The Hidden Life of Trees

By Peter Wohlleben

The world's oldest recorded tree is a 9,550 year old spruce in the Dalarna province of Sweden. The spruce tree has shown to be a tenacious survivor that has endured by growing between erect trees and smaller bushes in pace with the dramatic climate changes over time. – Science Daily

Summary

1. Wohlleben goes into the nitty gritty of how trees survive, communicate, protect themselves, grow, are social (much like human families), share nutrients, and so much more.

Key Takeaways

1. Trees' Time Horizons
    - One reason that many of us fail to understand trees is that they live on a different time scale than us. One of the oldest trees on Earth, a spruce in Sweden, is more than 9,500 years old. That's 115 times longer than the average human lifetime. Creatures with such a luxury of time on their hands can afford to take things at a leisurely pace. The electrical impulses that pass through the roots of trees, for example, move at the slow rate of one third of an inch per second. But why, you might ask, do trees pass electrical impulses through their tissues at all? The answer is that trees need to communicate, and electrical impulses are just one of their many means of communication. Trees also use the senses of smell and taste for communication.
2. Trees' Social Nature
    - But the most astonishing thing about trees is how social they are. The trees in a forest care for each other, sometimes even going so far as to nourish the stump of a felled tree for centuries after it was cut down by feeding it sugars and other nutrients, and so keeping it alive.
    - A tree's most important means of staying connected to other trees is a "wood wide web" of soil fungi that connects vegetation in an intimate network that allows the sharing of an enormous amount of information and goods.
    - The reason trees share food and communicate is that they need each other. It takes a forest to create a microclimate suitable for tree growth and sustenance. So, it's not surprising that isolated trees have far shorter lives than those living connected together in forests. Perhaps the saddest plants of all are those we have enslaved in our agricultural systems. They seem to have lost the ability to communicate, and, as Wohlleben says, are thus rendered deaf and dumb.

- Scientists investigating similar situations have discovered that assistance may either be delivered remotely by fungal networks around the root tips—which facilitate nutrient exchange between trees1—or the roots themselves may be interconnected. In the case of the stump I had stumbled upon, I couldn't find out what was going on, because I didn't want to injure the old stump by digging around it, but one thing was clear: the surrounding beeches were pumping sugar to the stump to keep it alive.
- It appears that nutrient exchange and helping neighbors in times of need is the rule, and this leads to the conclusion that forests are superorganisms with interconnections much like ant colonies.
- Together, many trees create an ecosystem that moderates extremes of heat and cold, stores a great deal of water, and generates a great deal of humidity. And in this protected environment, trees can live to be very old. To get to this point, the community must remain intact no matter what. If every tree were looking out only for itself, then quite a few of them would never reach old age. Regular fatalities would result in many large gaps in the tree canopy, which would make it easier for storms to get inside the forest and uproot more trees. The heat of summer would reach the forest floor and dry it out. Every tree would suffer. Every tree, therefore, is valuable to the community and worth keeping around for as long as possible. And that is why even sick individuals are supported and nourished until they recover. Next time, perhaps it will be the other way round, and the supporting tree might be the one in need of assistance.
- Do tree societies have second-class citizens just like human societies? It seems they do, though the idea of "class" doesn't quite fit. It is rather the degree of connection—or maybe even affection—that decides how helpful a tree's colleagues will be.
    i. *Degree of connection determines "class" and "health"*
- Trees, it turns out, have a completely different way of communicating: they use scent.
- Similar processes are at work in our forests here at home. Beeches, spruce, and oaks all register pain as soon as some creature starts nibbling on them. When a caterpillar takes a hearty bite out of a leaf, the tissue around the site of the damage changes. In addition, the leaf tissue sends out electrical signals, just as human tissue does when it is hurt. However, the signal is not transmitted in milliseconds, as human signals are; instead, the plant signal travels at the slow speed of a third of an inch per minute.4 Accordingly, it takes an hour or so before

defensive compounds reach the leaves to spoil the pest's meal. Trees live their lives in the really slow lane, even when they are in danger. But this slow tempo doesn't mean that a tree is not on top of what is happening in different parts of its structure. If the roots find themselves in trouble, this information is broadcast throughout the tree, which can trigger the leaves to release scent compounds. And not just any old scent compounds, but compounds that are specifically formulated for the task at hand.

- The saliva of each species is different, and trees can match the saliva to the insect. Indeed, the match can be so precise that trees can release pheromones that summon specific beneficial predators. The beneficial predators help trees by eagerly devouring the insects that are bothering them.
- Tree roots extend a long way, more than twice the spread of the crown. So the root systems of neighboring trees inevitably intersect and grow into one another—though there are always some exceptions. Even in a forest, there are loners, would-be hermits who want little to do with others.
- Can such antisocial trees block alarm calls simply by not participating? Luckily, they can't. For usually there are fungi present that act as intermediaries to guarantee quick dissemination of news. These fungi operate like fiber-optic Internet cables. Their thin filaments penetrate the ground, weaving through it in almost unbelievable density.
- The fungi are pursuing their own agendas and appear to be very much in favor of conciliation and equitable distribution of information and resources.
- So trees communicate by means of olfactory, visual, and electrical signals. (The electrical signals travel via a form of nerve cell at the tips of the roots.)
- What's really surprising is how much betulin there is in birch bark. A tree that makes its bark primarily out of defensive compounds is a tree that is constantly on the alert. In such a tree there is no carefully calibrated balance between growth and healing compounds. Instead, defensive armoring is being thrown up at a breakneck pace everywhere. Why doesn't every species of tree do that? Wouldn't it make sense to be so thoroughly prepared against attack that potential aggressors would breathe their last the moment they took the first bite? Species that live in social groups don't entertain this option because every individual belongs to a community that will look after it in times of need, warn it of impending dangers, and feed it when it is sick or in distress. Cutting back on defense saves energy, which the tree can then invest in producing wood, leaves, and fruit. Not so with the birches, which must be completely self-reliant if they are to survive. But they,

too, grow wood—and indeed, they do so a lot faster—and they, too, want to, and do, reproduce. Where does all their energy come from? Can this species somehow photosynthesize more efficiently than others? No. The secret, it turns out, lies in wildly overtaxing their resources. Birches rush through life, live beyond their means, and eventually wear themselves out.

- The wood wide web has been mapped, traced, monitored, and coaxed to reveal the beautiful structures and finely adapted languages of the forest network. We have learned that mother trees recognize and talk with their kin, shaping future generations. In addition, injured trees pass their legacies on to their neighbors, affecting gene regulation, defense chemistry, and resilience in the forest community. These discoveries have transformed our understanding of trees from competitive crusaders of the self to members of a connected, relating, communicating system.

3. Survival & Growth
    - If you are a tree, slow growth is the key to growing old. Growth fueled by hefty additions of excess nitrogen from agricultural operations is unhealthy. And so the tried and tested rule holds true: less (carbon dioxide) is more (life-span).
    - The surprising result: the older the tree, the more quickly it grows. Trees with trunks 3 feet in diameter generated three times as much biomass as trees that were only half as wide. So, in the case of trees, being old doesn't mean being weak, bowed, and fragile. Quite the opposite, it means being full of energy and highly productive. This means elders are markedly more productive than young whippersnappers
    - Under normal circumstances, a tree carefully apportions its energy. The largest portion is used for daily living: the tree has to breathe, "digest" its food, supply its fungal allies with sugar, and grow a bit every day. Then the tree has to keep hidden reserves of energy on hand to fight off pests.
    - If the carefully calibrated balance of energy for growth and defense gets thrown out of alignment, then a tree might get sick. This can happen, for example, when a neighboring tree dies. Suddenly, the crown gets more light, and now what the tree wants more than anything is more photosynthesis. That makes sense because a chance like this comes along only about once every hundred years. The tree, finding itself suddenly bathed in sunlight, forgets about everything else and focuses exclusively on growing branches. It has no option really, because its surrounding cohort is doing the same thing, which means that the gap in the canopy will close again in about twenty years, which, if you are a tree, means you

don't have much time. Suddenly, growth speeds up, and instead of adding a few fractions of an inch each year, the tree is adding about 20 inches. This takes energy, which is then not available for fending off illnesses and pests. If the tree is lucky, all goes well, and once the canopy closes again, the tree will have increased the size of its crown. Then it will take a break and settle back into apportioning its energy in a way that suits its lifestyle. But woe betide the tree if something goes wrong during this growth spurt.

- To grow its trunk, a mature beech needs as much sugar and cellulose as there is in a 2.5-acre field of wheat. Of course, it takes not 1 but 150 years to grow such a mighty structure, but once it's up there, hardly any other plants—except for other trees—can reach it, and the rest of its life is worry free.
- Trees maintain an inner balance. They budget their strength carefully, and they must be economical with energy so that they can meet all their needs. They expend some energy growing. They must lengthen their branches and widen the diameter of their trunks to support their increasing weight. They also hold some energy in reserve so that they can react immediately and activate defensive compounds in their leaves and bark if insects or fungi attack.
- Species that blossom every year plan for this Herculean task by carefully calibrating their energy levels. However, species that blossom only every three to five years, such as beeches or oaks, are thrown off kilter by such events. Most of their energy has already been earmarked for other tasks, but they need to produce such enormous numbers of beechnuts and acorns that everything else must now take second place.
- We know from times of high forest mortality that it is usually the particularly battered individuals that burst into bloom. If they die, their genetic legacy might disappear, and so they probably want to reproduce right away to make sure it continues.
- Young trees are so keen on growing quickly that it would be no problem at all for them to grow about 18 inches taller per season. Unfortunately for them, their own mothers do not approve of rapid growth. They shade their offspring with their enormous crowns, and the crowns of all the mature trees close up to form a thick canopy over the forest floor. This canopy lets only 3 percent of available sunlight reach the ground and, therefore, their children's leaves. Three percent—that's practically nothing. With that amount of sunlight, a tree can photosynthesize just enough to keep its own body from dying. There's nothing left to fuel a decent

drive upward or even a thicker trunk. And rebellion against this strict upbringing is impossible, because there's no energy to sustain it.

- Scientists have determined that slow growth when the tree is young is a prerequisite if a tree is to live to a ripe old age.
- A good upbringing is necessary for a long life, but sometimes the patience of the young trees is sorely tested.
- And what is the point of all this? Deep down inside, do trees secretly appreciate beauty? Unfortunately, I cannot say, but what I can tell you is that there is a good reason for this ideal appearance: stability. The large crowns of mature trees are exposed to turbulent winds, torrential rains, and heavy loads of snow. The tree must cushion the impact of these forces, which travel down the trunk to the roots. The roots must hold out under the onslaught so that the tree doesn't topple over. To avoid this, the roots cling to the earth and to rocks. The redirected power of a windstorm can tear at the base of the trunk with a force equivalent to a weight of 220 tons. If there is a weak spot anywhere in the tree, it will crack. In the worst-case scenario, the trunk breaks off completely and the whole crown tumbles down. Evenly formed trees absorb the shock of buffeting forces, using their shape to direct and divide these forces evenly throughout their structure.
- Trees that don't follow the etiquette manual find themselves in trouble. For example, if a trunk is curved, it has difficulties even when it is just standing there. The enormous weight of the crown is not evenly divided over the diameter of the trunk but weighs more heavily on the wood on one side. To prevent the trunk from giving way, the tree must reinforce the wood in this area. This reinforcement shows up as particularly dark areas in the growth rings, which indicate places where the tree has laid down less air and more wood.
- The most severely affected trees are those that grow in soils where moisture is usually particularly abundant. These trees don't know the meaning of restraint and are lavish in their water use, and it is usually the largest and most vigorous trees that pay the price for this behavior.
- The process of learning stability is triggered by painful micro-tears that occur when the trees bend way over in the wind, first in one direction and then in the other. Wherever it hurts, that's where the tree must strengthen its support structure. This takes a whole lot of energy, which is then unavailable for growing upward.
- Trees are very social beings, and they help each other out. But that is not sufficient for successful survival in the forest ecosystem. Every species of tree

tries to procure more space for itself, to optimize its performance, and, in this way, to crowd out other species. After the fight for light, it is the fight for water that finally decides who wins.

- But this tough little Beech tree has taken precautions. Right from the beginning, it puts considerably more energy into building up its root system than other species of trees. Here, it stashes away nutrients, and if misfortune strikes above ground, it grows right back without missing a beat. This often leads to the formation of multiple trunks, which may merge when the tree reaches an advanced age, giving the tree an untidy appearance. And boy can these trees grow old! Living to be a thousand years old or more, they easily outstrip the closest competition, and over the course of centuries, they increasingly get to bask in the sun whenever an old tree growing above them breathes its last. Despite this, yews grow no more than 65 feet tall. They are fine with this, and they don't strive to reach greater heights.
- Healthy trees advertise their readiness to defend themselves in the coming spring by displaying brightly colored fall leaves. Aphids & Co. recognize these trees as unfavorable places for their offspring because they will probably be particularly vigorous about producing toxins. Therefore, they search out weaker, less colorful trees.
- When you take a closer look, their behavior in fall actually makes a lot of sense. By discarding their leaves, they avoid a critical force—winter storms.
- The trunk and branches are shaped so that their combined wind resistance is somewhat less than that of a modern car. Moreover, the whole construction is so flexible that the forces of a strong gust of wind are absorbed and distributed throughout the tree.
- Mature trees can adapt as well. If spruce survive a dry period with little water, in the future they are markedly more economical with moisture and they don't suck it all up out of the ground right at the beginning of summer. The leaves and needles are the organs where most water is lost through transpiration. If the tree notices that water is in short supply and thirst is becoming a long-term problem, it puts on a thicker coat. The tree toughens up the protective waxy layer on the upper surface of its leaves. The walls of the cells within the leaves keep them watertight, and the tree increases the thickness of the cell walls by adding extra layers. As the tree battens down the hatches, however, it also has a harder time breathing.

4. Aging, Decay, and Death

- A break in its bark, then, is at least as uncomfortable for a tree as a wound in our skin is for us. And, therefore, the tree relies on mechanisms similar to the ones we use to stop this from happening.
- More light, more sun, more ultraviolet radiation. The last causes changes in people's skin, and it appears the same thing happens with trees. Intriguingly, the outer bark on the sunny side of the trees is harder, and this means it is more inflexible and more inclined to crack.
- Apart from wrinkled skin and mossy growths, there are other physical changes that indicate a tree's age. Take, for example, the crown, which I can compare with something I have as well. Up top, my hair is thinning. It just doesn't grow like it did when I was young. And it's the same with the highest branches up in a tree's crown. After a specific time—one hundred to three hundred years, depending on the species—the annual new growth gets shorter and shorter.
- In any event, every tree gradually stops growing taller. Its roots and vascular system cannot pump water and nutrients any higher because this exertion would be too much for the tree. Instead, the tree just gets wider (another parallel to many people of advancing years…). The tree is also not capable of maintaining its mature height for long because its energy levels diminish slowly over the years. At first, it can no longer manage to feed its topmost twigs, and these die off. And so, just as an old person gradually loses body mass, an old tree does too.
- A healthy tree doesn't bother to sink energy into developing that kind of growth, preferring instead to extend the reach of its crown up above.
- Sometimes dead wood is directly beneficial to trees, for example, when a downed trunk serves as a cradle for its own young. Young spruce sprout particularly well in the dead bodies of their parents. This is known as "nurse-log reproduction" in English and, somewhat gruesomely, as Kadaververjüngung, or "cadaver rejuvenation," in German.
- Sleep deprivation affects trees and people in much the same way: it is life threatening. That's why oaks and beeches can't survive if we try to grow them in containers in our living rooms. We don't allow them to get any rest there, and so most of them die within the first year.
- It goes without saying that constant struggle and rapid growth exact their toll. After the first three decades, exhaustion sets in.

5. The Importance of Roots
    - So, let's get back to why the roots are the most important part of a tree. Conceivably, this is where the tree equivalent of a brain is located. Brain? you

ask. Isn't that a bit farfetched? Possibly, but now we know that trees can learn. This means they must store experiences somewhere, and therefore, there must be some kind of a storage mechanism inside the organism. Just where it is, no one knows, but the roots are the part of the tree best suited to the task. The old spruce in Sweden also shows that what grows underground is the most permanent part of the tree—and where else would it store important information over a long period of time?

- If the root encounters toxic substances, impenetrable stones, or saturated soil, it analyzes the situation and transmits the necessary adjustments to the growing tip. The root tip changes direction as a result of this communication and steers the growing root around the critical areas.
- A forest would have no problem doing without its larger inhabitants. Deer, wild boar, carnivores, and even most birds wouldn't leave any yawning gaps in the ecosystem. Even if they were all to disappear at once, the forest would simply go on growing without many adverse effects. Things are completely different when it comes to the tiny creatures under their feet.
- A severely pruned crown is a severe blow for the roots, which grow to a size optimally suited to serve the above-ground parts of the tree. If a large percentage of the branches is removed and the level of photosynthesis drops, then just as large a percentage of the underground part of the tree starves.

6. Symbiosis with Fungi
    - You find twice the amount of life-giving nitrogen and phosphorus in plants that cooperate with fungal partners than in plants that tap the soil with their roots alone.
    - The fungus not only penetrates and envelops the tree's roots, but also allows its web to roam through the surrounding forest floor. In so doing, it extends the reach of the tree's own roots as the web grows out toward other trees. Here, it connects with other trees' fungal partners and roots. And so a network is created, and now it's easy for the trees to exchange vital nutrients (see chapter 3, "Social Security") and even information—such as an impending insect attack. This connection makes fungi something like the forest Internet. And such a connection has its price. As we know, these organisms—more like animals in many ways—depend on other species for food. Without a supply of food, they would, quite simply, starve. Therefore, they demand payment in the form of sugar and other carbohydrates, which their partner tree has to deliver. And fungi are not exactly dainty in their requirements. They demand up to a third of the tree's total food

production in return for their services. It makes sense, in a situation where you are so dependent on another species, to leave nothing to chance. And so the delicate fibers begin to manipulate the root tips they envelop. First, the fungi listen in on what the tree has to say through its underground structures. Depending on whether that information is useful for them, the fungi begin to produce plant hormones that direct the tree's cell growth to their advantage.26 In exchange for the rich sugary reward, the fungi provide a few complimentary benefits for the tree, such as filtering out heavy metals, which are less detrimental to the fungi than to the tree's roots.

- These fungi are mutualistic. They connect the trees with the soil in a market exchange of carbon and nutrients and link the roots of paper birches and Douglas firs in a busy, cooperative Internet. When the interwoven birches and firs were spiked with stable and radioactive isotopes, I could see, using mass spectrometers and scintillation counters, carbon being transmitted back and forth between the trees, like neurotransmitters firing in our own neural networks. The trees were communicating through the web! I was staggered to discover that Douglas firs were receiving more photosynthetic carbon from paper birches than they were transmitting, especially when the firs were in the shade of their leafy neighbors. This helped explain the synergy of the pair's relationship. The birches, it turns out, were spurring the growth of the firs, like carers in human social networks. Looking further, we discovered that the exchange between the two tree species was dynamic: each took different turns as "mother," depending on the season. And so, they forged their duality into a oneness, making a forest.

7. The Physics of Water – Narrow Vessels, Transpiration, Osmosis
    - Narrow vessels, however, are not enough to explain how water reaches the crown of trees that are more than 300 feet tall. In even the narrowest of vessels, there is only enough force to account for a rise of 3 feet at most. Ah, but we have another candidate: transpiration. In the warmer part of the year, leaves and needles transpire by steadily breathing out water vapor. In the case of a mature beech, the tree exhales hundreds of gallons of water a day. This exhalation causes suction, which pulls a constant supply of water up through the transportation pathways in the tree. Suction works as long as the columns of water are continuous. Bonding forces cause the water molecules to adhere to each other, and because they are strung together like links in a chain, as soon as space becomes available in the leaf thanks to transpiration, the bonded molecules pull each other a little higher up the trunk. And because even this is not enough, osmosis also comes into play.

When the concentration of sugar in one cell is higher than in the neighboring cell, water flows through the cell walls into the more sugary solution until both cells contain the same percentage of water. And when that happens from cell to cell up into the crown, water makes its way up to the top of the tree.

- So where are the noises coming from? The researchers think they are coming from tiny bubbles of carbon dioxide in the narrow water-filled tubes. Bubbles in the pipes? That means the supposedly continuous column of water is interrupted thousands of times. And if that is the case, transpiration, cohesion, and capillary action contribute very little to water transport. So many questions remain unanswered. Perhaps we are poorer for having lost a possible explanation or richer for having gained a mystery. But aren't both possibilities equally intriguing?

8. Trees & The Environment
    - The forest can lose as much as 2,900 tons per square mile per year. The same area can replace only 290 tons annually through the weathering of stones underground, leading to a huge annual loss of soil. Sooner or later, only the stones remain. Today, you can find many such depleted areas in forests growing in exhausted soils that were cultivated centuries ago. In contrast, forests left undisturbed lose only 1 to 14 tons of soil per square mile per year. In intact forests, the soil under the trees becomes deeper and richer over time so that growing conditions for trees constantly improve.
    - This transformation is a good example of what trees can do to change their environment. As foresters like to say, the forest creates its own ideal habitat.
    - Given this reciprocal relationship between trees and weather, forest ecosystems probably play an important role in slowing down climate change.
    - The forest ecosystem is held in a delicate balance. Every being has its niche and its function, which contribute to the well-being of all. Nature is often described like that, or something along those lines; however, that is, unfortunately, false. For out there under the trees, the law of the jungle rules. Every species wants to survive, and each takes from the others what it needs. All are basically ruthless, and the only reason everything doesn't collapse is because there are safeguards against those who demand more than their due. And one final limitation is an organism's own genetics: an organism that is too greedy and takes too much without giving anything in return destroys what it needs for life and dies out. Most species, therefore, have developed innate behaviors that protect the forest from overexploitation. We are already familiar with a good example, and that is

the jay that eats acorns and beechnuts but buries a multitude of them as it does so, ensuring that the trees can multiply more efficiently with it than without it.

9. Other
    - When you know that trees experience pain and have memories and that tree parents live together with their children, then you can no longer just chop them down and disrupt their lives with large machines. Machines have been banned from the forest for a couple of decades now, and if a few individual trees need to be harvested from time to time, the work is done with care by foresters using horses instead. A healthier—perhaps you could even say happier—forest is considerably more productive, and that means it is also more profitable.
    - Some species have a particularly effective way of avoiding inbreeding: each individual has only one gender. For example, there are both male and female willows, which means they can never mate with themselves but only procreate with other willows.
    - Spruce store essential oils in their needles and bark, which act like antifreeze.
    - In Fishlake National Forest, Utah, there is a quaking aspen that has taken thousands of years to cover more than 100 acres and grow more than forty thousand trunks. This organism, which looks like a large forest, has been given the name "Pando" (from the Latin "pandere," which means to spread).
    - To produce 1 pound of wood, they need 22 gallons of water. Does this sound like a lot? Most other species of tree need up to 36 gallons, almost twice as much, and that is the deciding factor that enables beeches to shoot up quickly and suppress other species.
    - Trees employ two strategies to stoically endure these changes: behavior and genetic variability. Trees exhibit great tolerance for variations in climate.
    - Consider this. Threatened forests are inherently unstable, and therefore, they are not appropriate places for human beings to live. And because our Stone Age ancestors were always on the lookout for ideal places to set up camp, it would make sense if we could intuitively pick up on the state of our surroundings. There is a scientific observation that speaks to this: the blood pressure of forest visitors rises when they are under conifers, whereas it calms down and falls in stands of oaks.
    - Why do we find it so much more difficult to understand plants than animals? It's because of the history of evolution, which split us off from vegetation very early

on. All our senses developed differently, and so we have to use our imaginations to get even the slightest idea of what is going on inside trees.

Summary

1. Fascinating how advanced nature is how it can communicate, adapt, learn, and evolve! There are also some beautiful analogies to business and relationships that we should honor and live by. Slow growth is the key to growing old yet the older the tree, the more quickly it grows (the power of compounding), developing deep roots where one aims to give and communicate and help as much as possible…