Letter from the Desk of David Challinor
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A few decades ago there were several articles in the popular press about people who talked to plants. I do not recall exactly what was spoken or the plants' response offered to these monologues, but what I do know is that the response was not verbal. Nonetheless, Gertrude Jekyll (1843-1932), the great English garden designer, is reported to have believed that plants had "ears," and once determined the location of a grove of trees by appealing "to the little trees themselves and see what they had to say about it."[1] At about the same time, there were several books that reported humans talking to dogs and horses with some astounding results. All this may be reasonable from the human point of view; mammals and birds have evolved to hear sounds and the audible range of a human voice is surely heard by most of these creatures. For centuries, verbal commands such as "gee" and "haw" directed dog teams and yoked oxen to turn either right or left. Nonetheless, certain plants, despite having neither ears nor vocal chords, can successfully communicate with each other. This month's letter will consider some of the plants scientists have discovered that can effectively communicate with one another and even with unrelated neighboring plants. Plant-human communication I will leave to those who believe and practice it.

Most plants, once rooted and growing, are relatively immobile, although streamside willow and alder, which are occasionally washed out by flooding, can re-root successfully on downstream banks. To extend their range, most plants have to rely on their seeds being moved by external forces such as wind, animals and flowing water. There is no evidence yet that upstream plants can warn their conspecifics that a flood is on the way because such a warning would be useless (evolutionarily) as the downstream plants could do nothing to protect themselves. What some plants can do, however, is to warn their downwind neighbors that they are being attacked by foliavores (leaf-eaters) so that the latter can prepare their defenses.

A recent elegant experiment confirming this warning capability is reported in *Ecology* (Karban, R., K. Shiojiri, M. Huntzinger and A.C. McCall. 2006 *Damage-Induced Resistance in Sagebrush: Volatiles are Key to Intra and Interplant Communication*. *Ecology* 87 (4): 922-930). Sagebrush (*Artemisia tridentata*) is the dominant plant of the US's western Great Basin, where in some places it makes up > 90% of plant biomass. Its small-leafed, grey-green foliage is easily recognized and it often grows in pure stands. At both California sites studied, sagebrush foliage was heavily consumed by insects during spring after snowmelt and again in the fall by mule deer. In summer the principal foliavores are grasshoppers.

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[1] Jane Brown (1994) *Gardens of a Golden Afternoon—The Story of a Partnership: Edwin Lutyens and Gertrude Jekyll*," Penguin Books, London p.50.

The main experiment consisted of manually clipping sagebrush leaf ends with scissors to emulate herbivory. By carefully measuring downwind distance to neighboring plants, the scientists determined that when sagebrush were separated by < 60cm (2 feet), statistically, the downwind plant became significantly (50%) less damaged by herbivores than those downwind of unclipped plants. The clipped plants emitted large quantities of volatile methyl jasmonate. The mechanics of the receptors in the downwind plants to the jasmonate are still not clear, but the receptors certainly are effective. The released volatiles peaked four hours after the leaves were clipped, triggering the downwind plants to become more resistant to herbivory within five days of exposure, and they continued this resistance for the rest of the growing season.

Even more remarkable is that sagebrush performs the same function for tomatoes (as shown by greenhouse experiments) and for wild tobacco (*Nicotiana attenuata*), which often grow in proximity to sagebrush. However, tests on other neighboring leafy plants such as lupine and valerian showed no resistance to herbivory from high levels of airborne jasmonate. Tobacco and tomato, incidentally, are both in the Solanaceae family. Clipping the leaves of wild tobacco has no resistance effect on downwind tobacco or any other plant tested so far.[2]

Sagebrush is not the only plant that releases clues such as jasmonate to warn its neighbors to protect themselves from herbivore assault. Eurasian alder (*Alnus glutinosa*) that are growing near a conspecific that is being attacked by its major herbivore, the alder leaf beetle, receive an airborne clue to produce more substances that make their leaves unpalatable.

The same wild tobacco plant that can eavesdrop on unrelated nearby sagebrush to prepare its resistance to herbivory has also evolved another novel defense system to compensate for simulated herbivore attacks. Ian T. Baldwin and his colleagues at the Max Planck Institute have shown that when attacked by herbivores early in its development, wild tobacco can increase allocation of sugars to its roots. The plant uses this reserve to prolong flowering and thereby be in a better position to tolerate its leaves being eaten by shifting its reserves to its roots; they are evidently better protected than its leaves.

How plants defend themselves from attack by herbivores is still only partially understood because they employ multiple techniques, most of which are invisible to humans, such as the jasmonate volatiles released by sagebrush. Among the most detailed studies of plant/insect interactions is one on North American milkweed.[3] I learned that there are about 130 milkweed species growing in our continent, and another 200 or so

[2] Karban, R., M. Huntzinger and A. McCall. 2004 *Ecology* 85(7) pp.1846-52.

[3] In Agrawal, A.A. and M. Fishbein. 2006 Plant Defense Syndromes. *Ecology*. 87(7) Supplement: pp.S132-S130.

species of various African milkweeds. The plant genus *Asclepias*, named for the Greek god of medicine, is most easily identified by the milk-colored latex that oozes from its leaves or stem whenever one of the specialized canals that deliver the sticky latex to most plant parts is severed. Not only is the copiously exuded latex sticky, but it also contains cardenolides (bitter-tasting steroids) that are toxic to most animals. Milkweed thus uses multiple defenses to protect itself: sticky latex, toxic cardenolides and tough leaves covered with trichomes (fine hairs). Despite all this, a common milkweed (*A. syriaca*) growing around Washington, D.C. has at least a dozen different insect predators—aphids suck the phloem cells, several beetles and caterpillars eat the leaves, weevils penetrate the stem to eat the pith, and beetle larvae enter the roots to feed.

Despite milkweed's well-known defenses against insects, the latter have managed to overcome most of the safeguards. For example, when Monarch caterpillar larvae first hatch, they eat the hairy trichomes on the milkweed's leaf. Then they bite in a circle through the laticifers (the ducts that carry the sticky latex through the plant). In a relatively short time, the surrounding latex oozes through the severed ducts allowing the small caterpillar to eat the drained leaf tissue within the circle of cuts.

No matter what defenses an organism evolves to protect itself, a predator will come along with a way to penetrate them. Examples abound: oysters have thick protective shells and a strong adductor muscle to keep them clamped shut, yet the small oyster drill (a mollusk about the size of a periwinkle) can drill a hole through the oyster shell to feed on the internal soft parts. Even the quills of a porcupine will not protect it from its principal predator, the fisher (a large arboreal member of the weasel family), which has learned to flip them over to bite the quill-free underbody.

There are innumerable other ways that plants and trees can communicate and one worth a future "Challinor Letter" is root grafting. Such grafts are common in forest-grown trees and often occur between different species, so that a radioactive tracer injected into one tree can turn up quite unexpectedly in another tree through natural root grafts. Groves of American beech are in a special class of their own; often every tree in the grove is connected by the roots. These connections are not only by grafts, but by the American beech's habit of sprouting suckers from their root systems. By drawing on the nutrient reserves of the surrounding mature beech, the sprouts grow rapidly. The downside of these wide-spread root connections is the vulnerability of the connected stand to attack by viral or fungal pathogens. Should one tree become infected, the pathogen could spread to all the other trees connected by root grafts.

Of all the interactions between prey and predator and within each group as well, the emission of volatile jasmonate by sagebrush when its leaves are being eaten is near the top of my list as the most extraordinary communication technique for mutual defense. Still hidden from human sight, however, must be myriad other bizarre ways that plants communicate. How do individual species of bamboo, planted by humans in all appropriate parts of the world, synchronize their flowering? We have no idea what the mechanism is. For some bamboo species, flowering can occur at intervals of almost a century. So many questions have yet to be answered; generations of botanists, entomologists and zoologists of every stripe will always have an unending supply of natural secrets to uncover. The curious scientist who studies these has been and always will be, I believe, an essential and crucial component of human culture.

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