



SOME TREES GO EXTREME

Pine trees growing more than four kilometres above sea level in Mexico form one of the world's highest forests. Tropical botanist **Steven Jansen** and colleagues explore how *Pinus hartwegii* has adapted to the harsh conditions at these altitudes – and its potential for introducing terrestrial ecosystems to Mars.

Life on Earth depends on plants' ability to produce oxygen while storing millions of tonnes of carbon, a process that is intimately linked with transpiration of water. This is when water evaporates from pores in plants' leaves as they photosynthesise. Ultimately, plant transpiration is essential for moderating the planet's temperature and regulating run-off of water from the land to the ocean. Plants can only absorb atmospheric CO₂ when enough water is supplied to their leaves to replenish what they lose to transpiration.

The hydraulic system that transports water from the roots to the leaves in conifer trees is composed of unicellular cells, which make up most of the wood tissue. These conductive cells may become filled with air due to environmental stresses such as drought and freezing. When this happens, they fail to conduct water, which reduces the capacity to deliver water to sites of gas exchange and in extreme cases can cause plant die-back and death. But plants have been able to adapt their hydraulic network over many years of evolution to balance water loss



Below: Measuring the water potential of *Pinus hartwegii* twigs above 4000m.



and carbon gain across an extremely wide range of environments. And yet, there are still environmental conditions that limit plant distribution on Earth.

The overall purpose of our research is to investigate how variation in the microscopic structure of water conductive cells in plants is influenced by environmental stresses. These variations can in turn be understood as functional adaptations to balance hydraulic efficiency and safety. In particular, we investigate how the pine species *Pinus hartwegii* is able to dominate the high mountains at 3500m above sea level in

various parts of Mexico. What adaptations make this tree such an absolute champion at these elevations?

Breathless field work at 4000m

We conducted several one-day field trips to the Cofre de Perote and the Pico de Orizaba in the Mexican state of Veracruz, where one of the world's highest tree lines is found at elevations up to 4300m. For comparison, the timberline in cold temperate areas usually occurs around 2000-2400m above sea level. Being loaded with scientific equipment forced us to drive up the mountains by jeep and to ascend almost 3000m in several hours, which makes it impossible to acclimatise to the altitude.

Since only 60 per cent of the oxygen concentration at sea level is available at 4000m, conducting measurements and taking wood samples made this field trip pretty challenging and puffing. Fortunately, the breathtaking views and scientific curiosity of standing among *Pinus hartwegii* trees made all our efforts worthwhile.

The fact that conifers dominate at many timberlines and include the tallest plants (*Sequoia sempervirens*) and the oldest known

individual trees (*Pinus longaeva*) is in no small part because they have clever microscopic valves in their water conductive cells. These valves play an essential role in letting water pass through special channels between neighbouring cells without sacrificing safety from air entry.

Comparing the wood of *Pinus hartwegii* with that of other conifers reveals that the valves in this pine species are exceptionally large in relation to the channel structure. These fancy valves suggest that *Pinus hartwegii* has relatively high safety

margins when facing drought- or freezing-induced water stress, and may explain why the trees dominate at elevations of 3500m and more.

Terraforming Mars

Scientists doing basic fundamental research are probably all too often tempted to think that their work cannot be easily disseminated to a wider audience. But our research on *Pinus hartwegii* covers an interesting side story: this species could potentially be used as a pioneering tree for Mars.

It is clear that no living tree species could

survive the current Martian atmosphere. For one thing, temperatures are far too extreme, varying from a numbing -111°C during the polar winters to pleasant highs of up to 26°C in summer. Another serious problem is the thin (that is, low-pressure) atmosphere, which means liquid water is not stable at the surface. Obviously, growing on Mars is not what terrestrial trees have evolved for. If any living organism is capable of surviving such conditions, then some microbes or tough lichens would seem much more suitable than pine trees.

However, in line with recent ideas about geo-engineering our climate on planet Earth, we might be able to heat up Mars and increase its atmospheric density by introducing greenhouse gases. Once there is liquid water on Mars, the planet should be ready to support living plants, and the Martian soil has been shown to contain all the nutrients they need. *Pinus hartwegii*, and other plants that are well adapted to frost, drought, high solar radiation and low oxygen levels, could play a crucial role in the terraforming of Mars, because plants will produce oxygen and accelerate the warming of the planet.

While descending from a high Mexican mountain, it is easy to imagine how altitudinal changes in environment can be associated with plans for the terraforming of Mars: each drop in elevation results in a warmer, wetter and more diverse biological community. Perhaps a similar ecosystem change on Mars may not be impossible once the basic elements have been introduced and life has got a foothold.

Whether or not the terraforming of Mars falls within our technological capabilities, the economic resources required are undoubtedly far more than what any society is willing to spend on such a project. But both NASA and ESA plan historic Mars missions in the near future, so perhaps dreaming about a green home for humans more than 55 million kilometres from Earth isn't so crazy after all. ❖

MORE INFORMATION

Until recently Dr Steven Jansen was a scientific collaborator at the Royal Botanic Gardens, Kew, and now holds a Carl-Zeiss junior professorship in tropical botany at the Institute of Systematic Botany and Ecology, Ulm University, Germany, email: steven.jansen@uni-ulm.de

Dr Guillermo Angeles is a researcher at the Institute of Ecology at Xalapa, Veracruz, Mexico.