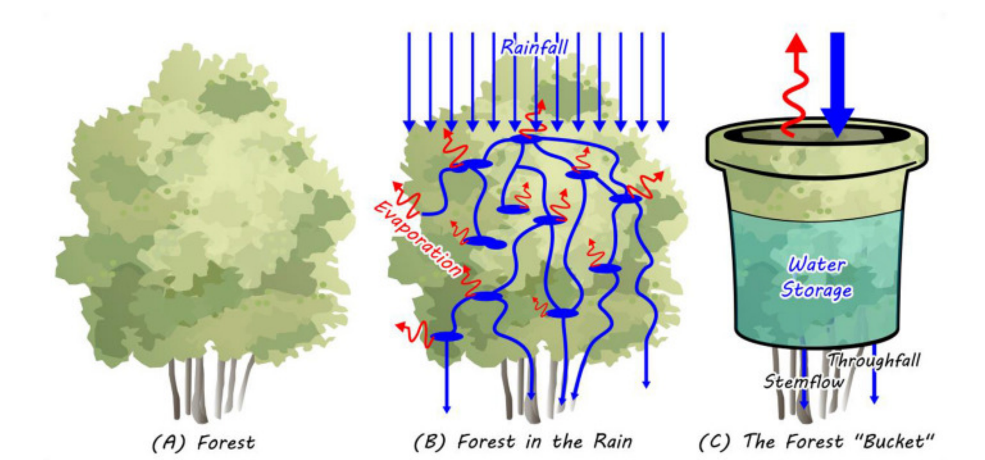


Figure 1

**Figure 1**

**(A)** A complex forest canopy. **(B)** In real life, the flow of rainwater through the canopy to the ground is a messy process. Blue arrows show rainfall and red arrows are evaporation. **(C)** Using reductionism, hydrologists can create a simple bucket model to make water flow in the forest easier to understand. This allows us to use simple math to describe the process of rainfall interception as the filling and emptying of the bucket.

rain that drains down the tree trunks as **stemflow** ($R_S$), then we can estimate E.

**STEMFLOW**

Rainwater that drains down the tree trunk to the forest floor.

## POKING HOLES IN HYDROLOGISTS' BUCKETS

Most of a hydrologists' buckets have a big hole at the top, so that storms can fill the buckets and evaporation can empty them. This is the case for a canopy bucket—the rain fills it up, while some water is constantly evaporating back into the atmosphere. But, to make the canopy bucket reduction more useful, we must poke two holes in it: one for throughfall and another for stemflow. These holes need to change based on how much water enters the canopy bucket over time. And all canopy buckets are not the same because there are many different kinds of trees.

Let us say that the bucket model is being used by hydrologists to understand and predict stemflow. The amount and timing of stemflow mostly depend on how much water the tree bucket can hold, how well the tree can drain rainwater to the trunk, and how the storm delivers the rainfall. All three of these categories are described by what are called **variables**, describing characteristics or values that can be measured or counted. For example, some trees have flat leaves, others have needles, and the leaves of some trees fall off during the winter. Trees can have a lot of trunks and branches or only one main trunk, and some trees have smooth bark while the others have thick, rough bark. All of these are different variables/tree properties that determine the size of the bucket and how well the canopy will drain rainwater to that bucket (Figure 2). That is a lot of properties, so let us reduce them all to a single number that will adjust the rainfall amount by the portion of rainfall that is captured by the canopy and drained to the trunk. Hydrologists call this the **trunk drainage coefficient** ($p_t$), and it can range from 0 to 100%! Thus, the bucket that overflows to make stemflow only receives the rainfall (R) times this coefficient,

**VARIABLES**

Characteristics, number, or quantity that can be measured or counted.

**TRUNK DRAINAGE COEFFICIENT**

The portion of rainfall that is captured by the canopy and drained to the trunk.

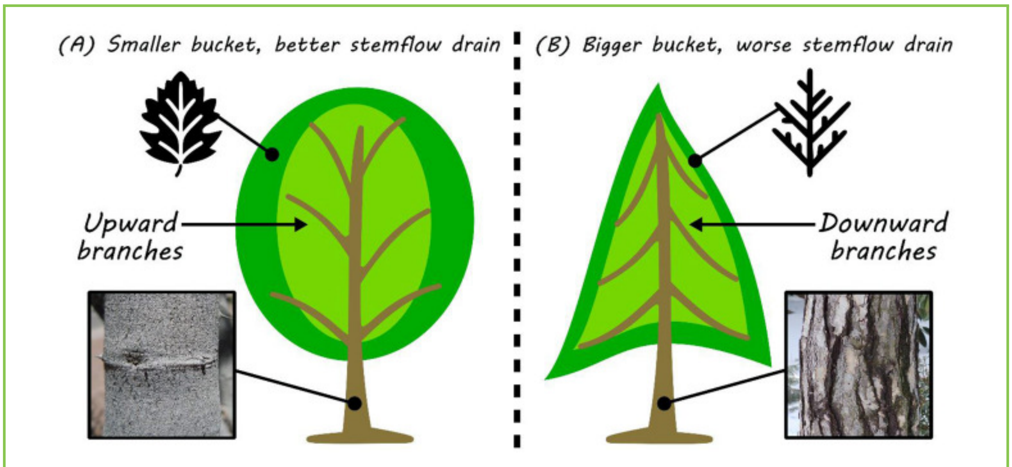


**Figure 2**

Different types of trees have different canopy properties that affect the flow of rainwater to the ground. **(A)** This tree has a smaller water storage bucket that drains greater amounts of rainwater to the trunk, compared to the tree in **(B)**, which has a larger water storage bucket that poorly drains rainwater to the trunk.

and minus the evaporation. Since the amount of water in the bucket (C) can sometimes be less than the total capacity of the bucket (S), we can adjust the evaporation rate [3]. Using math, we can write it like this:

$$R_S = (R \times p_t) - (E \times C/S)$$

To estimate the evaporation rate, we need also information about the weather. Water will run down the trunk differently during a short, intense summer rainstorm, a long winter rainstorm, or a gentle spring drizzle. It is as if different holes are poked in the bucket depending on how much rain falls during the storm, how long it falls for, how much wind is blowing, whether it is warm or cold, and whether raindrops are large, small, numerous, or scattered. So, what is a useful way to deal with all these interacting conditions?

## STATISTICS: CRAFTING BUCKETS FOR ALL WEATHER AND TREES

If we are not careful, all of these interacting forest and weather variables can turn our simple bucket water park back into a complex mess. Then, the equations we described above will seem too simple to be useful. But this does not happen because hydrologists pair these reductions with other mathematical methods, called statistics. This field of math helps us to make sense of large amounts of data, including its collection, organization, and analysis.

For example, hydrologists will often look to see if stemflow from a certain tree has a relationship with one weather variable, like the amount of rainfall. This relationship, called a correlation, can help us calculate the size of the bucket, how well the canopy drains rainwater to the trunk, and even how much evaporation occurs on the bark! Figure 3A shows an example tree that required 10 mm of rainfall to fill the canopy bucket and to get the bark wet enough to start stemflow

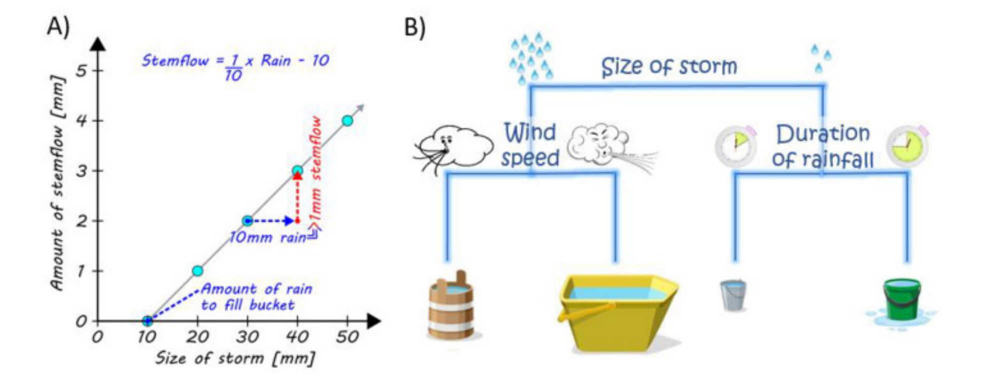


Figure 3

**Figure 3**

Statistical analysis of stemflow data for an example tree. **(A)** A simple correlation plot between rainfall and stemflow that shows how a bucket can be sized (the lowest point on the horizontal axis) and the drainage coefficient estimated (blue and red arrows). **(B)** A simplification of a more complex statistical method, showing consideration of more variables in determining the most appropriate type of bucket [4]. Using more observations of stemflow across more types of storms, we can discover what types of buckets would be better for windy or calm conditions or for storms of different durations (longer or shorter).

flowing. Once stemflow began, the tree canopy could drain 1 mm of every additional 10 mm of rain to the trunk as stemflow. So, we now have the bucket size (10 mm) and the stem drainage coefficient (1/10 = 10%) for this tree!

This example uses only two variables, but we can look for correlations between stemflow and all the tree and weather variables at the same time, using more complex statistical methods. For example, hydrologists can use statistics to represent a tree canopy as different types of buckets according to different weather conditions (Figure 3B). In this way, hydrologists can still use the bucket concept even if the tree canopy responds differently in big windy storms compared to small windless storms. Using these methods, hydrologists can not only poke the right kinds of holes in the bucket, but they can also understand why some holes should be larger or why they should be positioned differently. These methods transform the messy reality of nature into the neat and orderly bucket water park.

## THE IMPORTANCE OF HYDROLOGISTS' BUCKETS

Water is needed for all life on Earth, so it is no wonder that there is water all over our planet—including inside the Earth and inside us! It is therefore difficult to know where water is, how it moves around, and when it is where. Still, it is important to follow, understand, and predict the water cycle and how human actions will influence it. To reduce this complex water cycle into something we humans can follow, understand, and predict, the reductionist bucket approach is very useful. In this article, we focused on one type of bucket (the forest canopy) and one type of water flow that occurs during storms in the forest (stemflow). The forest bucket and its water flows are extremely important to understand because forests provide many services to humanity—from producing lumber used to build houses to cooling the air. Many of these services depend on the way water flows through the forest "water park." By reducing the complexity of the forest water cycle, hydrologists can describe those complex processes using math, which you now know is simple enough to be learned by kids all over the world!


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## YOUNG REVIEWERS

**ELI, ELLA, JACK, AGE: 13**

The article was easy to read and enjoyable. We were wondering why they used buckets and not jars or other containers, and the authors answered our question during the review.

**ELLE, AGE: 12**

My name is Elle, and I just turned 12 years old. I love cats, and wish I had one of my own. I love to dance, write, sing, read, and draw. I would like to become a lawyer when I am older. My favorite subjects in school have always been ELA and history. I have participated in the science fair all of my life, and I enjoy watching videos and reading articles to better understand the world around me. Fashion is a passion of mine too.

**JOSI, AGE: 9**

My name is Josi. I love to read and write stories. My favorite animals are pigs because they are really cute. Pink is my favortite color. Science is one of my favorite subjects along with math. For my science project this year, I explored the physics of a scooter because riding my scooter is a favorite activity of mine.

**MANVI, AGE: 13**

My name is Manvi Sharma and I live in Fort Worth, Tx. I like to read, play tennis, draw, and listen to music.

**SAHANA, AGE: 13**

Sahana was born in Canada and moved to the US when she was 4. She has a wide variety of interests and hobbies, but really loves math and science, spending extra time studying over the pandemic so that she could complete accelerated math courses. She is also active in student government, writes for the school newspaper and is helping put together the yearbook. In her spare time, she plays piano, ice skates and acts in her school theater productions.

## AUTHORS

**KATARINA ZABRET**

Katarina Zabret is a researcher involved in studies on water in our everyday life and on water—plants interaction. As a Ph.D. student she worked in an urban park, maintaining the measuring equipment and collecting data on rainfall, throughfall, and stemflow. By analyzing the data, she began to really appreciate how challenging field work could be during extreme weather conditions or due to interactions with animals. She also loves to use advanced statistical methods to get new insights into the collected data. *katarina.zabret@izvrs.si

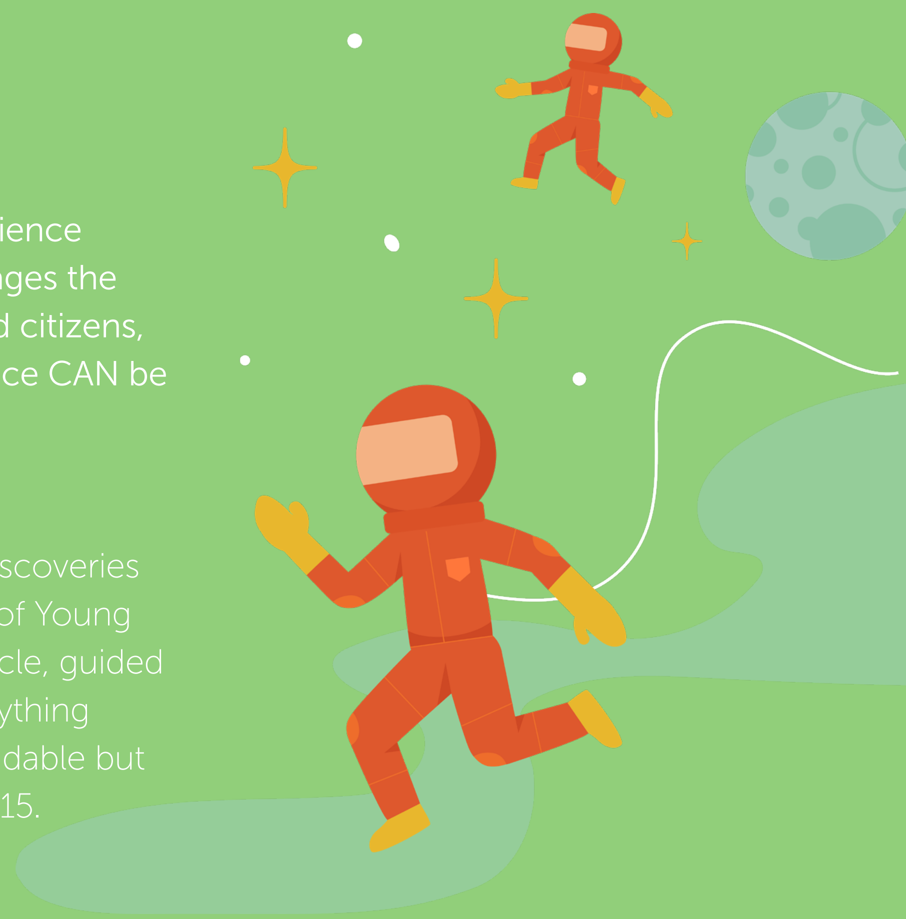
**MOJCA ŠRAJ**

Mojca Šraj is an associate professor at the Faculty of Civil and Geodetic Engineering at the University of Ljubljana. She studied civil engineering at the same university and is now working as a hydrologist, which means her research is related to water. Her main areas of interest are floods, droughts, hydrological data analysis, water balance analysis, and hydrological modeling. She is particularly interested in rainfall interception by trees, which was also the topic of her Ph.D. thesis.

**JOHN T. VAN STAN**

John Van Stan is an ecohydrologist interested in what happens when plants and water meet during storms—rain, snow, sleet, or otherwise. He enjoys researching the roles that wet plants play in our Earth's energy balance, nutrient cycles, and landscape ecology. He is currently an associate professor at Cleveland State University, where he leads the Wet Plant Lab.

# Frontiers for Young Minds



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