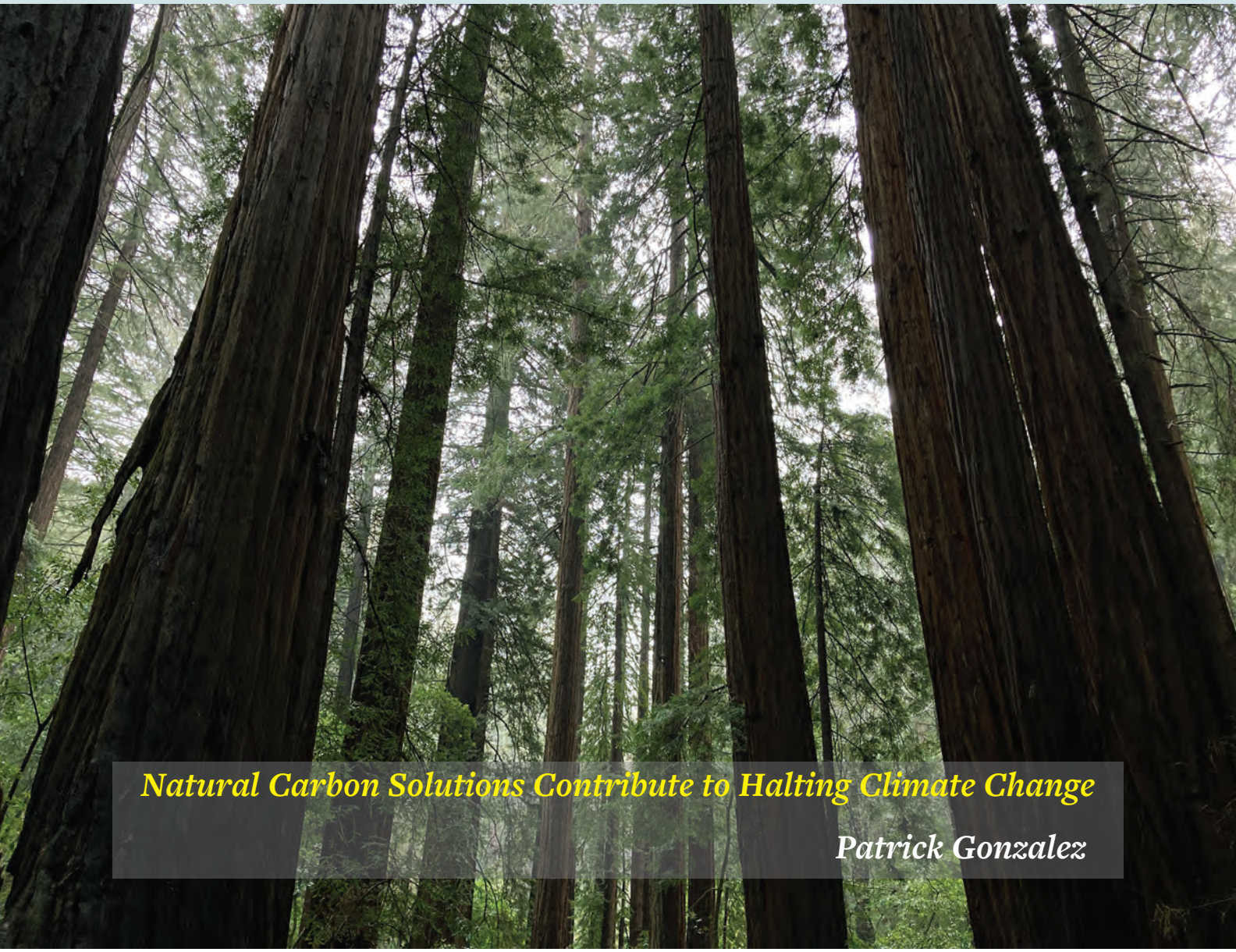

Natural Carbon Solutions Contribute to Halting Climate Change

Patrick Gonzalez

On a misty morning in March in Muir Woods National Monument, California, I stood gazing up at the majestic coast redwood trees (*Sequoia sempervirens*), the tallest living beings on Earth. I had hiked into the park after disembarking from a West Marin Transit bus above the far end of the valley. Rain overnight had delayed the opening of the park that morning. So, I was fortunate to experience solitude and the quiet of the deep green forest, hearing the calm sprinkle of water and the gentle pips of birds. Among the redwood trees, I felt gladness and awe.

Each time I'm in a national park, I feel grateful for the foresight of people long ago who worked to protect the land for people in the future—for us. In 1905, William Kent and his wife Elizabeth Thacher Kent purchased this land and donated it to the US government, which protected Muir Woods as a national monument in 1908.

This coast redwood ecosystem provides habitat for unique biodiversity, protects the local water supply,

▲ Redwood trees (*Sequoia sempervirens*), Muir Woods National Monument, California, March 2023 PATRICK GONZALEZ

and provides people an inspirational, moving experience of nature. The inspiration of Muir Woods drew delegates from around the world on May 19, 1945, as part of the conference in San Francisco that established the United Nations.

Redwood trees provide another important ecosystem service: preventing carbon emissions that cause climate change by storing carbon in vegetation. In Redwood National Park in 2006, three scientists identified and measured the tallest tree in the world, a redwood 115.9 meters tall (Sillett et al. 2015). With such great height, redwoods store the most carbon per area on the ground of any ecosystem in the world, up to 2,600 tons of carbon per hectare, as found in Jedediah Smith Redwoods State Park, California (Van Pelt et al. 2016).

This coast redwood forest and other terrestrial ecosystems around the world naturally remove 3 billion tons of carbon per year from the atmosphere (Friedlingstein et al. (2022) for all carbon budget figures in this paragraph). Marine ecosystems remove an additional 3 billion tons of carbon per year. Yet, cars, power plants, deforestation, and other human sources pump 11 billion tons of carbon into the atmosphere each year, overwhelming the natural removal capacities of ecosystems. The remaining 5 billion tons accumulate in the atmosphere—it's this fundamental imbalance that intensifies the greenhouse effect and causes climate change.

Photosynthesis is a miracle. Green chlorophyll in a plant absorbs photons of sunlight to energize the conversion of two simple compounds—carbon dioxide and water—into two very useful compounds—carbohydrates and oxygen. One type of carbohydrate is cellulose, the main compound in wood. Oxygen makes possible life on Earth.

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The reverse of photosynthesis is oxidation, in which carbohydrates are burned with oxygen, generating energy, carbon dioxide, and water. Slow oxidation is respiration, the way humans get energy from food. Fast oxidation is fire. Coal, oil, and methane gas—fossil fuels—are underground deposits derived from ancient vegetation, containing concentrated stores of energy. Any burning of fossil fuels or destruction of live vegetation releases carbon dioxide into the atmosphere through oxidation, driving climate change, while any increase of live vegetation through photosynthesis removes carbon dioxide from the atmosphere, reducing the cause of climate change.

Globally, terrestrial ecosystems contain stocks of 450 billion tons of carbon in vegetation (range 380–540 billion tons), 1,700 ± 250 billion tons in soils, and 1,400 ± 200 billion tons in permafrost (IPCC 2022). Tropical forests and Arctic permafrost contain the highest ecosystem carbon stocks in aboveground vegetation and soil, respectively, in the world (IPCC 2022). Terrestrial ecosystems contain three to four times more carbon than unextracted fossil fuels (IPCC 2021).

National parks and other protected areas safeguard ecosystem carbon, preventing emissions to the atmosphere that cause climate change. Protected areas, which currently cover 16% of global terrestrial area (UNEP 2023), contain ~20% of global vegetation carbon and ~5% of global soil carbon while accounting for ~16% of annual ecosystem carbon removal from the atmosphere (Melillo et al. 2016). In the Amazon, protected areas store more than half of the aboveground vegetation carbon of the region but account for only one-tenth of net ecosystem emissions (Walker et al. 2020). When conserving vegetation and soil, natural resource managers are fundamentally working to reduce climate change.

High biodiversity and high ecosystem carbon generally occur together, with the tropical rainforests of the Amazon, the Congo, and Indonesia containing the largest aboveground vegetation carbon stocks and the highest plant species richness in the world (Soto-

Navarro et al. 2020; Spawn et al. 2020; Sabatini et al. 2022). Aboveground carbon is correlated to genus richness globally (Cavanaugh et al. 2014) and to species richness locally (Poorter et al. 2015; Sullivan et al. 2017). So, conserving ecosystem carbon generally conserves biodiversity.

Human activities cause the most severe deforestation in tropical rainforests (Harris et al. 2021; Vancutsem et al. 2021; Potapov et al. 2022). Deforestation from commercial logging and burning trees for cattle pastures and agriculture reduced moist tropical forest from 1990 to 2020 by an area equivalent to the extent of Texas and Alaska combined, 2.2 million km², a net loss of 17% (Vancutsem et al. 2021).

Tropical deforestation generated 10% of global carbon emissions from 2012 to 2021, averaging 1.2 billion tons per year (Friedlingstein et al. 2022; IPCC 2022). In the Amazon rainforest, the combination of deforestation for agriculture, cattle, and timber and the heat of climate change have driven fires and tree mortality that now emit more carbon to the atmosphere than the forests naturally remove through vegetation growth (Hubau et al. 2020; Gatti et al. 2021; Qin et al. 2021, Fawcett et al. 2023).

Production of beef, palm oil, soy, timber, and other export commodities drive half of tropical deforestation (Curtis et al. 2018). The Brazil cattle industry is the main driver of tropical deforestation in the Amazon and globally (zu Ermgassen et al. 2022), followed, in the Amazon, by clearing for commercial soybean cultivation (Villoria et al. 2022). In the Congo Basin rainforest, clearing by small farmers and commercial timber logging are the main drivers of deforestation (Tyukavina et al. 2018; Kleinschroth et al. 2019). In Indonesia rainforest, clearing for palm oil plantations drives deforestation (Tsujino et al. 2016; Curtis et al. 2018). China imports more beef and soy from Brazil than any other country (zu Ermgassen et al. 2020; Villoria et al. 2022), China and Europe import the most timber from the Congo Basin (Partzsch et al. 2023), and Europe imports the most palm oil from Indonesia (Busch et al. 2022). The US also imports beef, palm oil, and timber from rainforest countries (World Bank 2023).

Published research and field experience show that protection of forests in a national park or other protected area offers a very effective way to halt deforestation.

Published research and field experience show that protection of forests in a national park or other protected area offers a very effective way to halt deforestation (Ernst et al. 2013; Gonzalez et al. 2014; Goncalves-Souza et al. 2021; Shah et al. 2021). In the Amazon rainforest, national parks, Indigenous reserves, and other protected areas can effectively prevent fires, which are not natural in rainforests (Adeney et al. 2009). Globally, national parks and other protected areas that were established from 2000 to 2012 effectively reduced deforestation in those areas 72%, saving 86,000 km² of forest (Shah et al. 2021). Indigenous lands reduce deforestation of moist tropical forests more than or as much as protected areas (Sze et al. 2022).

The principal international policy aimed at halting forest carbon losses is the Reducing Emissions from Deforestation and Degradation and through improved forest management (REDD+) approach of the UN Framework Convention on Climate Change (UNFCCC). In early versions of REDD+, an organization would pledge to protect a small area of forest, project how much carbon would have been lost in the future to deforestation, and sell credits of future carbon to fossil fuel companies seeking to voluntarily offset their emissions. The projections, however, could be speculative and overly optimistic, projects could unintentionally displace deforestation to other areas (a phenomenon known as "leakage"), and the credits allowed fossil fuel companies to continue polluting, leading to little or no global reduction in emissions (van Kooten et al. 2015; West et al. 2020).

Improved REDD+ programs of the UNFCCC Green Climate Fund encompass large jurisdictions, such as provinces or entire countries, to avoid leakage,

Forest conservation, halting deforestation, reforestation, agricultural soil carbon storage, and all other natural carbon solutions could mitigate up to 4 billion tons of global carbon emissions per year by 2030.

and involve results-based payments to countries documenting past reductions of deforestation, to avoid inflated future projections. Moreover, new programs send funds back to a country to strengthen government parks and forest services, not to fossil fuel companies, to further reduce deforestation. In one newer REDD+ program, Indonesia placed a moratorium in 2011 on concession licenses for palm oil plantations and logging, reducing deforestation (1,200–1,500 km^2) and carbon emissions (18–24 million tons) from 2011 to 2018 (Groom et al. 2022).

Temperate forests in North America have lost much less area and carbon than tropical forests in Africa, Asia, and South America (Harris et al. 2021; Potapov et al. 2022). In the US, net forest loss from 2000 to 2020 was 35,000 km^2, a net decline of 1%, equivalent to the area of Connecticut and Massachusetts combined (Potapov et al. 2022).

In the US, timber harvesting is the main driver of forest loss (Curtis et al. 2018) and forest carbon emissions (Harris et al. 2016; Berner et al. 2017; Hudiburg et al. 2019). Therefore, halting timber harvesting on US federal lands would cut carbon emissions and advance US goals of net-zero emissions by 2050 (USA 2021a) and halting natural forest loss by 2030 (USA 2021b). Other forest management actions that can increase carbon storage and conserve biodiversity include retaining the oldest and largest trees, increasing time between harvests, avoiding damage to non-harvested trees, and removing competing shrubs from the understory (Kaarakka et al. 2021).

In addition, research in the Sierra Nevada, California, indicates that prescribed burning in forests with a natural high frequency-low severity fire regime can increase long-term carbon storage by clearing the understory and promoting the growth of larger, older trees (Hurteau and North 2009; Krofcheck et al. 2017; Liang et al. 2018). Carbon stocks increase as long-term growth of large old trees outweighs short-term losses from prescribed burns.

Reforestation of former forest land with native species will also increase carbon storage. On the other hand, some ecosystem restoration, such as removal of invasive alien plant species, could reduce carbon storage. In those cases, generally limited in extent, it makes sense for national parks and protected areas to prioritize their primary goal of biodiversity conservation over carbon storage. Reforestation elsewhere could be implemented to balance the carbon losses. Forest conservation, halting deforestation, reforestation, agricultural soil carbon storage, and all other natural carbon solutions could mitigate up to 4 billion tons of global carbon emissions per year by 2030 (IPCC 2023).

In the 27 US national parks in California, vegetation stores 42 ± 15 million tons of carbon, equivalent to one year of carbon emissions from 7.4 ± 2.6 million Americans (Gonzalez et al. 2015). That's equivalent to the population of the cities of Boston, Charlotte, Dallas, Kansas City, Los Angeles, and Miami combined. That may seem like a lot of carbon, yet it will take just one year for those people to burn through the equivalent of all the carbon in the coast redwoods, giant sequoia trees, Joshua trees, and all other vegetation in the national parks in California. This shows how natural carbon solutions are, by themselves, insufficient. Cutting carbon pollution from fossil fuels is essential.

The threats of continued climate change to the two largest sinks of ecosystem carbon in the world, Arctic tundra and Amazon rainforest, underscore the urgency of cutting carbon pollution. Climate change of 4°C above pre-industrial temperatures could cause fires and thaw permafrost across extensive areas of the Arctic, releasing the equivalent of up to 15 years of 2019 global carbon emissions (Turetsky et al. 2020; Miner et al. 2022). Fires due to continued climate change and deforestation could convert up to half of Amazon

▲ Amazon rainforest, with local resident Juan Peña, Reserva Comunal Yanesha, Perú. PATRICK GONZALEZ

rainforest to non-forest, releasing the equivalent of one to three years of 2019 global carbon emissions (Salazar and Nobre 2010; Cano et al. 2022; Assis et al. 2022).

In each issue of *Parks Stewardship Forum*, I offer a specific solution that each of us can implement to reduce climate change and help protect natural areas globally. Here, I recommend an action to cut emissions from cattle and other livestock, major sources of methane, a greenhouse gas 30 times more damaging than carbon dioxide (IPCC 2021). In addition, the tractors, water pumping, and infrastructure used to grow animal feed burn fossil fuel and generate substantial amounts of carbon dioxide. Global adoption of a plant-rich, meat-free diet could cut global greenhouse gas emissions 40% (Springmann et al. 2018; Clark et al. 2020; Eisen and Brown 2022; Halpern et al. 2022). So, you can take meaningful action on climate change through a plant-rich, meat-free diet, as I do. Any reduction of your meat consumption reduces climate change. In addition, decreasing meat consumption improves personal health by lowering the risk of heart disease (You et al. 2023) and conserves biodiversity by protecting natural habitat (Tilman and Clark 2014). This action can contribute meaningfully to achieving our 2050 net-zero carbon emissions goal, helping to halt climate change and protect people and nature.

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