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Water in their veins

How trees survive drought

The State of Canada's Forests
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Canada

Global climate change is marked by rising temperatures and shifiting precipitation patterns, resulting in an increase in the frequency and intensity of drought episodes.[1] Globally, droughts have a significant impact on forest ecosystems, reducing tree growth and increasing tree mortality.[2,3] For example, in Canada's boreal forest, the severe drought of 2001–2002[4] caused large-scale dieback of trembling aspen (*Populus tremuloides* Michx.) in western Canada.

The resistance of trees to drought is closely linked to the maintenance of sap circulation (water plus soil nutrients) throughout the plant.[5,6] However, the strategies for achieving this vary among species. It is therefore essential to understand the factors that influence sap flow and drought resistance in different tree species. Such knowledge will help professionals and involved parties in the forest sector better respond to the challenges of climate change.

How does a tree transport water?

Water is the key element in a plant's life because it:

1. transports soil nutrients from roots to other organs (stems, leaves, fruit);
2. regulates leaf temperature through transpiration;
3. is involved in photosynthesis, which produces the sugars needed to meet energy requirements (e.g., for growth, reproduction, resistance to pathogens).

Water from the soil is absorbed by the roots and transported to the leaves through the xylem, a plant tissue consisting of a series of sap-conducting elements called "vessels." In the leaves, water is released into the atomosphere through tiny pores called "stomata". This water loss occurs because the water vapour content of the air is lower than that inside the leaves. Approximately 95% of the water absorbed from the soil is lost through transpiration.[7]

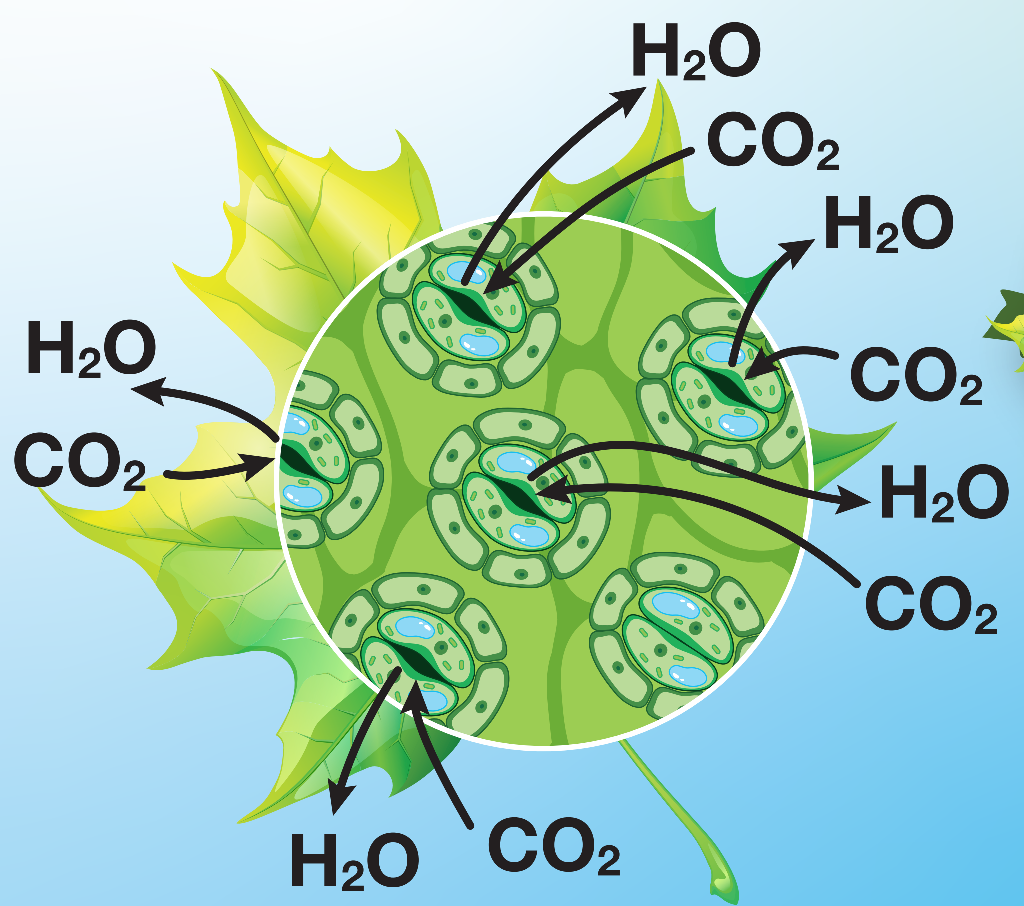
The movement and circulation of raw sap in a tree is considered a "passive" phenomenon because it does not require energy. Transpiration from the leaves drives this process. The loss of water from the leaves creates a suction effect that pulls the water from the vessels (tension-cohesion principle),[8] thereby absorbing water from the soil. The exchange of water between leaves and the atmosphere through the stomata occurs simultaneously with the absorption of carbon dioxide (CO_2), a key component of photosynthesis. In other words, trees lose water at the same time as they absorb CO_2. A balance must be achieved, plants need to absorb enough CO_2 for sugar production and tissue growth, while miniminzing excessive water loss. This balance is achieved by regulating stomatal openings.

What happens during a drought?

Under normal conditions when soil water availability is not limited, trees keep their stomata open: they transpire large amounts of water, but also absorb signifcant amounts of CO_2.

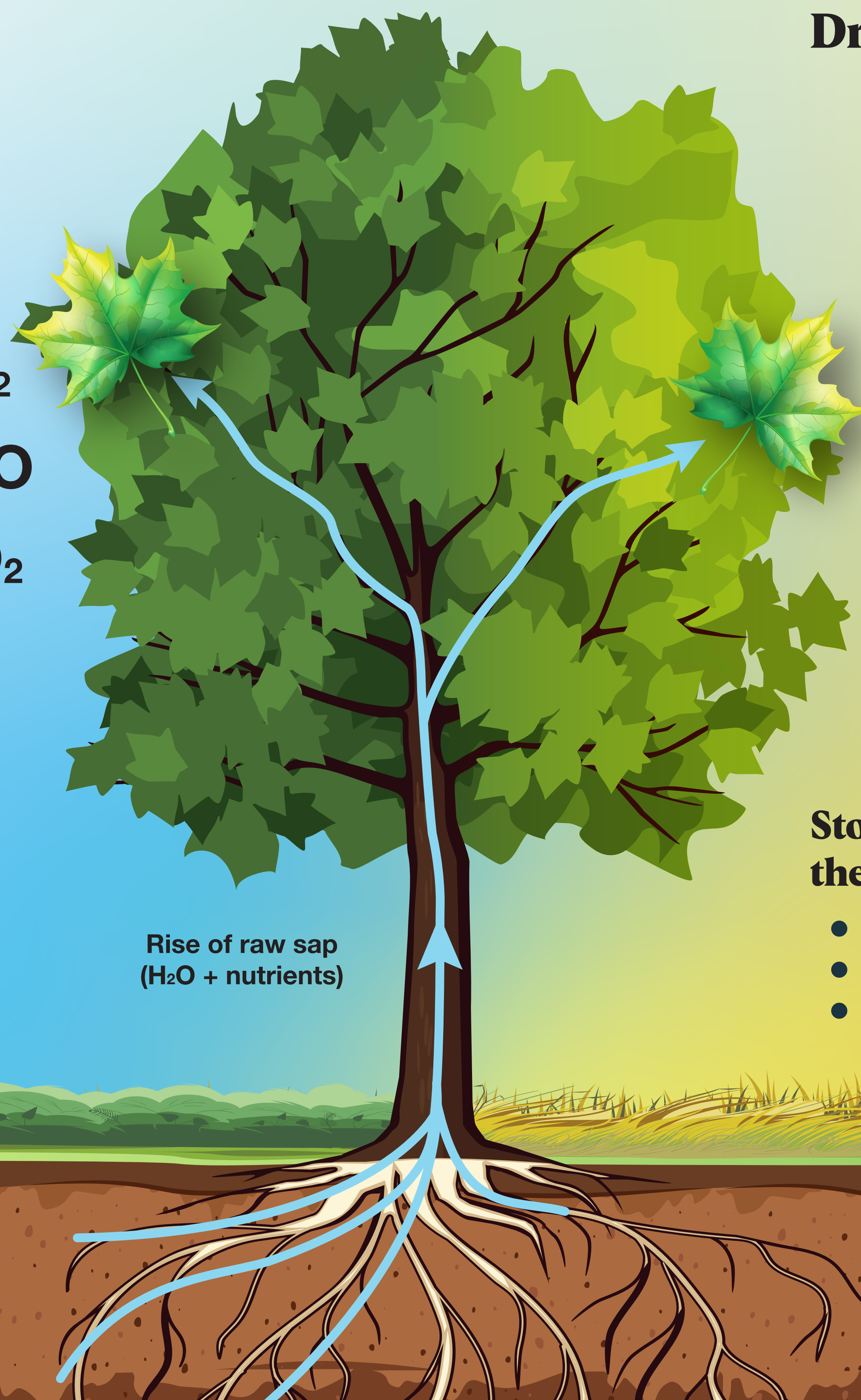
The regulation of stomatal opening becomes relevant when a period of drought occurs and it becomes increasingly difficult to extract water from the soil. Trees progressively close their stomata to reduce excessive water loss through transpiration while maintaining sap circulation. When a drought persists and intensifies, air bubbles form in the vessels, disturbing the circulation of raw sap. This phenomenon, known as xylem embolism, can trigger a cascade of critical events: cell death, leaf/needle drop, drying out of branches and crown, and even premature plant death.

Abundance of water

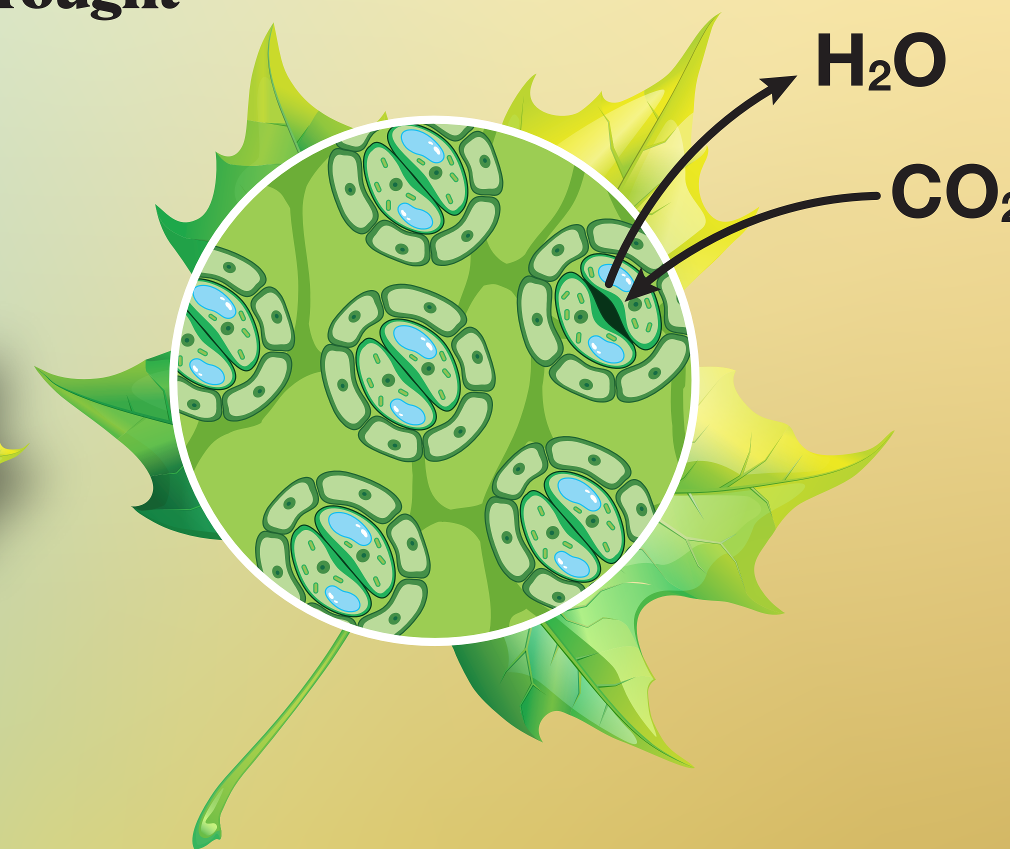


Stomata: the majority are open

- high leaf transpiration (water loss)
- high CO_2 absorption
- promotes sustained tree growth



Drought



Stomata: the majority are closed

- very little water loss through transpiration
- low CO_2 absorption
- if drought persists, possible xylem embolism leading to reduced growth and possibly death of the tree

H_2O = water
CO_2 = carbon dioxide

How is embolism resistance measured?

Recent techonolgical advances such as X-ray microtomography and optical techniques, have enabled researchers to directly track the onset and spread of xylem embolism in trees with greater accuracy.[9-10] In fact, these observations are made directly on intact plants. These new techniques have reaveld that:

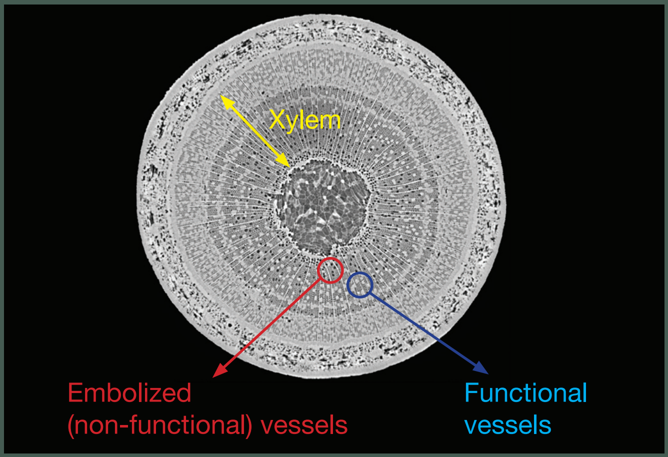
1. species are generally more resistant to embolism than previously thought, a conclusion drawn by measuring embolism resistance on cut branches[10-11];

2. xylem embolism seems irreversible[12]; in other words, it's unlikely that embolized vessels can be repaired and sap flow restored.

Visualization of xylem embolism

Both visualisation techniques presented are considered indirect and non-invasive because they do not involve cutting any organs (branches, roots). Observations are made in vivo on intact plants during the dehydration process. These techniques rely on the principle that water and air differ in how they reflect light. A specific part of the tree is scanned (e.g., the main stem, a root, or a leaf structure).

Synchrotron X-ray microtomography



Cross-sectional image of a stem obtained using synchrotron X-ray microtomography. X-rays pass through embolized air-filled vessels, but not through functional water-filled vessels. Functional vessels appear grey in the image, while embolized vessels appear black.

Optical technique

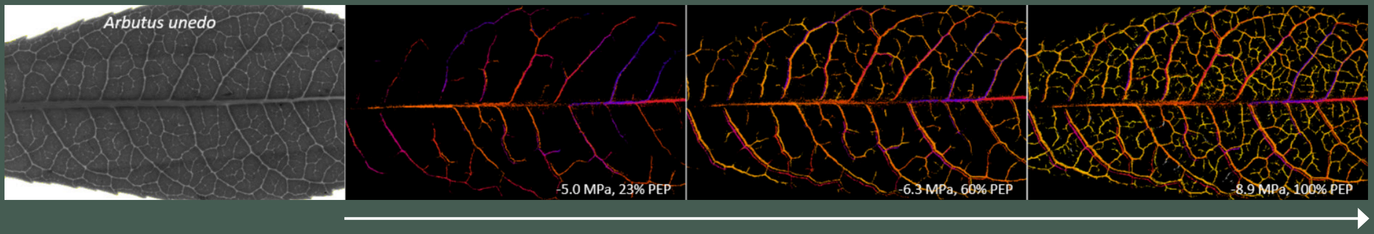


Image obtained by optical technique using a scanner or small cameras. A specific part of the plant is scanned at regular intervals (e.g., every 5 minutes) throughout the dehydration process. The scanner light passes through air-filled vessels, but not through water-filled ones. Embolized vessels are shown in colour due to the image processing of this technique.

Which strategies limit the risk of disrupting sap flow?

Globally, tree species show a wide range of resistance to embolism.[5-13] Unsurprisingly, species from the driest habitats are the most resistant to the disruption of water transport, a seen in the *Callitris* species in Australia.[14] In Canada, current measurements suggest that the variation in embolism resistance among species is realatively narrow, with the exception of Virginia juniper (*Juniperus virginiana* L.), a resistant species found in southeastern Ontario.

During a drought, trees can employ a number of complementary strategies to maintain sap circulation and water storage.

For example, they can:

1. develop a deep root system[15] that allows water to be extracted when the surface layers of the soil have dried up, as is generally the case with hardwood species (oaks, maples, poplars)[16-17] and pines (jack pine, lodgepole pine)[17];

2. implement stricter stomatal regulation (early stomatal closure), as coniferous species (pine, fir, spruce)[18-19] generally do; or

3. have leaves with a thick outer layer (cuticle) that is more impermeable to water loss.[20]

Conclusion

Climate change adaptation forestry practices and sustainable forest management in Canada require a thorough understanding of all tree characteristics (traits) that enable them to maintain water circulation for as long as possible during severe drought. This is particularly important for the boreal forest, a regions whose geographical zone is warming at an accelerated rate.

Ultimately, this research will improve predictions of forest succession in a warmer, drier climate and help lead to the identification of species with greater drought resistance. Such species could be prioritized in reforestation and regeneration programs on logged sites.

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