Why Are Coast Redwood And Giant Sequoia Not Where They Are Not?[1]

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Abstract

Models predicting future climates and other kinds of information are being developed to anticipate where these two species may fail, where they may continue to thrive, and where they may colonize, given changes in climate and other elements of the environment. Important elements of such predictions, among others, are: photoperiod; site qualities; changes in levels and yearly patterns of temperature, wind, fog and precipitation; the effects of these on interactions with other biota at each site; the effects of changes in fire frequency and intensity; the availability of seeds and seed vectors; and the effects of human activity. Examples are presented, with focus on fire and human activity. Natural migration may need assistance. Establishing groves far from the native ranges is advocated.

Keywords: assisted colonization, assisted migration, climate change, fire, *Sequoia*, *Sequoiadendron*

When preparing this talk and then paper, it became increasingly clear that it is more of an Op-Ed than a comprehensive review, and is meant for people interested in and familiar with coast redwood (*Sequoia sempervirens* (D. Don) Endl.) and giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchholz). Thus, four background references are provided, and they in turn provide detail on many of the topics covered. The final two references provide background on future speculative scenarios. Possible responses to such future scenarios are suggested.

Coast redwood's current natural latitudinal range begins with discontinuous canyon-bottom populations near the southern Monterey County border, extends north through increasingly-continuous coastal and generally-separated interior populations, and stops just north of the Oregon/California border. Where a gradient in ecological conditions becomes limiting for a species, individuals near that edge of the population usually grow less well than individuals growing in more-optimal conditions. But rather than its trees being less healthy near that northern edge, those redwoods are among the largest and most robust in its entire range, suggesting that conditions just beyond the current northern species edge would also support healthy and vigorous growth of redwoods.

Pollen deposits and other fossils indicate that redwood used to live south of its current southern population, with extirpated populations near Santa Barbara and even La Brea, and also farther north on the Oregon coast. A few planted redwoods are currently growing reasonably well in the Los Angeles Basin and, although redwood's native range stops abruptly at its northern edge, planted redwoods are thriving in some favorable locations as far north as Vancouver Island, British Columbia.

Giant sequoia's native range has a similar but latitudinally inverted pattern. Its closely-spaced native groves and largest trees are in the southern Sierra Nevada, where the climate is hotter and apparently drier than in sequoia's few and widespread more-northern native groves.

Recent fossil evidence, mostly layers of pollen deposits, indicates that sequoia has been at higher elevations during the warmer period 6,000 years ago, and lower than it is now during the last ice age. But there is no evidence of it recently or ever being north or south of its present groves within California. And like coast redwood, planted sequoias are thriving over a substantially greater

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latitudinal range, from southern Spain to part-way up the coast of Norway in Europe, and in many locations in western North America from southern California's San Bernardino Mountains to northern Oregon and beyond. Yet, there are no native sequoia groves in the Cascades and northern Sierra, and only a few in the central Sierra.

Using climate data from the native ranges of these two species, and from sites with observed performance of their planted trees in other climates, we now have a pretty good idea which climates are permissive for redwood and sequoia to survive and thrive, which are marginal for them, and which of the much larger range of climate conditions are exclusionary. If even just-modest summer rainfall is reliably well-distributed through the summer months, both species can thrive with as little as 700 mm of annual precipitation. But if summer rains are inadequate, redwood may rely on summer fogs and both species thrive on apparently-good soils with favorable hydrology supplying groundwater. Perhaps surprisingly, many well-established planted sequoias exposed to temperatures of -28 ^{o}C have survived in northern Europe, as have a few planted redwoods in southern and central Europe, and planted redwoods in California's Central Valley exposed to brief episodes of +50 ^{o}C also have survived.

So why don't they naturally occur in more of those permissive climates? First, they have to get there and, if the colonists establish, they have to successfully reproduce. For example, redwood plantations are thriving in several locations between about 1,000 and 2,000 m elevation in Hawaii. However, in remote Hawaiian plantations, thriving redwood trees fail to produce cones and (apparently) pollen. (Nearby redwoods do produce abundant cones in the presence of light breaks from buildings or automobile headlights during the night, so photoperiod seems to be important for redwood's sexual reproduction.) And of course it would have taken a strong wind or bird to get some viable redwood seeds to Hawaii naturally.

Having arrived and successfully reproduced, there may be resident insects and pathogens that harm them. For example, planted sequoias are often deformed or killed by redwood canker, a stress disease caused by the fungus *Botryosphaeria dothidia*, that infects them in near-coastal California. For reasons still unclear (to me, at least), the severity of *Botryosphaeria* damage on planted sequoias decreases with increases in elevation and latitude in both Europe and North America. It is quickly lethal on planted sequoias near sea-level in southern France, but is either benign or absent near sea-level in Denmark and Norway. In California and southern Europe, *Botryosphaeria* is not a problem for native or planted sequoias above about 800 m elevation.

Colonizing seedlings have to compete with the local vegetation. Serious competitors sequentially range from ferns, forbs and grasses to aggressive brush to other tree species, especially those trees that start faster from seed or can thrive in more shade than redwoods and sequoias can. (Small established redwoods and sequoias can *endure* many decades of overtopping shade, but unless root-grafted to overstory trees, they do not thrive unless they have full or nearly-full sunlight.)

The following observations were told to me several decades ago by Jim Rydelius, and were catalytic in my thinking about why these two species are not occupying apparently-permissive sites near their current native ranges: In the late 19th and early 20th centuries, as extensive areas of redwood forests were increasingly being harvested, ranchers often attempted to convert the newly-cut forests to grazing lands by burning the logging debris and sowing grass seeds. But many of the redwood stumps vigorously sprouted, and in typical cases many seedlings of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), plus a few of redwood and other conifers such as grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don) established in spite of the grass. After a few years, the ranch-hands cut the encroaching young trees and then again burned the site after the grass and felled slash had dried. Each such fire killed the seedlings of the other conifers, but the redwood stump-sprouts resprouted, the larger ones producing 'fire columns' sprouting from their scorched boles. The recently-established redwood seedlings also sprouted, usually from the root-collar burl below their burned-back stem. New seedlings of Douglas-fir, redwood, and other conifers often established the following spring, but the redwood sprouts were already vigorously growing in advance of the new germinants. This process may have been repeated several more times before the rancher gave up and, in most cut-and burn cycles, additional redwoods had survived the fires. In this way, the percentage of redwood in the new forest became increasingly greater than it had been in the previous native stand, and the new redwoods enjoyed a root-size and sprout-vigor advantage over the competing conifers, which had to start over with new seedlings after each fire.

It seems possible, even likely, that as climate warms, fire severity and frequency will increase in both coastal Oregon and in the Sierra-Cascade Mountains, and the monsoons that sometimes bring useful summer rains to the southern Sierra may also become more frequent farther north. Intense stand-replacing fires may more-frequently be followed by repeated mild fires that retard competing conifers, while colonizing seedlings of both redwood and sequoia thus gain a competitive edge by sprouting and then resprouting following the subsequent fires. Increased fire intensity and frequency resulting from a rapidly warming climate may facilitate the recolonization of redwood into coastal Oregon, and the recolonization and new colonization of sequoia not only onto additional sites in the central and southern Sierra, but even into the northern Sierra and southern Cascades.

Both redwood and giant sequoia have migrated great distances in the past, and fires have probably been important facilitators of those migrations. A new natural colonization would not happen after every intense stand-replacing fire near an established population, because seeds would have to blow in, or maybe be brought in cones by such animals as squirrels, followed by favorable weather for their successful germination and establishment. Germinating seedlings of both redwood and sequoia are unusually susceptible to damping-off fungi, which are common in many soils and are killed by hot fires. Giant sequoias, in particular, retain many years' production of seeds in closed cones, which open and massively release seeds following hot fires.

It is pretty clear that natural migration by colonization of new sites is a hit-or-miss process that operated over long periods of time. Redwoods and giant sequoias have been able to thus far survive several events or conditions that led to the extinction of many other species. They have repeatedly migrated when necessary to places where they then continued to thrive. Very recently, they produced forests that inspire pleasure and awe in the humans that visit them.

Native Americans have lived in or near redwoods and sequoias for over 10,000 years, and some of them have done a pretty good job of managing the native groves with frequent burning. But there are now (mostly European-origin) American humans in the picture. Some of them create new problems, as important examples: by converting (particularly redwood) forests to such things as vineyards and/or permanent structures; by emitting greenhouse gases that rapidly warm climate; and by forest practices that favor shade-tolerant species that then outcompete and thus replace redwoods and sequoias. But some people in that high-impact invasive population of (particularly but hardly exclusively American) humans are concerned about the future of redwoods and sequoias, and are or could be doing something about it. Knowing what seems to impede their natural colonization and range extension helps some of the current humans who care about them help them continue on Earth.

There is no doubt that humans can successfully plant and husband redwoods and sequoias outside of their current native ranges. Some, most notably Sierra Pacific Industries with sequoia and, more modestly, Archangel Ancient Tree Archive with redwood, have recently been doing that with samples of sequoia and redwood from known origins of both single and multiple native-populations. They and others have the stated intention of providing and then planting new locations for redwoods and sequoias to grow and thrive, and doing so in time scales of decades rather than the centuries or millennia it historically has taken these two species to migrate long distances naturally. We have been calling such dedicated planting programs 'assisted migration', and even 'assisted colonization' when the trees successfully reproduce and a population naturalizes on and near the planted site.

It seems that it may take unacceptably long times for redwood and giant sequoia to naturally migrate to safer sites in response to unusually-rapid climate change and other changing environmental stresses, even if a warming climate results in more fires that facilitate their migration. However, helpful humans could and are successfully assisting in their migration and sometimes colonization, including locations far outside of their current natural distributions. So why do we need to be concerned about the natural ability of redwood and giant sequoia to migrate?

One answer is that we cannot be sure that active planting of these species will always be done in the future. It is conceivable that,-following some catastrophic disaster, few or no surviving helpful humans will be available to continue planting forests. The effects of such a catastrophe may last for centuries or even millennia before the survivors reorganize and again establish the social and technical ability to plant and husband redwood and sequoia. Today, though, some humans have the knowledge and ability to expand these species' distributions, to thus add to their natural migration and better ensure their survival in the uncertain future.

How might-entire regional forests be destroyed, or altruistic forest management be abandoned, either regionally or worldwide? Since the 1945 nuclear bombing of Hiroshima, apocalyptic worriers have accumulated some pretty realistic scenarios. We've learned that a collision with an asteroid has caused widespread loss of species and might do so again. And here are two (among several) examples of possible new self-inflicted catastrophes with contrasting implications for the future of redwoods and sequoias.

A massive use of nuclear weapons between or among the current nuclear powers may occur. Such madness will likely kill most or all humans and other living things in targeted regions, including redwoods and sequoias. The current distribution of nations with nuclear capability makes it likely that such madness will mostly affect the Northern Hemisphere, and people and forests in the Southern Hemisphere will survive. It may then take many decades or even centuries before people can again safely inhabit the northern half of Earth. There is already a magnificent 106-year-old grove of redwoods in Rotorua, New Zealand, a somewhat younger but faster-growing redwood grove near Taumarunui, New Zealand, other such planted groves might be found and dedicated, and assisted migration could establish additional groves of redwoods and sequoias in Chile, Pategonia, Australia, New Zealand and South Africa in advance of such a hemispheric extirpation.

A historical example is the 14th through 18th century black plague pandemics, which not only killed a lot of people, but also disrupted the social, political and commercial structures of nations and regions. The black plague is even credited with saving European forests. Many 14th century European forests were being converted to other uses by rapidly growing human populations and resulting commercial exploitation. The plague pandemics greatly reduced those human populations and their needs for agricultural land and wood, and forests then reclaimed much of the land. An engineered weaponized pathogen, if it is released or escapes, would likely be more efficient than the black plague was in quickly spreading and then killing humans. But, like the black plague, it would probably leave most of Earth's biota essentially intact, and perhaps even better off. And, as in most pandemics, a few humans might be resistant or escape the disease, begin to repopulate Earth, and their progeny would eventually again visit and appreciate groves of enormous redwoods and sequoias. In this scenario, conserving and perhaps expanding the redwood and sequoia populations in North America, plus some additional groves in Europe and Asia, would have been good enough.

Such an apocalyptic catastrophe may not occur for a long time, or at all. Meanwhile, in the near future, Earth's human population will continue to increase, as will population-related problems and stresses. It is noteworthy that the United Nations held one of its founding ceremonies in a Muir Woods redwood grove, probably because humans find not only pleasure and awe in such groves, but many also gain perspectives on time and feelings of peacefulness and well-being. Additional such magnificent long-lived groves of redwood and sequoia in many places on Earth could serve its hopeful future in possibly important ways.

There are at least two options for new human-assisted groves. One is to sample and thus nearly duplicate only one redwood population or sequoia grove per new planting, thus conserving the genetic structures of the different native populations and groves. A second is to combine samples of many populations or groves per new planting, thus increasing the genetic variation in the new plantations and thereby increasing their ability to better adapt to different environments.

There are many locations far outside of their native ranges where redwood and/or giant sequoia could thrive and grow to become magnificent groves. Why they are not now on such sites has until recently been because they could not get there naturally. But now that assisted migration is technically possible, human motivation and competing demands on those sites will guide the future. If enough new groves are established, it is likely that some will be in the right places to thrive and reproduce even in substantially changing conditions. Such assisted colonization seems like a good thing to do, whether or not humans survive (or other sentient creatures evolve) to appreciate these two magnificent species.

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