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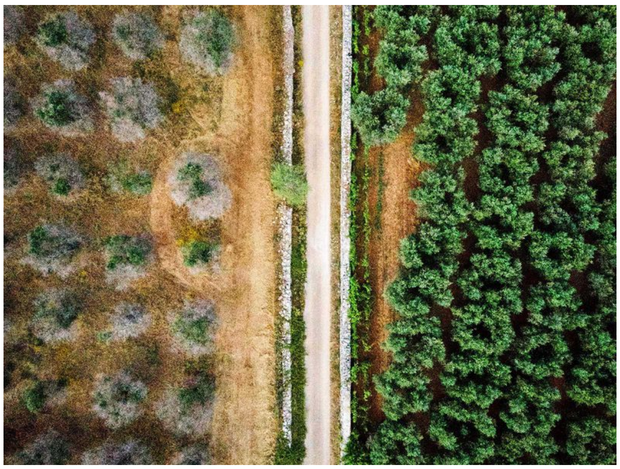
Why Tree-Killing Epidemics Are on the Rise

Globetrotting pathogens have caused forest-felling disasters that scientists are doing their best to contain



In southern Italy, two varieties of olive trees, some infected with a disease called Xylella fastidiosa, a bacteria carried from tree to tree by a little bug, and some resisting the infection (CHARLES ONIANS/AFP via Getty Images)

By Stephanie Pain, Knowable smithsonianmag.com
September 28, 2020 7:30AM

My adopted hometown of Brighton on England's south coast is best known as a party town. It grew from fishing village to chic resort thanks to a prince's desire for a fun place to hang out with his secret wife and, more than two centuries later, people still flock here in pursuit of pleasure. The city's most famous landmarks are a wacky pastiche of an oriental palace, a glitzy pier and a vast pebble beach backed by flamboyant Regency squares and terraces.

Away from the bright lights and bling, though, something more dignified makes this place unique. Lining its streets and adorning its parks are around 17,000 elm trees. Welcome to Elm City, the last great refuge of trees that once shaped the English landscape.

The UK lost most of its elms to an epidemic of Dutch elm disease in the 1970s. As a teenager, I witnessed the terrible transformation of the local countryside as stately giants became lifeless skeletons. In little more than a decade, 30 million elms died. The nation's second most important source of hardwood timber, a key component of hedgerows and woodlands, and home to at least 80 species of invertebrates, virtually disappeared. Brighton's elms survived thanks to a quirk of geography and a take-no-prisoners policy of fell-and-burn at the first sign of infection. For almost half a century, those trees have stood as a salutary reminder of the dangers posed by globetrotting plant pathogens.

Tree-killing microorganisms like the microfungus responsible for Dutch elm disease have been criss-crossing the world for centuries, shipped along with exotic trees and shrubs, timber and wood products, even packaging. In the twentieth century, a slew of epidemics hammered home the message that hitchhiking bacteria and fungi — the rusts and blights and their kin — and the fearful fungus-like phytophthoras are seriously bad news for agriculture, forestry and natural wooded habitats. Yet despite those woeful experiences and the tougher biosecurity measures that they prompted, the number of arrivals is rising.

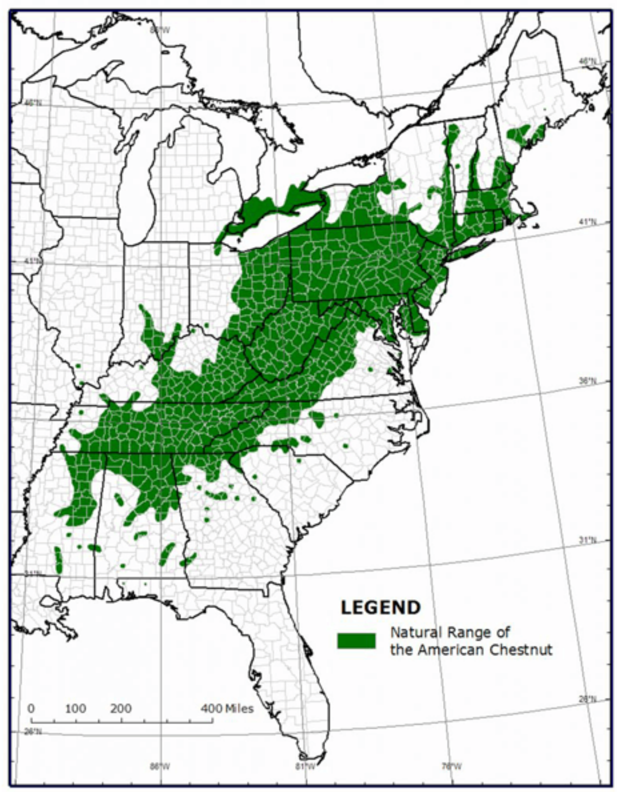
With wildfires growing fiercer and more frequent and world leaders vowing to plant trillions of trees to help restore nature and tackle the climate emergency, there's an urgent need to find ways to fight future epidemics. This year is the UN Year of Plant Health, so it's a good time to see how we're doing. And the blunt answer is badly, but with bright spots that offer some hope that things will improve.

"We are getting better at it because we are better equipped, but at the same time the challenges are increasing," says plant disease epidemiologist Stephen Parnell of the University of Salford in northern England, who presented the case for surveillance in the *Annual Review of Phytopathology*. "We need to get ahead of epidemics, not just monitor the damage. If we don't, we stand to lose many more species and billions of trees that we depend on for so much."

Historic horror stories

In their native ranges, trees and pathogens evolve in tandem: Trees acquire resistance, pathogens try harder, trees ramp up their defenses another notch — and so on until they reach a sort of truce where trees tolerate infection and the pathogen does little harm. Transport the pathogens elsewhere, though, and all bets are off. Loosed among defenseless trees, seemingly mild microbes can turn nasty and fell whole forests. Every part of the world has experienced a loss so traumatic that it's left a permanent scar on the public consciousness.

Take the US: It lost the magnificent chestnut forests that once stretched from Maine to Alabama, from the East Coast west to Michigan and southern Illinois — an event considered one of the world's worst ecological disasters. The killer was chestnut blight, a fungus native to China and Japan that was introduced with ornamental Japanese chestnuts in the early 1900s. In susceptible trees like America's native chestnut, the blight kills live tissue just beneath the bark, eventually blocking supplies of water and nutrients. In the 40 years after the Bronx Zoo first reported it in 1904, the fungus killed more than 3 billion native trees.



American chestnut forests covered a vast swath of the eastern US until the accidental introduction of chestnut blight at the start of the twentieth century. In 1910, the Great Smoky Mountains of North Carolina (where the photograph on left was taken) were still home to the ancient and monumental trees. By the 1940s, the forests had gone. (Forest History Society, Durham, NC (Left); The American Chestnut Foundation (Right))

Australia's heartbreaker was (and still is) cinnamon fungus, an untreatable root-rotting phytophthora from Southeast Asia that poses such a risk to the nation's native trees it's officially designated a "key threatening process." It was first identified in Australia in the 1930s, with lethal potential that really hit home in the mid-twentieth century after it began to destroy the country's Jarrah Forest, an internationally important hotspot of biodiversity that's home to hundreds of unique species. The fungus attacks roots, starving trees of water and nutrients and progressively killing them from the top down — a phenomenon known as dieback. The disease is now widespread in Australia, attacking more than 40 percent of native species, including half of the endangered species in the Jarrah Forest, with some close to extinction.

For the UK, the 1970s epidemic of Dutch elm disease is the one etched on people's memories, including mine. Europe had a foretaste of disaster in the early twentieth century when an unknown disease swept the continent from Scandinavia to southern Italy. Dutch botanists identified the pathogen responsible as a microfungus carried by bark beetles that breed in mature elms. Infected trees try to block the pathogen's progress by plugging their water transport system, suicidally depriving themselves of water. That epidemic died down in the 1940s — but in the late 1960s, a far more aggressive form of the microfungus showed up. Imported to the UK in a consignment of elm logs from Canada and distributed across the nation through the sale of logs from diseased trees, it swiftly dispatched more than 90 percent of the nation's elms.

So there have been warnings aplenty, followed by decades of research to find ways of stamping out newly arrived diseases. Cures and treatments remain elusive; fungicides and vector-zapping pesticides can sometimes help in commercial settings but not in the wider environment, where the task is too big and the remedy too ecologically harmful. In almost every case, the main control strategy remains culling trees. Better, then, to stop pathogens arriving in the first place: That's led to tougher quarantine procedures, rigorous health checks and tighter regulation of the plant trade.

But still they come.

Killers on the loose

Wherever you live, you'll probably have heard of some of them. Citrus greening, or huanglongbing, a bacterial disease delivered by sapsucking insects, has devastated Florida's citrus industry and now threatens California's. Sudden oak death, caused by another phytophthora known as ramorum fungus (even though, like cinnamon fungus, it's a different organism entirely), has ravaged oak and tan oak forests along the US West Coast.

Sudden oak death has reached the UK too, although confusingly here it's mostly killing larch trees, while ash dieback, another fungal disease, is poised to reshape the British landscape as dramatically as Dutch elm disease once did. And on the horizon but approaching fast is *Xylella fastidiosa*, a bacterium currently on a killing spree in the olive groves of southern Italy but moving steadily north and west across Europe.

In Australia, one of the latest headline horrors is myrtle rust, a fungal pathogen that has circled the globe and made landfall in New South Wales in 2010. The rust infects trees and shrubs belonging, as the name suggests, to the myrtle family — and Australia is myrtle central, home to 2,250 native species, including eucalyptuses, tea trees and paperbarks. With more than 350 Australian species known to be susceptible, within a few years of arrival the disease was doing serious damage to native ecosystems.

"At least two once-common trees are now known to be critically endangered, and there could be many more," says government forest pathologist Angus Carnegie, who examined the lessons learned from this invasion in the *2018 Annual Review of Phytopathology*. One, the native guava, is at imminent risk of extinction.

Another effect of globalism

To get a clearer picture of the scale of the problem and how it's being tackled, I took a train to London and the Royal Botanic Gardens at Kew to meet Richard Buggs, who leads research in plant health at Kew. "Everyone is sharing their pests and pathogens," Buggs tells me. "Europe has pathogens from the Americas and America has some from Europe. The US has Chinese pathogens and China has trees dying from American pathogens. And so on and so on." Most go undetected until they are on the loose, and each year they cause the loss of crops worth billions of dollars and do incalculable damage in the wider environment.

How did it get so bad? In a word: Globalization. Speedier travel and the rapid expansion of trade, including the movement of billions of plants for the horticulture industry, have proved disastrous. "The scale of global trade is overwhelming attempts to control accidental imports of pests and pathogens," Buggs says. In the US, for instance, data from the Department of Transportation on 63 US ports show a doubling of the number of arriving shipping containers between 2000 and 2017.

Myrtle rust: The ultimate globetrotting tree pathogen

1 1884 Brazil
Discovered on guava; 1973 first of series of epidemics in exotic eucalyptus grown for timber.

2 1934 Jamaica
Causes massive losses to the allspice industry.

3 1977 US
First reported in Florida; outbreaks in California in 2006.

4 2005 Hawaii
Epidemic does widespread damage to exotic rose apple, an important landscape tree; threat to iconic ‘ōhi‘a, the islands' most widespread native tree.

5 2007 Japan

6 2009 China

7 2010 Australia
Spreads quickly through eastern forests; extensive damage to native ecosystems. Many native species now in decline; at least two common species critically endangered. Impact on lemon myrtle industry.

8 2013 South Africa

9 2013 New Caledonia
Rapid spread throughout the archipelago.

10 2015 Indonesia

11 2016 Singapore

12 2017 New Zealand
Windblown spores arrive from Australia. Threatens sacred pohutakawa, manuka and other native myrtles. Fears for honey industry.

SOURCE: REPORTING BY S. PAIN; MAP FROM INVASIVE SPECIES COMPENDIUM / CABI

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Native to Latin America, myrtle rust (Austropuccinia psidii) was discovered in Brazil in 1884 and spread slowly across South and Central America and the Caribbean, with outbreaks in the southern US. In 1973, it devastated eucalyptus plantations in Brazil, alerting the world to the risk it poses. In 2005, the pathogen reached Hawaii and since then has raced round the world, reaching Asia, the Pacific and South

Africa. (Reporting by S. Pain; Map from Invasive Species Compendium/CABI)

Despite trade policies aimed at reducing the risk of accidental imports, better standards of plant hygiene and tighter biosecurity measures at ports, pathogens will inevitably slip through, Buggs says. “However good your system of quarantine checks, you are going to miss things.” Spotting insect pests is difficult enough, but how much harder it is to detect microscopic bacteria and fungi, especially when infected plants often show no symptoms. “There’s no indication anything is wrong until they hop onto another species, and away they go,” Buggs says. To make matters worse, some potential tree-killers aren’t yet on any checklist: Unknown and unseen, they have a free pass until a sharp-eyed forester, gardener or nature-lover spots trees sickening with a puzzling new disease.

Once in, if they encounter susceptible hosts — and some pathogens can infect hundreds of species — they establish a foothold and begin to spread. Some, like myrtle rust and ash dieback, travel naturally via windblown spores, while the sudden oak death pathogen disperses more in splashes of rain. But all advance further with human help — distributed through plant sales, in soil-filled tire treads, even on hikers’ clothing and footwear.

Pathogens like the bacteria responsible for huanglongbing and Xylella rely on sapsucking insects to inject them into their hosts — and they hijack local species to do the job. Climate change also figures in the equation: Changes in temperature, wind patterns and rainfall aid both survival and dispersal of pathogens, encouraging their expansion into newly hospitable areas. Warmer, wetter springs see the sudden oak death pathogen spread much more prolifically, while the frost-sensitive cinnamon fungus benefits from Europe’s milder winters and is likely to spread northward.

“You can put in place measures to reduce the risk of incursions, but you can’t reduce the risk to zero,” Parnell says. “Nor can you always predict if an introduced species will take off. You only know it’s a disaster once it is.”

Need for speed

The best hope of containing a newly arrived pathogen is two-pronged: Detect it early, act fast. In the UK, ash dieback was first detected in 2012 — at least seven years after it’s thought to have arrived, and by then it had already spread widely. It’s now on course to kill an estimated 70 percent of the country’s 150 million to 200 million ash trees.

In California, the signs of sudden oak death were spotted early, but tough, coordinated action came too late. The first sightings of sick trees were in 1995 near San Francisco but the response was slow and piecemeal. A recent study that looked at what might have been if things had been done differently concluded that the epidemic could have been controlled if a strict culling policy had been in place before 2002. It wasn’t, and after that, control was impossible. “We need to put more effort into stopping things coming but also in early detection to at least give us a chance to eradicate before the horse has bolted,” Carnegie says.

Surveillance is key. Nurseries and trees near ports are relatively easy to monitor, but beyond that, where to start looking? Parnell and his colleagues are developing computer models that help narrow the search. By combining information on a pathogen’s most likely points of entry and what’s known of its biology and epidemiology — how far and fast it can travel, where conditions suit it, and the distribution of potential host trees — they can identify the places most at risk, providing targets for surveillance.

Yet even with some idea of where to look, finding infected trees in the early stages of an outbreak is a monumental challenge — and not just in wild woodlands. Spotting early signs of disease in commercial plantings can be pretty near impossible with pathogens that are cryptic or symptomless for many months. Olive trees infected with Xylella, for example, can look healthy for a year or more before symptoms appear, while huanglongbing might not reveal itself for two or three years. “There’s a wave of silent spread,” Parnell tells me. “When you are looking at symptoms, you are looking at history. It’s already moved on.”

Ace detectives

Encouragingly, there are promising new methods of diagnosis in the pipeline, as well as an untapped army of people ready and willing to join the hunt: farmers and landowners, growers and tree lovers of all kinds. New smartphone apps that help diagnose diseases provide a way to harness the potential of all those citizen spotters. In the US, OakMapper is being used to monitor outbreaks of sudden oak death; in France, the app Vigil'Encre allows citizen scientists to detect and report chestnut ink disease, one of the devastating results of infection with *Phytophthora cinnamoni*.

If large numbers of eyes on the ground improve the chances of spotting disease early, eyes in the sky could be more efficient still, especially if they can see what human eyes can't. Pablo Zarco-Tejada, a remote-sensing specialist at the University of Melbourne, and colleagues at the European Commission Joint Research Centre in Italy have test-flown a Xylella detector system over olive groves, with good results.

Two detectors, a thermal imaging camera and a hyperspectral sensor that resolves color into hundreds of shades, picked out signs of infection from a height of 500 meters. Infection causes subtle but signature changes in leaf color and temperature because it disrupts two key physiological processes: photosynthesis and cooling evaporation from leaves. The team flew over 15 olive groves — more than 7,000 olive trees — and identified sick trees with more than 80 percent accuracy.

Advanced technology isn't always the answer, though. The best news citrus growers fearful of huanglongbing have had in a long time is that a dog's nose offers a quicker and more accurate diagnosis than any other method.

Normally, human spotters walk citrus groves looking for leaves with tell-tale green-and-yellow blotches, yellow shoots or corky leaf veins. If they see suspect trees, they send leaf samples to a lab to check for bacterial DNA. That's slow and unreliable in the early stages of infection, because random samples of leaves can easily miss the scattered few that carry the bacterium. Dogs, on the other hand, sample the whole tree with a sniff and pick up the scent of huanglongbing within a few weeks of infection and with remarkable accuracy.

Earlier this year, plant pathologist Tim Gottwald of the US Department of Agriculture reported results of trials with sniffer dogs. He and his colleagues trained dogs to recognize the scent of the huanglongbing bacterium and to sit whenever they detected it. When put through their paces, the dogs identified infected trees with 99 percent accuracy and as early as two weeks after infection. "With dogs, we've moved on from a situation where it wasn't possible to eradicate the disease to one where it is," Parnell says.

Szaboles the sniffer dog, seen here in a California orchard, is on the front line in the battle against huanglongbing, also known as citrus greening. (T. Gottwald / USDA-ARS)

The ones that got away

But if it's too late to stop a killer disease from spreading, what then? Are we doomed to a treeless landscape? "No," Buggs says. "We will have trees, but they won't be the same ones." One option is to plant related but resistant species from a pathogen's original haunts. In the UK, even in Brighton, unfamiliar sorts of elms have begun to appear in parks and gardens. But such alien trees are out of place in native woodlands.

In the US, a nation still mourning its lost chestnut forests, scientists are pursuing two other strategies for resurrecting them. One is to cross native trees with resistant Chinese ones, then increase the American component by backcrossing with native trees. The hoped-for result is an almost-American chestnut that won't succumb to blight. The second, more controversial strategy is to slip a resistance gene into the tree's DNA, to produce a transgenic chestnut.

Better than any of these options is to work with native trees, encouraging the evolution of resistance — naturally, or with a helping human hand.

The devastation caused by ash dieback prompted urgent research to find ways of preserving Europe's native species. Observations from surveys and trials across Europe suggest that there are a few trees in every wood that exhibit some tolerance to the dieback fungus. "Between 1 and 5 percent stay healthy, but the number of trees that survive with some damage is higher," Buggs says. Critically, there is also evidence that at least some of that tolerance is genetically based and can be passed on to offspring. "So if we leave healthy-looking trees standing and let them regenerate from seed, then their offspring are more likely to be resistant," Buggs tells me. "Eventually, that should lead to populations of trees adapted to withstand the fungus."

That is a long, slow process. But there is a way to accelerate and improve on nature's efforts, by identifying trees with resistance genes and designing a breeding program that strengthens their progeny's defenses.

Almost as soon as dieback was spotted in England, Buggs started to sequence the ash genome, publishing the work in 2016. Last year, he and colleagues at Queen Mary University of London and elsewhere reported that multiple genes are linked to resistance. If those genes have additive effects, then careful crossbreeding should produce trees with even greater resistance. "I'm optimistic," Buggs says. "If we accept that lots of ash trees will die, in the long term we will still have native ash because they do have the genetic basis for resistance. And because that's based on many genes it makes it harder for the pathogen to evolve to overcome the tree's defenses."

By January, 3,000 ash saplings had been planted at a secret location in southern England. These young trees have all been propagated from the shoots of trees that showed some signs of tolerance. Together, they form the Ash Archive, a living library of genes for researchers to study and breeders to draw on in their quest for trees that will restore ash trees to the landscape.

Lest we forget, new invasions are not the only worry. Old enemies are still with us, including Dutch elm disease. Since the onslaught of the 1970s, elms that escaped infection because they were too small to support breeding beetles, and trees regenerated from surviving elm roots, have reached maturity. As soon as they are large enough, though, the beetles return and set off new cycles of disease.

Here in Elm City, the arboriculturists can't ever lower their guard. Each year, a few more elms are quietly felled and burned. Late last year, sad memories were reawakened when a chainsaw gang set to work on a national icon — one of sibling elms known as the Preston Twins. This venerable pair, thought to be the oldest and largest elms in the world, were planted in 1613 — when Shakespeare was still writing plays and the Pilgrim Fathers hadn't yet left England. The only consolation is that the loss of our much-loved Methuselah thrust the issue of travelling tree-killers back into the limelight, exactly where it needs to be.