The wood wide web

Environmental resilience in times of climate change starts with protecting what we cannot see, explains Ian Edwards.

I am writing this article in the wake of the historic COP26 Climate Change conference, held in Glasgow in November 2021. Whether you feel world leaders made some bold agreements on halting global deforestation or that it was all blah, blah, blah, it is clear that resilience is needed within the forest ecosystem to meet the challenge of unpredictable and unavoidable climate change, which will stretch nature's ability to adapt to the limit. It will take a continual rebalancing of all components within natural systems, with some elements inevitably taking on an ever more significant role, while others become less important or even redundant. Much of the attention given to the loss of species has focused on animals and plants that we are familiar with, those with names and scientific identities. However, arguably the organisms at most critical risk of extinction are often the lesser known or unknown species, that may or may not have been described scientifically, and that we understand next to nothing about.

Research over the past three decades is helping us appreciate the vital contribution that the fungal kingdom, along with other microbes, are making to ecological resilience. Much of this biodiversity is hidden within the soil beneath our feet. We know that most soil teems with life but current research is helping us understand how critical retaining a healthy below-ground biome is for survival of a fully functioning ecosystem.

Cooperation

The pioneering work of Suzanne Simard and others in revealing the function of a complex network of fungal mycelia that extends throughout the forest soil, creating living highways between the root systems of neighbouring trees, is a radical example of scientific progress in this area. Simard, a Canadian forest ecologist working in the Pacific northwest, has spent her career investigating what the fungal mycelia do for forests, chiefly, providing pathways for transport of nutrients (carbon, minerals, water) between individual trees. She and her graduate students carried out a variety of brilliantly executed field experiments to prove the existence of a two-way nutrient exchange, via the root-mycelium-root bridges, between trees in what became known as the 'wood wide web'. Many of her (male) colleagues in forestry research remained sceptical even after she made the lead article in the journal, *Nature* [1].

The belief that competition restricts tree growth during the establishment of commercial tree crops is deeply embedded in forestry policy. As a consequence, policy dictates that crop species must be released from competition by poisoning or otherwise destroying naturally regenerated tree seedlings, coppice shoots, shrubs, herbs and grasses. Simard's experiments in areas replanted after clear-felling old growth forest proved that cooperation, involving the sharing of resources, also occurs between individual trees of the same species and between different species. A dynamic exchange of nutrients between broadleaved trees, like alder or birch, and planted conifers, occurred with direction of flow changing at different times of the year. Her more recent work showed active transfer between mature 'mother trees' and younger seedling and sapling trees, both planted and naturally regenerated. The mature trees were not necessarily the actual parent, or female, but were 'mothers' in the sense of providing sustenance for the young trees.

Simard's recent book, *Finding the mother tree* [2] (reviewed in issue 64, page 39) offers a compelling case for ending 20th century forestry practises such as poisoning or removing competing trees, shrubs and other plants when planting commercial forests. Her experimental data also demonstrates why leaving some 'mother' trees standing, to help nurture the next generation

Above: Pine seedling inoculated with the 'false truffle' *Rhizopogon*, an ectomycorrhizal fungus that forms extensive white rhizomorphs (root-like mycelium) in soil.
Right: A tripartite mycorrhizal network connecting pine roots, the translucent hyphae of the crust-forming ectomycorrhizal fungus *Tulasnella*, and the underground 'ghostwort' *Aneura* from the shores of Loch Affric. The pine exchanges carbohydrates for mineral nutrients with the fungus, and the ghostwort gets some of those pine carbohydrates via the fungus.
Photos: M. Bidartondo.

makes practical sense. What it does not dwell on is how these critical transport pathways work. For this level of detail you are directed to the other 'book of the year' (if not decade), Merlin Sheldrake's *Entangled life* [3]. Sheldrake is a brilliant advocate for fungi and he has made it his mission to explain in plain English how much we owe to the fungal kingdom for the 'ecosystem services' that it provides.

Protect the web

Simard and Sheldrake provide us with a powerful image of a brightly-coloured web formed by fine fungal filaments, extending out in every direction through the soil layer beneath our feet, connecting with and incorporating the roots of trees and other plants, on a landscape scale. As well as being scientifically correct this concept of a network spreading through the earth, with no heed to borders and with the sole purpose of sharing resources and communicating for the mutual good of the community, is also quite poetic. Those of us who were taught to believe that competition was at the heart of what makes the world tick must think again in the light of research that shows trees helping their neighbours, including those they are not related to and even extending to members of other species. If symbiosis and mutualism are dominant forces within nature we must consider what implications this has for growing food and managing forests.

We know that a natural woodland is a diverse ecosystem but can we appreciate how diverse when our knowledge of the fungi on most sites is limited to the species that produce fruiting bodies (mushrooms) and we know next to nothing about the fungal mycelia that make up the bulk of biomass below ground? Our level of ignorance extends deeper in the soil as we consider the incredible diversity of micro-organisms, many of which work in as yet unstudied symbiotic relationships with mychorrhiza systems to recycle nutrients. Suffice to say that from what we do know about the wood wide web and its role in distributing essential materials and communicating between members of the community, we would do well to avoid disturbing it as much as possible. Yet traditional gardening and agricultural techniques such as double digging and deep ploughing aim to maximise disturbance, literally turning the soil profile upside down. Chemicals applied to the above-ground surface of plants or applied to seeds before sowing, wash into the soil or are released as residues breakdown. The effect of this cocktail of herbicides, pesticides and fungicides on the below-ground biome is not understood but we can assume that it is rarely benign.

Just the beginning

It seems sensible to apply the precautionary principle here: as we are only beginning to learn the important role played by mycorrhizal fungi and symbiotic micro-organisms in the establishment and development of plants, we should aim to manage soil in a way that promotes the health of these organisms and minimises disturbance. In his most recent manifesto, *Silent Earth* [4], Dave Goulson argues that more of the international agricultural research effort needs to go into investigating alternatives to chemical agriculture, such as organic horticulture, permaculture, agroforestry and biodynamics. The critically important relationships between cultivation, chemical applications, resource distribution and mycorrhizal fungi demand more scientific study.

Simard, at a point in her career when she could have sat back on her laurels, embarks on another line of research to track the mycelial pathway of nitrogen which is transported by Pacific salmon from the ocean via rivers and then, with the help of bears, through the forest hinterland and into trees. The concept of salmon fertilising the forest will not be new to many Journal readers (for example, see Feeding an ecosystem in issue 59, page 11) but Simard wants to determine how far nitrogen can travel from where the bears deposit spent fish carcasses to where trees absorb it through their roots. In other words how far do the fungal highways extend through the forest? Her current research project, which is being carried out in collaboration with other university scientists and Indigenous people from the Tsimshian and other Nations, demonstrates how much there is still to learn about the role of fungi within the ecosystem that will be essential if we are going to protect the global forests from the many and increasing pressures they face.

References

1. Simard, S. W. *et al.* (1997). *Nature* 388, 579–582.
2. *Finding the mother tree: Uncovering the wisdom and intelligence of the forest.* Suzanne Simard, Allen Lane, 2021.
3. *Entangled life: How fungi make our worlds, change our minds and shape our futures*. Merlin Sheldrake, The Bodley Head, 2020.
4. *Silent Earth: Averting the insect apocalypse*. Dave Goulson, Vintage, 2021.

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An ectomycorrhizal fungus sheaths pine roots resulting in a mass of short and highly divided root-tips. Bundled threads of the fungus can be seen to the front and right forming cords spreading through the litter layer in search of nutrients. These root-tips can easily be found by rolling back and searching under decaying logs. Photo: David Genney.