A Brazilian nursery grows seedlings to support reforestation efforts.

MINT IMAGES/AURORA

HOW TO REBUILD A FOREST

As projects to restore woodlands accelerate, researchers are looking for ways to avoid repeating past failures.

BY RACHEL CERNANSKY

When the Philippines opened its first school of forestry in 1910, the institute's leaders hatched a plan to restore degraded woodlands surrounding the campus outside Manila. They planted dozens of tree varieties, both native and exotic. In 1913, the school received 1,012 mahogany (*Swietenia macrophylla*) seeds from a botanical garden in Calcutta, India, and started growing them around the grounds. The American hardwood became such a staple of reforestation efforts in the country that it spread throughout natural areas, so much so that it eventually proved a nuisance. The trees create veritable green deserts: their tannin-rich leaves are unpalatable to local animals and seem to stifle the growth of other plants where they fall. They also produce seeds annually, giving them an advantage over native hardwoods, which do so at intervals of five years or more.

It's hardly history's only forestry folly. "The whole notion of what species should be used in restoration tends not to receive, I would say, adequate attention," says Douglas McGuire, coordinator of the Forest and Landscape Restoration Mechanism at the Food and Agriculture Organization of the United Nations in Rome.

Many projects fail because they choose the wrong trees, use too few species or are not managed for the long term. Foresters and ecologists are realizing that for restoration efforts to succeed, they need to think more broadly — about matching trees to their location, about the effects on nearby insects and other animals and about relationships with soil and the changing climate. In other words: the ecosystem.

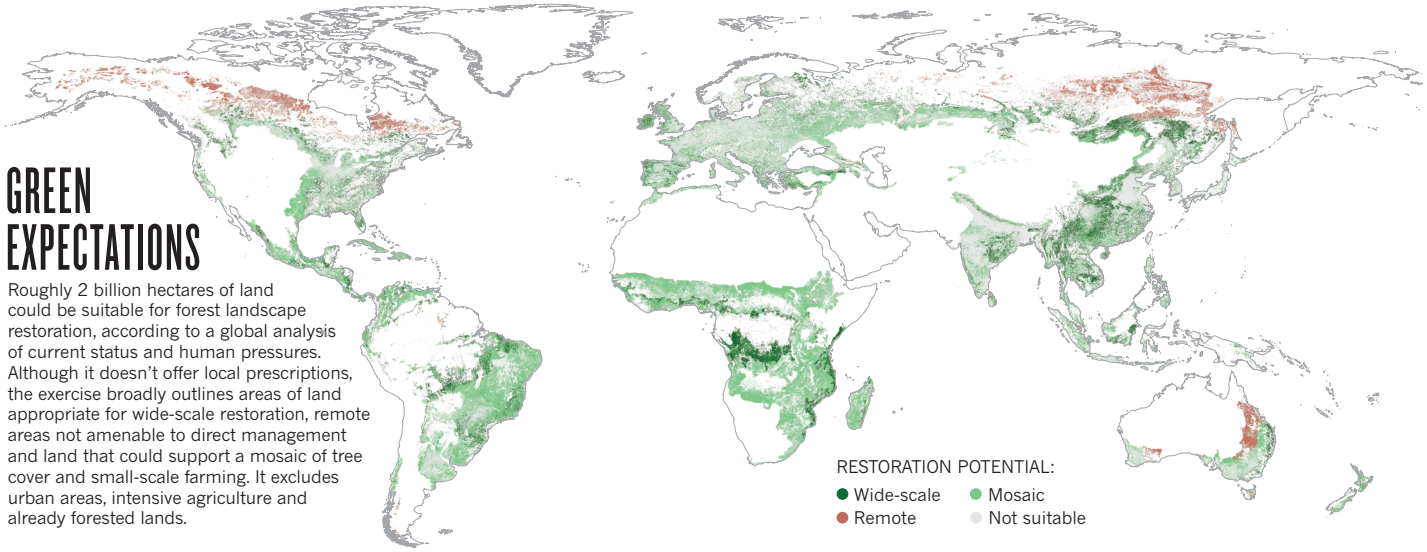
Scientists are now testing and comparing strategies that range from letting nature take its course, to forest-management approaches that look a lot like farming. There is no one-size-fits-all solution, but the work exposes some philosophical friction. Ecologists seeking to increase biodiversity might champion a broad range of species, whereas sustainable-development advocates could back exotic fruit-bearing trees that benefit local people. And researchers seeking to mitigate climate change might push for a single fast-growing variety.

"There've been different attitudes about what the goal of restoration is," says Robin Chazdon, a forest ecologist at the University of Connecticut in Storrs. "There is also some attempt to reconcile, which is very promising."

There is room for growth — a lot of it, in fact. A 2011 analysis suggested that some 2 billion hectares of land, an area larger than South America, is suitable for restoration (see 'Green expectations'). Much of this land has been deforested or degraded as a result of human activity. And many countries and organizations have made promises in the past decade to help fill that area. There are pledges to plant billions or even trillions of

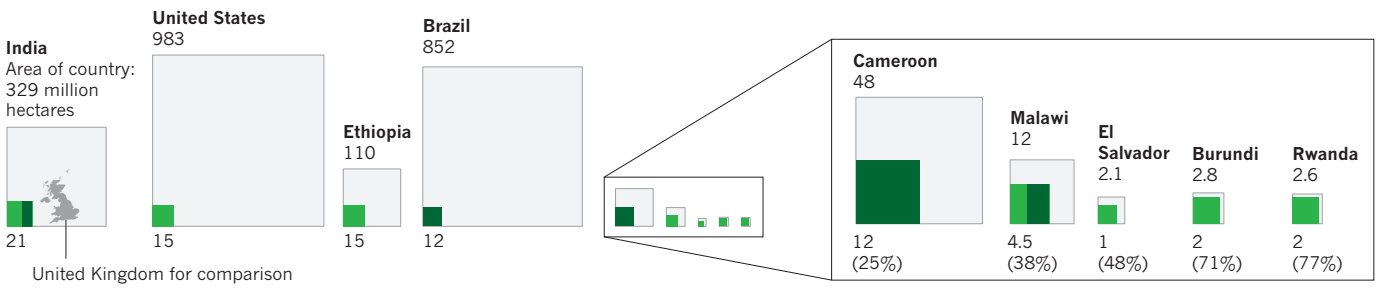
GREEN EXPECTATIONS

Roughly 2 billion hectares of land could be suitable for forest landscape restoration, according to a global analysis of current status and human pressures. Although it doesn't offer local prescriptions, the exercise broadly outlines areas of land appropriate for wide-scale restoration, remote areas not amenable to direct management and land that could support a mosaic of tree cover and small-scale farming. It excludes urban areas, intensive agriculture and already forested lands.



AMBITIOUS GOALS

Forty seven countries have pledged to restore degraded lands as part of the Bonn Challenge for 2020 and 2030. Here are some of the largest commitments by land area (left) and by proportion to the total size of the country (right).



SOURCES: WORLD RESOURCES INSTITUTE AND HTTP://WWW.BONNCHALLENGE.ORG/COMMITMENTS

trees, and regional programmes such as Africa's Great Green Wall, which would surround the Sahara Desert with vegetation. China has set some of the most ambitious national targets. It is aiming to plant 6.7 million hectares' worth of trees — roughly the size of Ireland — this year alone.

But some key deadlines are looming. The Bonn Challenge, established in 2011, for example, aims to restore 150 million hectares by 2020, and another 200 million in the subsequent decade. It has received ample commitment from countries around the world, but the strategies aren't always backed by evidence, and measures of success are still being defined. As conservation efforts move forwards, scientists say, it's imperative to look at the leading strategies. "There's a big risk in this restoration movement of big promises, big targets and a time frame that's really tight," McGuire says.

LET NATURE TAKE ITS COURSE

When people think of reforestation, they often think of planting trees. But some ecologists argue that the best way to repopulate a forest is to leave it alone. In the 1980s, Daniel Janzen and his partner Winnie Hallwachs, both biologists at the University of Pennsylvania in Philadelphia, developed a plan to reforest a small national park in Costa Rica that had been carved out of a former ranch. It was covered in African grasses that were intentionally burned during the dry season. The pair, along with partners including the government, employed local people to stop the fires and help guard the land. Over time, what had resembled overgrown African savannah became a tropical forest with rain trees (*Samanea saman*), guanacaste (*Enterolobium cyclocarpum*), hog plums (*Spondias mombin*) and other native trees. And with the help of donors and local workers, it grew.

Today, the Guanacaste Conservation Area, a World Heritage Site with more than 100,000 hectares of land, is seen as one of the best examples of this approach to restoration, known as natural regeneration. Janzen is a vocal proponent of the strategy. Take away the assault, and "nature takes care of the restoration", he says. "Organisms like to get their land back."

But natural regeneration won't work everywhere. There are countless areas around the world that are much more degraded than Guanacaste. In some places, soil nutrients are depleted, and there are no seeds or seedlings from native species to populate the space. Even with the political will to protect such regions, forests are unlikely to regrow.

That is where more aggressive efforts are needed, and conservationists are exploring different strategies. In Thailand, Stephen Elliott, research director for Chiang Mai University's Forest Restoration Research Unit, has been restoring local forest with native species for decades. He's followed a framework-species approach, which involves planting enough species to start attracting pollinators and seed dispersers. The key, he says, is getting the canopy to close quickly enough — by the second or third year — to prevent weeds from taking over.

Nigel Tucker, who helped to establish the framework-species approach in Australia in the 1990s, says that he noticed early on that some plants had an outsized role in supporting a thriving ecosystem. Take fig trees (*Ficus* spp.): in tropical forests around the world, they produce regular fruit crops that birds, bats and primates rely on — particularly during dry periods — and their foliage is an important food source for other animals. All of that helps with pollination and seed dispersal, which encourages regeneration of the forest. "In my work locally, figs always comprise 10% of any planting, and we plant as many fig species as possible," Tucker says.

Another strategy, known as applied nucleation, involves planting small clusters, or 'nuclei', of trees throughout a clearing. The goal is for these to gradually close in on each other, as the nuclei attract seed dispersers. Karen Holl, a restoration ecologist at the University of California, Santa Cruz, has studied this approach in Costa Rica and elsewhere. It can be just as effective as planting a whole area with trees, she says, but it requires fewer resources, and the outcome is a more varied-looking landscape.

Chazdon has been working with colleagues to write a review that compares how the different approaches affect timber production, wildlife populations, water and sediment retention, and other factors. But she is struggling to do so because, she says, there aren't many studies to review. "We don't have a lot of evidence. We have perceptions," she says. "The basis for decision-making is not very scientific at this point."

COOPERATIVE APPROACHES

Despite forestry blunders such as the Philippines' mahogany problem, researchers still debate whether restoration efforts must rely entirely or predominantly on native species. A growing number of efforts are showing that integrating exotic commercial species with native ones can produce promising results both for ecosystems and for economies. Species such as eucalyptus (*Eucalyptus globulus)* and pine (*Pinus* spp.) can grow quickly, and in very degraded soils; most of the native species that are being lost in forests around the world do neither. Planting them together means that the faster-growing trees — chosen because they can't spread on their own — can provide a canopy for the slower ones, giving them a helping hand. The canopy species can also be a source of income for communities or a way to appeal to timber companies to participate in restoration projects that promote species diversity. Restoration ecologist Pedro Brancalion at the University of São Paulo's Tropical Forestry Lab in Brazil is collaborating with a wood-pulp company to plant eucalyptus trees alongside native species in the Atlantic Forest and later harvest the eucalyptus. The approach has generated enough revenue to offset most of the project's costs.

Native species can benefit economies, too. Another effort Brancalion is involved with leans heavily on juçara (*Euterpe edulis*), a threatened relative of the better-known açai that also produces an edible fruit. Juçara trees are planted wherever people see fit: in home gardens, along the small dirt roads that connect villages, in fragments of remaining forest and in agroforests — where trees or shrubs are integrated with other food crops or with pastureland. A project known as the Juçara Network has also revived cultural appreciation for the fruit, which is now the focus of a national gastronomic festival and a key source of income for many small farmers.

> *"The whole notion of what species should be used in restoration tends not to receive, I would say, adequate attention."*

Chazdon and others say that in heavily populated areas, agroforestry seems like a good idea because it can provide food. "That will be a strong motivating factor for people to become involved and to make the restoration successful," she says.

It has been catching on in parts of Africa. Alex Munyao, a farmer in eastern Kenya, learned how to care for seedlings and graft trees at a training programme in 2013 hosted by the Nairobi-based World Agroforestry Centre, or ICRAF. He convinced the ICRAF team to establish a nursery that grows avocados (*Persea americana*) originally from Mesoamerica, kei apples (*Dovyalis caffra*), which are native to southern Africa, and a handful of other fruits. He has now sold more than 30,000 seedlings to other farmers and to local government officials for restoration projects. He has also donated some to local schools, and helps people in the community to graft their own local avocado trees with improved varieties.

Stepha McMullin, who runs the Fruiting Africa programme at ICRAF in Kenya, says that because people like Munyao are spreading the word, such training has been able to reach 10,000 or more farmers. The programme has distributed enough seedlings to plant trees on more than 500 hectares of farmland. It does include exotic species, partly because fruits such as mangoes and papayas often have higher market values, but farmers are learning the value of some native varieties, too.

The desert date (*Balanites aegyptiaca*), for example, was once common in the wild in much of Africa's dry lands and its fruit was nutritious and popular with children, but many farmers had cleared these trees from their land to make way for other crops. When McMullin's team approached farmers about planting — or simply sparing — desert dates, "they were very surprised and even laughed at the thought", she says. But after learning about the health benefits, particularly for children, more families have opted to preserve and plant the trees.

A QUESTION OF ORIGIN

In an effort to support restoration programmes elsewhere and on a larger scale, McMullin's colleagues are developing supplies of seeds and seedlings, maintaining gene banks and sequencing the genomes of indigenous trees and other crops. Their work deals with one of the problems that could block major restoration efforts in different parts of the world.

"Where's the planting material going to come from? That's one big bottleneck," says Ramni Jamnadass, a genetic-resources specialist who oversees ICRAF's Tree Diversity, Domestication and Delivery project.

In May, Bioversity International and other organizations released a report analysing the seed-supply systems in seven Latin American countries, focusing on the government and research agencies involved in restoration (see go.nature.com/2p3gmke); none paid much attention to the genetic origins of the seeds or the diversity of the native species available.

Brazil is an exception to that trend, having established thriving nurseries for native seedlings. It also has laws requiring landowners in the Amazon to maintain native vegetation on a certain amount of their property — although these laws have had mixed success. They were not enforced for a long time, and by some estimates, deforestation has increased over time, not declined.

Asia is arguably the region most neglected by global efforts to increase diversity in restoration and to study native species. Christopher Kettle, Bioversity International's director for forest genetic resources and restoration in Rome, says that the need for infrastructure — things such as mechanisms for collecting and storing seeds, and nurseries to raise seedlings — might be most desperate here because many trees are 'masting' species, which don't produce seeds every year. People need to be ready. "Otherwise, you miss the boat, you lose all the seed and you've got to wait another seven years," says Kettle. "This is a really, really critical issue for restoration in Southeast Asia, because many of the most important timber species and tree species — the ones that will lock up the most carbon — they're all masting species."

Climate change is a driving factor in the push to restore forests, but it also raises questions, such as where trees can thrive in the future. John Stanturf, a forest ecologist and research-group coordinator at the International Union of Forest Research Organizations in New York, sees promise in the concept of assisted migration, or moving plants to where they can survive today and thrive in the future. He and his colleagues last year collected seeds from Iran's Caspian forests, and brought them to Denmark. The Iranian trees are adapted to heat and droughts, but also related to the Danish species. Stanturf plans to test whether the introduction increases genetic diversity, resistance and resilience in the native trees.

Climate change is also expected to alter relationships between trees, insects, diseases and other forest species. "Insects that today are a minor problem may become a major problem if they can produce three or four generations in a year," says Stanturf. This remains a significant knowledge gap. "We know enough to know that this is a concern, but we don't know enough about how to respond to it yet. That's a great area to be doing research." So is soil, says Cindy Prescott, a forest ecologist at the University of British Columbia in Vancouver. "If you don't look at the soil at the start, you can spend a lot of money and time putting in species that aren't going to survive there."

With so much research left to do, leaders in the field have been doing some soul-searching, and acknowledging that restoration can be motivated by — and designed to meet — different needs. "When you talk about conservation or restoration, the first question has to be restoration by whom, for whom?" says Janzen.

The question can have more than one answer. Much of the global funding for restoration is dedicated to developing it as a tool to mitigate climate change, notes Brancalion. "But if you ask a farmer in Brazil if he or she is concerned about climate change, they would say, 'No, I am concerned about water,'" he says. Their interests as stewards of the land need to be better integrated with those who have the money to support restoration.

That has been the strongest lesson of all for Chazdon. Restoration is about more than what gets planted in the ground, she says. "Yes, it's about forests, but it's really about people. They are the agents of restoration." ■

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