frontiers FOR YOUNG MINDS

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THE WORLD'S TALLEST TREES CAN "DRINK" FOG!

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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

(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].

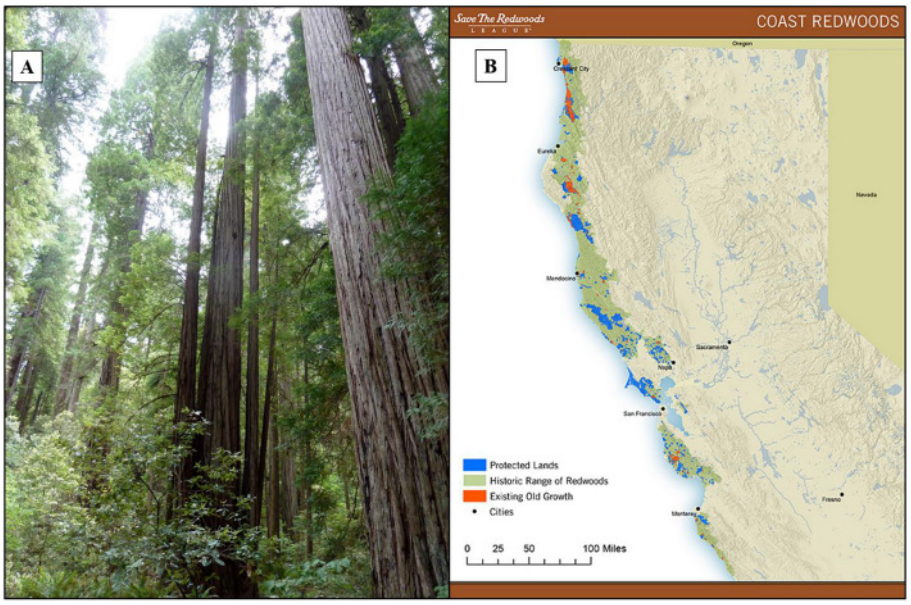

Figure 1

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).

CONIFER

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

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.

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.

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.

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.

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

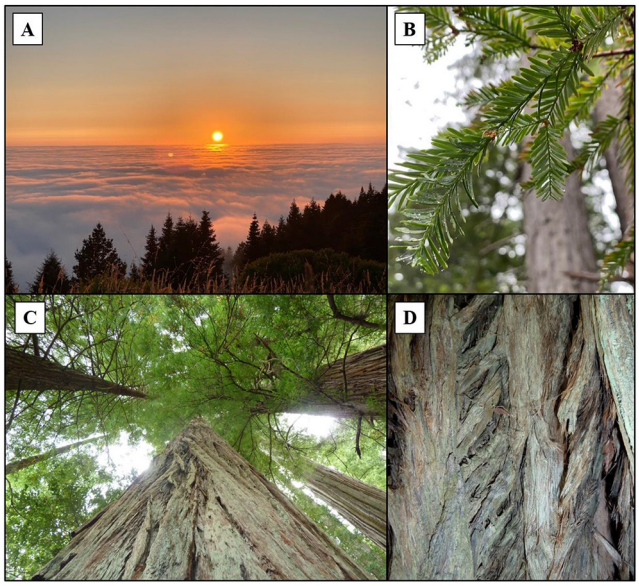

Figure 2

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].

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.

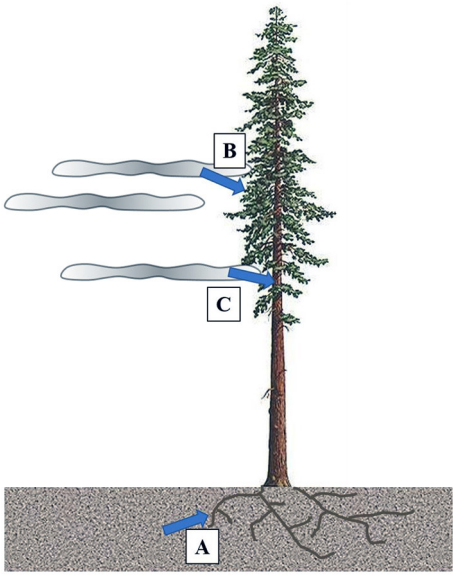

Figure 3

(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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CONFLICT OF INTEREST: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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

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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