Intentional forests: growing hope for the future

MARIE E. ANTOINE and Professor STEPHEN C. SILLETT, from California State Polytechnic University, Humboldt, have been studying the world's tallest and largest trees for over two decades. Here they share some of the results of their research and suggest ways ahead.

We study trees and forests. Coast redwood, giant sequoia, Douglas-fir, Sitka spruce. The four tallest conifers have been our main focus for over two decades. A recent article in Forest Ecology and Management (Sillett *et al.*, 2021) covers what we have learned. This represents a capstone on science spanning half a career, prompting a certain vein of reflection.

Why devote energy to climbing, measuring, and understanding trees? Yes, people love trees. They are engrained in our evolutionary history and cultural expressions. Their resilience inspires. We walk in awe of the forests they create. But is it really worth risking our lives to decipher a tree's rate of biomass production? Amidst the world's current clamor and calamities, does our work even matter?

One thing is certain: good work is important now more than ever, whatever the work. Overall, the world's problems seem overwhelming, but hope exists in the details. Big problems are made of smaller problems, which can be broken down into ever smaller problems. Eventually we find a problem whose scale allows a solution. What are your talents? What problems can you help solve? We choose trees.

Trees alone cannot solve the world's big problems, but they can solve many smaller problems. In this context, the pursuit of understanding trees is not esoteric. Basic knowledge of tree performance can inform how we manage them for the mutual benefit of human and nonhuman species. What have we learned about the four tallest conifers, and how could this amplify the problem-solving potential of trees?

There are few organisms as incredible as giant trees. Consider the sheer magnitude of what they accomplish over their lifespans. A tiny seed finds a nook for germination. The seedling connects its roots to symbiotic soil fungi. The sapling forages for resources (light, water, nutrients) to thrive. The treetop grows hopefully ever upward. The trunk and appendages thicken inexorably as new wood is deposited annually. Year after year this continues until someday there stands a forest giant. The lifespan of a tree may be long enough for human civilizations to rise and fall.

Trees bear witness to the passage of time with increasing size and structural complexity. Dead spire tops, replacement trunks, and gnarly limbs arise after crown damage, and as trees age, they become recognizable as individuals.

Figure 1 Primary forests dominated by *Sequoia sempervirens*, such as this example from Redwood National Park, California, hold global maximum aboveground biomass (up to 4,340 metric tons per hectare), carbon storage (up to 2,200 metric tons per hectare), and leaf area (leaf area index > 20). These are also the world's most productive primary forests, producing up to 19 metric tons of aboveground biomass annually, 80% of which is decay-resistant heartwood.

This concept was superbly illustrated in *National Geographic Magazine* with portraits of coast redwood (October 2009) and giant sequoia (December 2012). Ultimately, our obsession with remarkable individual trees set the stage for what followed in scientific research.

Our team's early work was associated with adventures in forest canopy exploration, some of which were documented in Richard Preston's *The Wild Trees* (2007). Tree-climbing techniques evolved rapidly with the logistical challenges of working high above the ground. Each new ascent promised discoveries in a largely unknown realm. Coast redwoods, for example, can hold car-sized fern mats that are home to salamanders and aquatic crustaceans—who knew?

Documenting biodiversity meant we needed to measure tree structure. Early tree-mapping efforts showed the link between structural complexity and arboreal biodiversity. Relatively few structurally elite trees support the bulk of creatures inhabiting the primary rainforest canopy. We use the term primary (instead of old-growth) to describe forests untouched by logging and the term secondary (instead of second-growth) for those regenerating after logging.

Quantifying tree structure required estimating biomass of wood, bark, and leaves. Since predictive equations from industrial forestry were unsuitable for the enormous trees in primary forests, we set into years of painstakingly detailed crown mapping. For coast redwood alone, 80 trees had every branch measured for height, diameter, and such. A small subset of branches was removed for dissection down to individual leaves. If that sounds like a whole lot of tedious work, it was, but necessary.

Those efforts resulted in comprehensive spatial datasets for the four tallest conifers. Our new equations accurately estimate biomass of aboveground tree components with just a few ground-based measurements. Happily, this did not involve destroying study trees to quantify them. Nearly all are still thriving and available for future consultation.

Studying tree performance over time led to us to core sampling and tree-ring analysis. In temperate forests, trees neatly store their growth histories in annual rings. We sample these rings by extracting thin cores of wood from trunks at multiple heights. Ring widths combined with trunk diameter measurements and the aforementioned equations allow reconstruction of tree size and growth back through time with annual resolution. This means we can frame current tree performance in a long-term context.

All these research avenues converge in our latest scientific article (Sillett *et al*., 2021). We consider what is known about aboveground development in coast redwood (*Sequoia sempervirens*, Figure 2, opposite) and giant sequoia (*Sequoiadendron giganteum*, Figure 3, page 59), collectively known as redwoods, plus Sitka spruce (*Picea sitchensis*, Figure 4, page 61) and Douglas-fir (*Pseudotsuga menziesii*, Figure 5, page 63). The four tallest conifers are endemic to western North America but widely celebrated and planted globally.

Data used for the four-conifer comparison came from several projects. The 169 study trees ranged from 24 to 116 meters tall and 39 to 3,298 years old. Tree mapping involved 55,000 diameter measurements, and 3,071 wood cores were collected with 580,000 rings analyzed. By comparing long-term tree development, we establish realistic expectations for tall forests managed for non-timber values like biodiversity conservation and carbon sequestration.

Understanding trees begins with photosynthesis in leaves, where water and carbon dioxide are converted to sugars and oxygen in the presence of sunlight. Carbon-based sugars are the building-blocks with which trees make new tissues and invest in their protection. Since a tree's annual sugar budget is finite, a balance is struck between making new roots, leaves, bark, and wood and giving them chemical or physical resistance against corruption. Fire and decay are two main factors curtailing the life of a tree.

Bark is a tree's first line of defense against fire. The two redwood species invest heavily in fibrous resin-free bark on their lower trunks. This allows them to survive repeated scorching by low- to moderate-intensity fires. Giant sequoia is superbly adapted to the frequent fires of their Sierra Nevada habitat prior to widespread fire suppression. Douglas-fir and Sitka spruce invest less in bark production, and both are easily killed by burning. In coastal rainforests

Figure 2 Coast redwood (*Sequoia sempervirens*), which stands up to 116 meters tall, can live over 2,000 years by virtue of strong resistance to fire and decay. Here is one of the largest specimens with Marie for scale.

where Sitka spruce thrives, risk of fire is low, so investment in rapid growth makes more sense than investment in thick bark for fire protection.

Durability of a tree also depends on how much it invests in chemical protection of its wood. Redwoods are named after the color of chemicals that provide their heartwood with strong resistance to fungal decay. These compounds may be metabolically expensive to produce, another investment in defense over rapid growth. Sitka spruce heartwood is poorly protected against fungal decay, whereas Douglas-fir has moderate protection. Both these non-redwood species may grow tall more quickly than redwoods because they invest less in heartwood protection.

Competing priorities of growth versus durability have important consequences; rapid growth comes at the expense of longevity. Sitka spruce reaches near-maximum size and maximum productivity after only two centuries. It can make appendages a meter thick in only 300 years. This is larger than any on Douglas-fir and as large as those on coast redwood twice as old and giant sequoia three times as old. Appendages are a tree's branches and limbs. The larger an appendage, the more useful it becomes in supporting arboreal biodiversity.

Sitka spruce and Douglas-fir make ecologically significant appendages sooner, but greater investment in protection gives redwoods the staying power to become the gnarliest trees on Earth. It might take a millennium for coast redwood or giant sequoia to make a limb more than a meter thick, but these are built to last another millennium or two. In primary rainforests, enormous coast redwood limbs support loads of arboreal soil. This enhances canopy water storage and provides critical habitat for plants, animals, and fungi. The biggest, oldest trees have the most ecological impact.

Across all four species, annual biomass production increases with tree size. Larger trees have more leaves for photosynthesis and more surface area across which bark and wood are deposited. This does not mean a tree will go on producing more and more wood until the moment it dies. The positive correlation between tree size and biomass production holds true until the effects of old age take their toll.

Old age in trees is not analogous to old age in humans. Trees die from accumulated injuries through outside influences such as wind, fire, insects, and decay. As trees age, they have to invest ever more of their annual sugar budget to priorities other than building roots, leaves, bark, and wood. Large old trees have higher metabolic costs associated with repairing damage and making resin and toxins for defense. Consequently, growth efficiency (amount of biomass made annually per unit leaf mass) decreases with age in all four species. The decline is fastest in Sitka spruce followed by Douglas-fir, coast redwood, and giant sequoia; in the same sequence as longevity.

Declining growth efficiency eventually results in a decreasing rate of biomass production at the tree level. When growth efficiency falls too low, a tree

Figure 3 Giant sequoia (*Sequoiadendron giganteum*), which stands up to 96 meters tall, is the longest-lived of the four conifers by virtue of unrivalled fire resistance and extremely durable heartwood. This enormous limb emerges from a trunk 44 meters above the ground, where it is over two meters diameter and approximately 3,000 years old.

will lose biomass and its crown will crumble into ruin; decay fungi and gravity win! What ultimately kills a tree is not old age itself but rather structural collapse due to the cumulative effects of damage from external agents and the tree's inability to mitigate the damage. This tendency towards collapse occurs most quickly in Sitka spruce, which rarely reaches 400 years. Douglas-firs over 700 years old are exceedingly rare. Heavier investments in protection allow coast redwoods to exceed 2,000 and giant sequoias to exceed 3,000 years old. What does all this mean for forests?

It is important to distinguish between tree-level and forest-level inferences. The biggest trees can have the highest individual rates of aboveground biomass production (up to 1,000 kilograms dry mass annually). However, productivity of primary forests is limited by a low density of big trees. Over the course of forest development there are ever more leaves on fewer and larger trees. A secondary forest densely stocked with small trees can produce more biomass annually than a primary forest. This physical reality has long been used as an argument for logging 'decadent' primary forests. Of course, biomass production is but one measure of a forest's value.

Consider two of the major challenges we now face: biodiversity conservation and anthropogenic climate change. The four tallest conifers have unrealized potential to help on both fronts. But let us be realistic: trees alone cannot solve these problems. Slowing extinction rates and mitigating atmospheric chemistry will require societal-scale changes in land use, fossil fuel consumption, and willingness to reexamine our collective actions. In the meantime, trees can help.

Primary forests, generally, are biodiversity refugia and massive carbon sinks. Every bit of these remaining forests should be protected. Primary forests of the four tall conifers now occupy only a tiny portion of the landscape. These forests store record-breaking quantities of carbon, often in decay-resistant heartwood, and giant trees provide critical arboreal habitat. Primary forests show what is possible. If we want trees to help us, then we need to help trees.

Intentional forests can scale up the hopeful potential of trees. Just as intentional living is the idea of making life choices to support your fundamental goals and values, intentional forests are stands of trees carefully tended with specific goals in mind. Obviously, the idea of managing trees and forests for particular purposes is not new. Timber and fiber plantations are intentional forests of a sort that can effectively ease societal pressures on primary forests. Conventional forestry and the management of these lands is outside our scope here.

What we suggest is more careful attention paid to individual trees with consideration of ecological functions far beyond a typical rotation age (the interval between planting and logging). From city parks to recovering timberlands, opportunities abound for intentional forests. These forests could be planted anew or nurtured through large-scale restoration efforts. With appropriate planning and careful tree selection, intentional forests we create now could still be making the world a better place in a thousand years.

Imagine an intentional forest with a subset of dominant trees placed in favored positions. These trees would have the best chance for rapid growth and appendage development. Let us call them potential elder trees (PETs). Periodic selective logging of smaller neighbors could be used to maintain uncrowded groves and thereby promote PETs. Trees are incredibly responsive. Pamper the PETs, and they will grow large relatively quickly.

A few big trees make an enormous difference at the forest level in terms of hosting arboreal biodiversity. Bigger trees also make more wood and invest more in decay-resistant heartwood than smaller trees, so the biggest individuals are carbon-sequestration champions. How long the carbon remains sequestered depends on species longevity. PETs of various species could optimize both short-term and long-term objectives.

Intentional forests could be created and nurtured at various scales. At the

Figure 4 Sitka spruce (*Picea sitchensis*), which stands up to 100 meters tall, has the shortest maximum longevity (< 500 years) and is least protected against fire and decay. Here is one of the largest specimens in California with Steve for scale. Its massive limbs support sprawling mats of the evergreen fern *Polypodium scouleri*.

small scale, there are innumerable plots of land that could hold a few special trees. Imagine all the parks that could have PETs tucked into current landscaping or areas in need of restoration. It is worth examining public spaces and even our own yards in terms of habitat value and carbon sequestration potential. Careful planning and creative thinking with economic incentives could mean feasibility for a larger coordinated effort… City Park PETs, anyone?

Small-scale intentional forests could become sources of local pride and employment for generations. Tree planting, monitoring crown development, and tending to tree health all require active participation. This might be a deeply rewarding career prospect for many people. Incidentally, management instructions for long-term tree care must also include provisions for promoting belowground health. Root compaction and starvation is a common doom for urban trees. Tree by tree, park by park, we can grow hope for the future.

At the landscape level, forest restoration might include selection of a low density of PETs to be nurtured and retained indefinitely for conservation. The idea of intentional forests over a large scale is tricky because managing forests beyond rotation age has little financial incentive. It is notoriously difficult to assign monetary value to ecosystem services.

PET-tending would require paying more people to work in the woods. There is no simple answer to the question of how this might be funded. Carbon credits could provide some support. As PETs enlarge with age, they could be periodically remeasured to quantify how much carbon was gained since the last measurement. The value of biodiversity provisioning is more abstract. PETs will eventually become ETs (elder trees) as their expanding crowns develop ecologically significant appendages. Ideally, these biodiversity services would also be incentivized to ensure not only PET-tending but also ET-retention.

Integration of conservation and restoration efforts into social and economic systems could allow a transition towards post-industrial societies, where more people might make a viable living in services related to ecosystem health. If PETs and ETs were considered long-term commodities with increasing value over time, then tending to these trees would be an essential service. With intentional forests, we see the forest for the trees.

This effort could begin with inventories of existing PETs and ETs. We recently measured a 380-year-old coast redwood on a school property in Arcata, California, a remnant of the primary forest once covering the area. This tree produces 500 kilograms of aboveground biomass annually. Most of that is decay-resistant heartwood. Its complex crown is heavily used by birds and mammals. If a solitary ET can do this, imagine how much good could be done, collectively, by a thousand intentional forests.

These ideas are not restricted to the four tallest conifers. However, since we know what these four species can do over the course of their lifespans, they are useful as examples. A proviso is that tall conifers need temperate climates with plentiful rainfall. Sitka spruce is restricted to particularly wet sites. In appropriate forests, Sitka spruce PETs would provide the fastest possible development of ecologically significant appendages.

Where canopy biodiversity is climatically favorable, it can be directly promoted. Windstorms often knock down plants from the primary forest canopy (chunks of fern mats, for example). These fallen plants can be respectfully scavenged from trails and roadsides for transplanting into PET crowns by climbers. This simple manipulation will quickly create favorable conditions for boosting arboreal biodiversity.

The relatively short life span of Sitka spruce could be mitigated by providing opportunities for natural regeneration as well as planting to replace fallen trees. The eventual downfall of an ET would add value to the forest floor community as woody debris. Meanwhile, Douglas-fir, coast redwood, and giant sequoia PETs would provision for longer-term ecosystem services. There is something profoundly hopeful about planting a tree that could still be there two thousand years from now.

Coast redwood has incredible regenerative capacity. It is one of the few stump-sprouting conifers, which makes this species an ideal candidate for populating temperate forests of the future. The carbon locked up in its heartwood will resist decay for centuries to millennia if not consumed by fire. Other long-lived species within the same group (cypress family) might also

Figure 5 Douglas-fir (*Pseudotsuga menziesii*), which stands up to 99 meters tall, can live twice as long as Sitka spruce and is moderately protected against fire and decay. Here is one of the largest specimens with Steve for scale.

make great PETs for intentional forests dedicated to carbon sequestration.

The four tallest conifers are already widely distributed across the temperate world. In only a century, all four species have exceeded 60 meters as planted trees outside their native ranges. There are thousands of remarkable coast redwoods, giant sequoias, and Douglas-firs across mainland Europe, the UK, southeast Australia, and New Zealand. Often, they are the tallest and largest trees (Table 1). Many of these individuals are in botanical gardens and arboreta, intentional forests designed to conserve and celebrate plant diversity. Although largely composed of non-native species, these areas provide important habitat for local species, particularly insects and birds. The four tall conifers have tremendous global potential in hybrid and novel ecosystems.

This brings up the controversial issue of planting non-native trees. Let us be very clear: we are not advocating replacing native forests with stands of the four tallest conifers! Consider, however, that nearly three-quarters of Earth's terrestrial surface has been substantially modified by human activity. The conservation value of land is often dismissed unless it can be restored to a prehistoric state. In many cases, it would serve us well to recognize the inherent worth of human-altered ecosystems.

Cautionary tales abound with good-intentioned introduction of non-native species, and we should do our best to control invasive species. However, the scale and urgency of habitat loss and ecosystem degradation make it increasingly prudent to move away from simple dichotomies like natural versus unnatural and native versus non-native. For a thoughtful review of this contentious topic, see Hobbes *et al*., 2014.

Conservation efforts typically focus on protecting and restoring wilderness areas. This is unquestionably necessary and worthwhile. However, that should not be at odds with enhancing ecosystem health in creative and proactive ways on more heavily used land. Acknowledging the potential value of hybrid and novel ecosystems vastly increases the land area available for building healthy ecosystems. Including the four tall conifers by no means excludes native species from being planted into the same intentional forests.

So, what is to be done and where? We embrace the idea of One Earth, Three Conditions (Ellis, 2019), officially known as Three Global Conditions for Biodiversity Conservation and Sustainable Use (Locke *et al*., 2019). This project is based on an intensive assessment of land use across all of Earth's land area except Antarctica. It provides a logical framework for considering appropriate management strategies with the big picture in mind. Here is synopsis of the three conditions and how intentional forests might be relevant.

The most altered and intensively used places cover about one-fifth of Earth's land area (18% in Condition 1, Locke *et al*., 2019). These are cities and farmlands where human populations are concentrated and most food production occurs. Land is fundamentally transformed, and native ecosystems are usually irreversibly disrupted from natural trajectories. Still, there is much

Table 1. Tallest trees of the four conifers outside their native ranges.

Species	Height (m)	Diameter (cm)	Age (years)	Planted (year)	Country	Significance
	64.0	242 (1.2)	163 ± 30	pre-1850	UK	Tallest *Picea* in Scotland
Picea sitchensis	62.8	128 (1.3)	102 ± 1	1916	UK	Tallest *Picea* grove (several trees > 60 m)
	60.0	88 (1.5)	119 ± 20	1900	UK	Tallest *Picea* in Wales
	69.6	214 (1.4)	154 ± 1	1859	NZ	Tallest *Pseudotsuga* grove (several trees > 60 m)
Pseudotsuga menziesii	67.5	99 (1.5)	95 ± 1	1921	UK	Tallest tree in UK, Wales
	67.1	108 (1.3)	106 ± 1	1913	Germany	Tallest tree in Germany
	73.4	158 (1.3)	116 ± 1	1901	NZ	Tallest *Sequoia* grove (several trees > 70 m)
Sequoia sempervirens	64.8	175 (1.4)	95 ± 10	1925	Australia	Tallest conifer in Australia
	63.0	175 (1.5)	135 ± 10	1885	France	Tallest *Sequoia* in Europe
	64.6	229 (1.4)	95 ± 10	1925	US	Tallest *Sequoiadendron* in Oregon
Sequoiadendron giganteum	58.0	178 (1.5)	156 ± 10	1860	UK	Tallest *Sequoiadendron* in UK
	57.7	159 (1.3)	159 ± 1	1856	France	Tallest *Sequoiadendron* in Europe

Adapted from Table 8 in Sillett *et al*. 2021, *Forest Ecology and Management* 480: 118688.

hopeful possibility for ecological improvement within these highly modified areas. City parks structured around well-tended PETs and ETs would enhance ecosystem services for nonhuman species and humans alike. Cities have the potential to be the most resource-efficient form of population distribution. An increasing number of city-dwellers might only experience 'nature' through hybrid and novel ecosystems. This need not be an impoverished experience.

A vast and underappreciated hopeful opportunity exists in the shared landscapes that cover over half of Earth's land surface (56% in Condition 2, Locke *et al*., 2019). These are places where at least half the land has been transformed by human use. Heavily used areas are interspersed with lightly used, restored, or remnant wilderness patches. Shared lands hold much promise for management practices that better support biodiversity and carbon sequestration. Intentional forests managed with an open-minded approach to using both native and non-native tree species could play an outsized role in improving ecosystem health of Condition 2 lands.

Approximately one quarter of Earth's land surface remains in large wilderness areas (26% in Condition 3, Locke *et al*., 2019). Many of these areas persist as such because they are inhospitable places for intensive human land use, although it is important to note that many so-called wildlands have long been shaped through stewardship by indigenous people. These wilderness areas include the parks and reserves that hold the last remaining primary forests. It should go without saying that all primary forests and other wildlands (along with their inhabitants both human and nonhuman) be protected from further degradation and exploitation. To make that hope a reality everywhere will require better incentivization for local people to have an interest in protection and enforcement against illegal logging and other extractive incursions. Intentional forests could be used to heal, bolster, and buffer primary forest edges with PETs carefully chosen from local species.

While Condition 3 lands are of the highest urgency for conservation, wilderness protection is not mutually exclusive with maximizing ecosystem services elsewhere. The goal should be building resilience across the biosphere. There are innumerable hopeful possibilities for improving ecosystem health within Condition 1 and 2 lands. Imagine an interconnected system of biological refugia with precious remaining wilderness linked by hybrid and novel ecosystems in the interstices of shared and heavily used lands. Even in the face of climate change, intentional forests built by PETs and ETs can be an important part of this vision.

Of course, no lands are immune to the disruption of climate change, however pristine they may be now. Protecting wilderness and building ecosystem resilience in human-altered landscapes creates the best possible chance for nonhuman species to thrive. In doing so we also make the planet a better place for ourselves. The future of nonhuman species depends on how effectively humans provide space for them and how well those spaces are interconnected. Even if we are powerless to predict and prevent change, we can provide sufficient space for nonhuman species to adapt and persist.

It is also worth contemplating assisted migration for the sake of species' survival. Consider the 2020 and 2021 fires in California's Sierra Nevada. Shocking numbers of elder giant sequoia were killed. A century of fire suppression allowed an unnaturally high density of firs, pines, and other trees to grow up around the giant sequoia. Many of these were standing dead due to recent drought stress and associated beetle outbreaks. Overcrowding combined with unusually hot and dry conditions created the perfect situation for devastating fires.

Giant sequoia is perfectly adapted to frequent low- to moderate-intensity fires, but the heat and intensity of the recent fires was unprecedented. Many trees died that had lived for millennia. While there are improvements to be made in land management for future protection of surviving giant sequoia, climate change could render ineffectual even the best management efforts. With hotter droughts and increased frequency of severe fires, much of the Sierra Nevada could become inhospitable to giant sequoia, the most fire-resistant tree in the world.

Does climate change mean geographically restricted species like giant sequoia are unavoidably doomed? No! Let us be proactive and hedge our bets with extensive off-site planting of this charismatic tree. We know giant sequoia thrives when planted beyond its range in temperate regions around the world. There is also the long view: redwoods once flourished across large swaths of the Northern Hemisphere until their range was constricted by glaciation. In

that sense, a wider planting of giant sequoia and other redwoods is not outside the realm of natural.

The habitat value and carbon-sequestering power of giant sequoia is undiminished in a planted tree. The question of where species 'belong' may ultimately become less important than what they can do when intentionally used across the landscape. Extraordinary problems require creative and unconventional solutions.

Perhaps all this talk of using trees and managing the Earth strikes you as cynical. We argue that the opposite is true. A fundamental awareness that we are inseparable from nature means we have a responsibility to reexamine our vast potential for shaping life on Earth. Human activity has altered the biosphere's functioning to such an extent that these impacts are observable in the geological record. The biosphere as it exists today has been indelibly wrought by many millennia of human cultures. The rate and scale of change accelerates continuously as human population increases and a growing proportion of the population participates in industrial societies.

Climate change adds a layer of chaos and urgency to our collective situation. As these unprecedented changes are anthropogenic in their causes, so too must be the solutions. Acknowledging this reality is not pessimistic or defeatist but rather optimistic and empowering. We need not be passive observers to the collapse of our biosphere!

The world's big problems are composed of smaller problems too numerous to count. Fortunately, there are also countless human talents and little ways we might help. Imagine what we could do if we each put our mind to picking a small problem and working our talents towards a solution. What small problems would you pick? What are your talents? We choose trees—hope grows on trees.

Acknowledgments
Our research has been supported by Kenneth L. Fisher, Save the Redwoods League, National Science Foundation, and Global Forest Science. We thank our team members past and present, particularly Robert Van Pelt, Allyson Carroll, and Russell Kramer. Special thanks to Laurie Wayburn of Pacific Forest Trust for first recognizing the PET acronym.

Our recent article
Sillett, S.C., R.D. Kramer, R. Van Pelt, A.L. Carroll, J. Campbell-Spickler, M.E. Antoine. 2021. Comparative development of the four tallest conifer species. *Forest Ecology and Management* 480: 118688. https://doi.org/10.1016/j.foreco.2020.118688

Other recommended reading
Ellis, E. C. (2019). To conserve nature in the Anthropocene, Half Earth is not nearly enough. *One Earth* 1: 163–167.
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