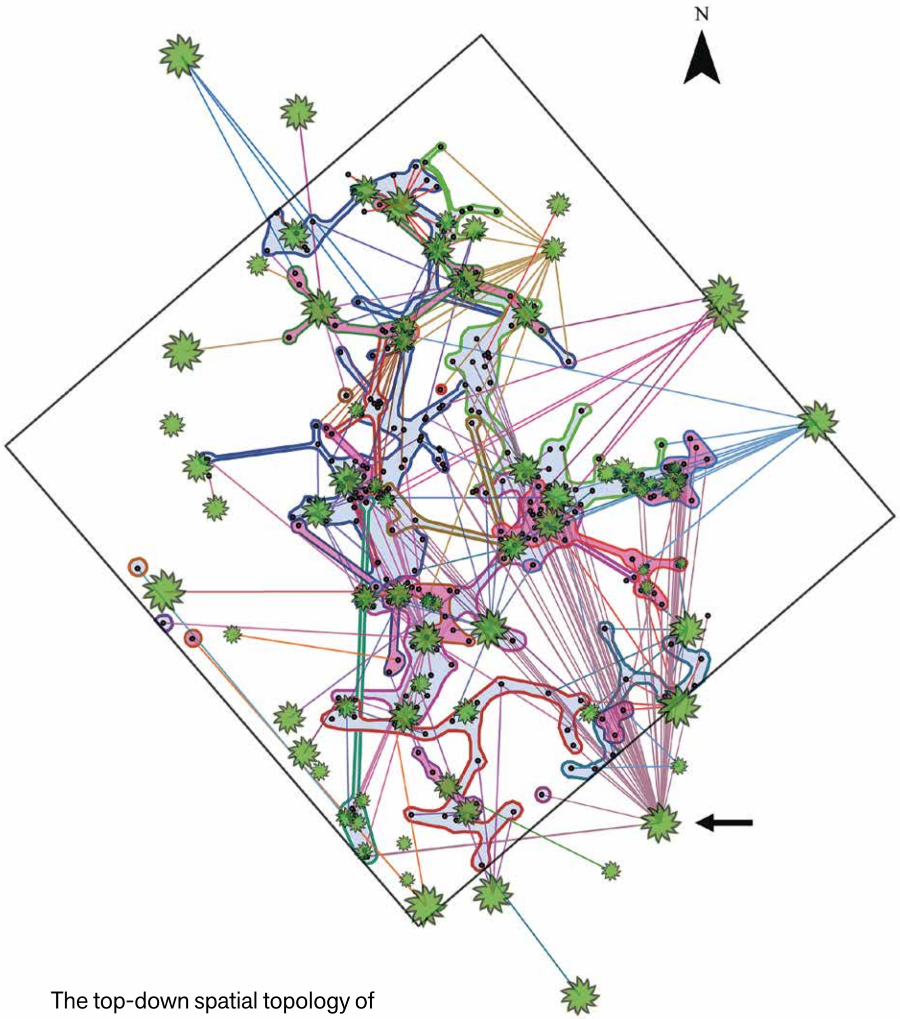


The top-down spatial topology of *Rhizopogon* species pluralis genets [in botany, a "genet," or clonal colony, is a group of genetically identical individuals] and Douglas fir trees in a thirty-by-thirty-meter plot. The plot (square outline) lies on a southeastern slope and contains sixty-seven trees of various ages (green shapes, sized relative to each tree's diameter). Small black dots mark *Rhizopogon* ectomycorrhiza sample locations (n = 401), 338 of which were associated with a specific tree and fungal genet based on microsatellite DNA analysis. Samples representative of each fungal genet are outlined in differing colors. *Rhizopogon vesiculosus* genets (n = 14) are shaded with a blue background, and *R. vinicolor* genets (n = 13) with pink. Lines illustrate the linkages between tree roots encountered in *Rhizopogon* ectomycorrhizas and corresponding source trees aboveground ("root lengths") and are colored according to tree genotype. An arrow points to the most highly connected tree, which was linked to forty-seven other trees through eight *R. vesiculosus* genets and three *R. vinicolor* genets inside the plot. Some trees, mycorrhiza samples, and/or genets may be obscured by overlapping features.

The Mother Tree

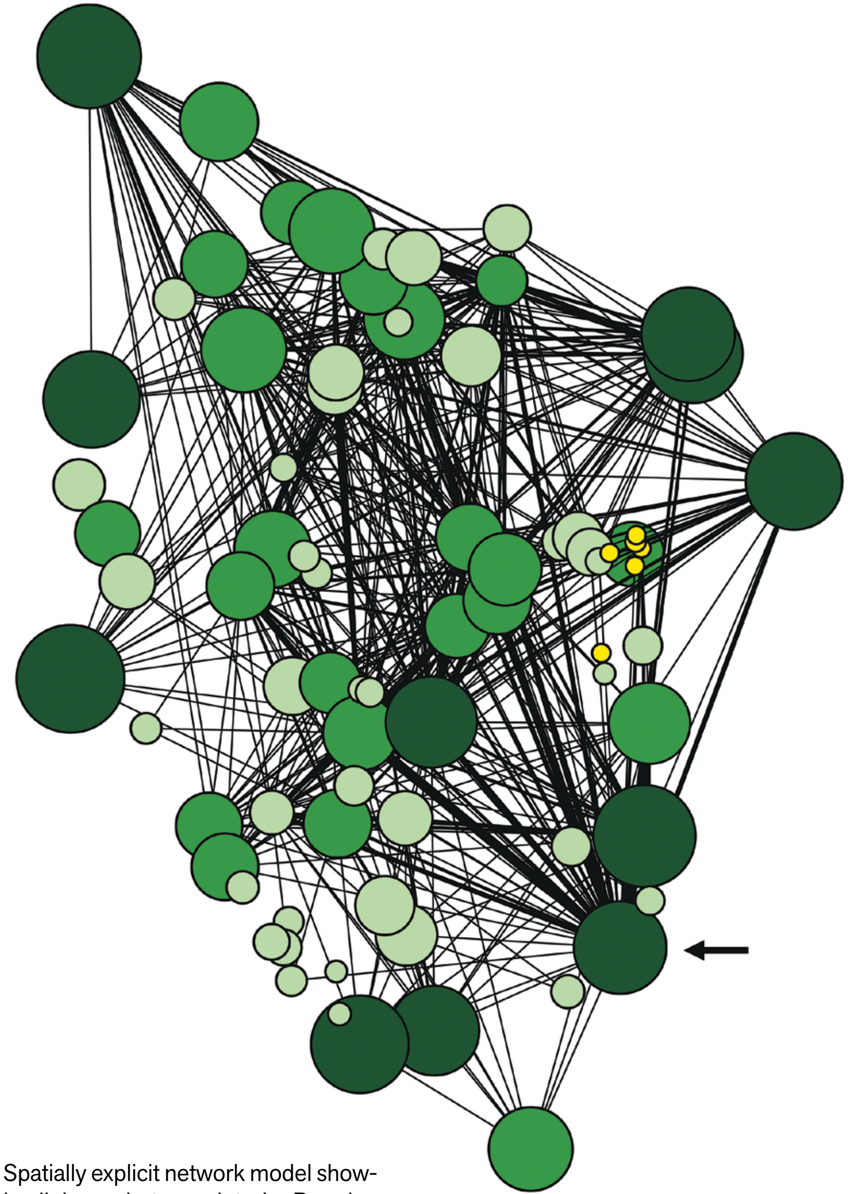
Text by Suzanne Simard
with visualizations by Kevin Beiler

Elders fill a special role in any community, having earned the respect of the tribe for their life-long wisdom, knowledge, and teaching. They help link individuals to the broader community as a whole, and connect the past with the future. Not all old individuals are elders, nor are all elders old. In my family, grandmothers and grandfathers usually filled the role of elders, although certain individuals, like my daughters, were born with wisdom beyond their years, connecting the family through the ages. This wisdom emerges from lives lived before them over many generations. In my life's work in the forest, I have learned that elders of many species, including humans, also connect the forest, providing an adaptive genetic scaffolding for change and resilience among the whole community. In the forest, the foundational species are the trees, and the elders of this foundation are the biggest and oldest trees. Elder trees provide an anchor for the diverse structure of the many-sized trees in their neighborhoods. These elders are important not just as habitat for the many plant, animal, fungal, and microbial creatures that live in the forest, but also the people who depend on the woods for their cultures and livelihoods.

The elder Douglas fir trees in my home forests of British Columbia, Canada, form symbioses with thousands of underground mycorrhizal fungal species, as do tree species in forests around the world. The first mycorrhizal fungi were detected in fossil records dating back about 400 million years, and are considered to have facilitated the migration of plants from the sea onto land. These mutualistic mycorrhizal fungi gather limited nutrients and water from the soil and trade them for photosynthetic carbon from the trees. Some of the fungi in today's forests today are late successional species associated with mature forests, and some are early successional species associated with younger forests, but all serve to connect individual trees within the forests. A single elder Douglas fir tree, for example, can be connected to hundreds of other trees, either of the same or different species, by the sheer magnitude of its massive root system and diverse fungal community. These subterranean connections form a mycorrhizal network, now known colloquially as the "Wood Wide Web," with a topology similar to that of neural networks, stream networks in watersheds, and the internet. In the Wood Wide Web, trees can be thought to serve as the nodes of the network, while fungi act as the vertices.[1]

The Wood Wide Web is a busy network, where the fungal links serve as pathways for the back-and-forth transport of carbon, water, and nutrients among trees. Among the shifting dynamics of growing trees, the taller, replete, and illuminated elders can shuttle a net amount of resources along a source-sink gradient to shorter, shaded, understory trees. The more resourceful the source tree, and the more needy the sink tree, the greater the net transfer of resources to the latter. In some forests, these trees also trade defense signals to warn each other of potential danger, thus increasing the resilience of the whole community. Some trees shuttle allelochemicals, or poisons, through the network if the neighboring tree species is an unwanted intruder. Elder trees are able to recognize neighbors that are genetically related, or that are kin, and they can send more or less resources to other trees to either favor or disfavor them, depending on the safety of the environment.[2] I have taken to calling these elders "Mother Trees" because they appear to be nurturing their young. Mother Trees thus connect the forest through space and time, just like elders connect human families across generations.

Mother Trees, particularly the ancient cedars and spruces of the Pacific West Coast, may also transmit nutrients through the forest with their massive fungal networks, thereby feeding the entire ecosystem. In my lab, Dr. Teresa Ryan of the Tsimshian First Nation, Ph.D. candidate Allen Larocque, and I are investigating these processes. Here is how we currently think it works: In the Pacific West Coast of British Columbia, salmon caught in fish traps built by the Aboriginal people at the mouth of marine spawning rivers are eaten by grizzlies and wolves. These predators transport their catch to safe, warm, dry benches under Mother Trees growing along the river banks in the forest. There, the bears safely eat the innards, leaving the carcasses to decay and nutrients to seep into the roots of the trees. The salmon nitrogen is acquired by the mycorrhizal networks and fertilizes the Mother Trees, which



Spatially explicit network model showing linkages between interior Douglas fir trees via shared colonization by *Rhizopogon vesiculosus* and *R. vinicolor* genets. Circles represent tree nodes, sized according to the tree's diameter, and colored with four different shades of yellow or green that increase in darkness with increasing age class. Lines represent the Euclidean distances between trees that are linked. Line width increases with the number of links between tree pairs (for example repeated links through multiple fungal genets). An arrow points to the most highly connected tree, which was linked to forty-seven other trees through eight *R. vesiculosus* genets and three *R. vinicolor* genets inside the plot. Some tree nodes and their links may be obscured by overlapping features.

we think then transmit the salmon nitrogen from tree to tree to tree through their fungal connections, deep into the forest.

The trees metabolize the nitrogen, facilitating their growth, and store it in their tissue (as shown by tree rings) for centuries. The salmon nitrogen in the tissues of the trees promotes the health and productivity of the forest. In turn, these luxurious forests shade and nurture the salmon rivers, modulating the water temperature and transmitting nutrients to the ebb tides through seepage, thus forming a positive feedback loop that promotes the health and productivity of the fish. The parts of the trees composed with salmon nitrogen—namely, the bark and roots—are harvested by the Northwest Coast First Nations, including the Tsimshian and Nuu-chah-nulth, to make clothing, art, and tools, including those used for the salmon harvest. Elder trees, or Mother Trees, play a crucial role in the closing of this circle. The health of the forest is thus tied to the health of the salmon, as they are cycled back to the rivers, the oceans, and the people. The integrity of this circle of life depends on what the First Nations call *reciprocity*, an exchange of mutual respect. Mother Trees play a crucial role in the closing of this circle, but this process is also an important example of how people can be sustainably embedded with the complex adaptive system of the forest.

Since the mid-1850s, great swaths of North American forests have been felled at the hands of European colonizers, first out of fear of the dark woods, then to make way for agriculture, and then for the profits they return as timber. The scale of changes that Europeans brought to these forests are in sharp contrast to those made by the Aboriginals, whose felling of trees is designed to enhance wildlife habitat, clear trade corridors, and protect against intruders; typically, the cutting of the forest is intended to support their local livelihoods in and with the forest. Thus, the varied forests of North America were shaped by the Aboriginal nations according to their needs. When European settlers arrived to colonize North America, the forests were instead cleared in their entirety for settlements and agriculture—and the elder trees were particularly sought after. Eventually, forestry practices were adopted from Germany, where forest management science had been honed and adapted to ensure regeneration in the local environment, and to meet social needs.[3] Even though the forests of North America were very different, European practices were typically applied with little thought to the peculiarities of the climate, soil, or species. Since the latter decades of the twentieth century, these practices have converged on a market basis into the common industrial practices of clearcutting and the planting of commercial tree species. This is true even in the mighty salmon forests of the Pacific Coast. These practices—lacking in any form of reciprocity—are rapidly dismantling the circle of life by undercutting biodiversity, productivity, and biogeochemical cycles.

There are responses to this situation within our reach. Here I suggest just four important trajectories for restoration and reparation. First, modern consumer societies need to recognize their relationship with nature. Many Aboriginal nations of North America acted as successful stewards of forests, rivers, and salmon for millennia; their practices were built on respect and reciprocity, honoring their place in nature. As scientific studies begin to recognize that these linkages, once ignored, not only exist, but are crucial to human and forest well-being, it is imperative that we fundamentally transform the modern scientific image of nature as a resource. Second, we humans need to maintain our connections in this web, especially as the stresses resulting from climate change increase. This can be done through the conservation of biodiversity, not only of species, but structures and functions as well. Third, conservation needs to honor the elders. This means fighting to keep elders alive and safe so that their genes and wisdom can be passed down through the generations. Finally, humans need to honor diversity. It is through our differences—whether social, botanical, or genetic—that productivity, creativity, adaptivity, and resilience are nurtured and maintained. It is also through her diversity that Mother Earth will adapt to and help regulate modern anthropogenic crises.

Images and annotations courtesy of Kevin Beiler.

1 Kevin Beiler et al., "Architecture of the Wood-Wide Web: *Rhizopogon* spp. Genets Link Multiple Douglas-Fir Cohorts," *New Phytologist* 185 (2010): 543–53.

2 Brian Pickles et al., "Transfer of ^{13}C between Paired Douglas-fir Seedlings Reveals Plant Kinship Effects and Uptake of Exudates by Ectomycorrhizas," *New Phytologist* (2016).

3 Editors' note: For a critical reading of the history of German forest science, see James C. Scott, *Seeing Like a State: How Certain Schemes to Improve the Human Condition Have Failed* (New Haven: Yale University Press, 1998), 11–52.