SPLINTERS OF THE AMAZON

Decades after Thomas Lovejoy isolated fragments of the Brazilian rainforest in a grand experiment, researchers are building on his legacy around the world.

BY
JEFF TOLLEFSON

Ecologist Thomas Lovejoy tucks his trousers into his socks with a casual warning about chiggers and then hikes off into the Amazon jungle. Shaded by a tall canopy and dense with ferns and underbrush, the old-growth forest looks healthy, but Lovejoy knows better. Three decades ago, the surrounding forest was mowed down and torched as part of a research project, and the effects have spread like a cancer deep into the uncut area. Large trees have perished. The spider monkeys have moved out, as have the army-ant colonies, and many of the birds that depend on them.

Lovejoy and his team have been studying this 10-hectare fragment of forest since the late 1970s as part of the largest and longest-running experiment in tropical ecology. In collaboration with ranchers, they cleared the trees around this and ten other plots of varying size to create islands of intact forest. The researchers have been monitoring the plots ever since, documenting how deforestation harms the adjacent untouched forest as specialist plants and animals gradually give way to generalists and pioneer species that prefer disturbed habitat. "We are chronicling the simplification of these forests," says Lovejoy, a professor at George Mason University in Fairfax, Virginia.

Covering roughly 1,000 square kilometres in an area north of Manaus in the central Amazon, the experiment was set up to test fundamental theories about the viability of small, disconnected ecosystems. By documenting pervasive changes in the forest fragments, Lovejoy and his co-workers provided the first hard data that conservationists needed to promote the preservation of extensive areas of intact forest. "It's the most important ecological experiment ever done," says Stuart Pimm, a conservation ecologist at Duke University in Durham, North Carolina, who has collaborated on the project. "We knew that small and isolated was bad, but we needed to know how bad."

The researchers are now exploring the long-term effects of habitat fragmentation, but the ecological record there is ironically threatened by forest that is taking over abandoned pastures. Although Lovejoy has struggled to maintain financing for long-term monitoring, the US National Science Foundation is breathing new life into the project by funding the team to isolate some of the plots anew.

The experiment has also helped to train and inspire a generation of 'fragmentologists', who are working around the world to understand the cascade of ecological impacts that follow human development. Most notably, in early April, an international team started chopping down trees in Borneo as part of an nearly £6-million (US$9-million) experiment that replicates and extends the Brazilian one.

"The Amazon experiment changed the game," says Rob Ewers, principal investigator on the Borneo project at Imperial College London. "I like to think of our project as the next step."

THE AMBASSADOR

"Welcome to Camp 41," says Lovejoy, beaming at a group of guests he invited to tour the experiment — and do a little bird-watching — over New Year's Eve, an annual tradition. Fit at 71, he has a slight paunch, a crop of thinning hair and pale skin that is a touch reddish from the heat and the hike to his forest base. Lovejoy offers a quick tour of the open-air shelters that house hammocks and dining facilities as well as the bathrooms, showers and a makeshift pool down a trail by the stream. Over the years, he has entertained a long list of high-profile guests here, ranging from Al Gore (when he was a senator) to actor Tom Cruise and high-ranking Brazilian officials.

Lovejoy has always served as a scientific ambassador and chief fund-raiser, and left the fieldwork to others. After cleaning up from a day tramping around the forest, he sits beneath a cashew tree and begins plying his guests with caipirinhas, the national cocktail of Brazil. Peering over wire-framed glasses, he guides conversations about the strange beauty of tropical creatures, environmental policy and the history of science and development in the Amazon. Darkness falls, and an orchestra of frogs claims the forest.

Lovejoy arrived in the Amazon to study birds as a graduate student from Yale University in New Haven, Connecticut, in 1965, just as concerns about development in the region were rising among scientists and politicians. That same year, Brazil enacted its modern Forest Code, which at the time required ranchers and farmers in the Amazon to maintain a 'legal reserve' on 50% of their land (the legal reserve is now 80%).

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'Islands' of forest near Manaus, Brazil, are allowing researchers to see how deforestation affects the local ecology.

Two years later, entomologist Edward O. Wilson and biologist Robert MacArthur published their influential *The Theory of Island Biogeography*, which laid the foundations for the modern understanding of species diversity and rates of extinction in isolated habitat, whether surrounded by water or by agricultural fields.

Soon after Lovejoy earned his PhD in 1971, ecologists became embroiled in what became known as the SLOSS debate, which stood for 'single large or several small'. The question was whether it would be better to protect massive continuous landscapes or many smaller biodiversity hotspots. Lovejoy thought about the Brazilian law and realized that the legal reserve could provide a way to probe these questions. "The ranchers were going to clear the land anyway," he says. "My crazy idea was that maybe you could arrange the 50% and create a giant experiment."

The project kicked off in 1978, with $500 a month from conservation group the WWF and the support of the Brazilian National Amazonian Research Institute (INPA) in Manaus. Lovejoy hired another former student from Yale, ecologist Rob Bierregaard, to run the project. A year later, he and a team of Brazilian scientists began surveying the forests areas they were planning to isolate, which came in sizes of 1, 10 and 100 hectares (see 'Fractured forest'). The first wave of machetes and chainsaws came through in June 1980, and in September, Bierregaard's team walked the perimeter of the plots, dripping burning rubber onto forest debris. When the conflagration died down, the first two square patches of old-growth rainforest were left standing amid swathes of smoking embers that remained hot enough to cook the crew's beans for days.

The early phase of the experiment was hardly smooth. The Brazilians complained that it was too much of a US initiative, and the ranchers were slow to clear the rest of their land. One year passed, then two. "It was really frustrating," says Bierregaard, who is now at the University of North Carolina at Charlotte. "We were publishing totally unreplicated results from the 1- and 10-hectare reserves."

By 1983, rather than waiting for the ranchers, Lovejoy secured more funding from the WWF to create another pair of fragments. The results began rolling in immediately, with the edges of the plots showing a substantial loss of key species. Yet, as the experiment grew, Lovejoy's team soon had more data than it could deal with, and in 1996 he brought on Bill Laurance to help make sense of the plant data. In 1997, Laurence and the team reported that up to 36% of the biomass in the first 100 metres of the forest fragments had disappeared in 10–17 years of isolation[1]. "It really taught people how edge effects are driving rapid changes in ecology," says Laurance, who is now stationed at James Cook University in Cairns, Australia.

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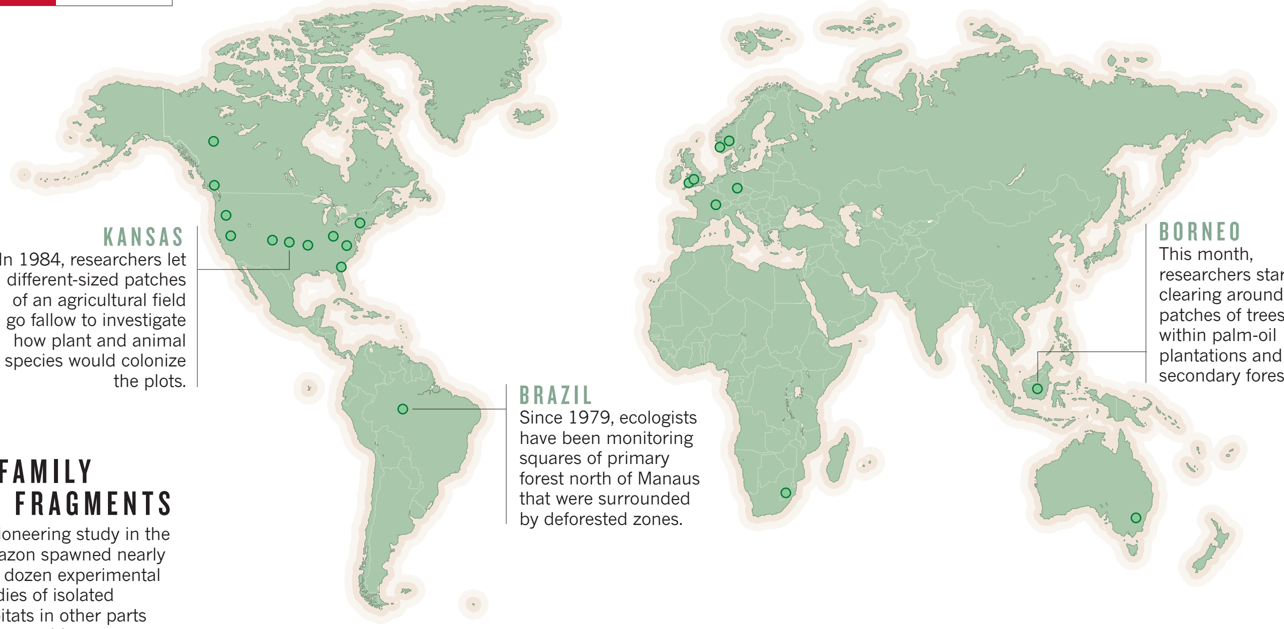
The main drivers are sunlight and air circulation. As the pastures and forest edges heat up each day, the air over those regions rises, drawing cool moist air out of the forest. The hot dry air takes a toll on large hardwood trees such as mahogany and ebony. The open fields also expose the forest to wind, which blows down trees and further opens up the canopy. Over time, these gaps are filled with fast-growing trees and vines. These pioneer species eventually seal off the forest like a scab, helping to delay further impacts, but neither the carbon density nor the diversity of the forest recovers quickly. Today, the researchers continue to track these effects as they work their way through the forest.

Those early results suggested that scientists were underestimating the broader impact of fragmentation, and in 1998, Laurance extrapolated the findings across the



A FAMILY OF FRAGMENTS

A pioneering study in the Amazon spawned nearly two dozen experimental studies of isolated habitats in other parts of the world.

tropics. His team's calculations suggested that the biomass loss around forest edges could produce up to 150 million tonnes of carbon emissions annually[2] — exceeding emissions from the United Kingdom.

In 2003, Lovejoy and his fellow fragmentologists took their first stab at one of the questions that had originally inspired the project: how big is big enough? Documenting a 50% decline in the number of bird species living beneath the canopy in the 100-hectare plots over the first 15 years of isolation, they derived a kind of half-life for extinction: the time it takes to lose half of the species increases roughly tenfold with a 1,000-fold rise in the area of a reserve[3].

The calculations were based only on birds and may not capture the ecological dynamics of larger reserves. But for Lovejoy, they suggest that a reserve would need to be on the order of 100,000 hectares in area to maintain relatively stable levels of biodiversity. Given that it is impractical in most places to set aside such large areas, this suggests that most fragmented landscapes around the globe may be doomed to a continuing decline in biodiversity.

Yet, the fragment experiment also points to a possible solution: the secondary forests that have sprung up in abandoned pastures. The regrown forests created wildlife corridors, which allowed army-ant colonies, birds and howler monkeys and other small mammals to migrate from intact forest into the experimental plots. For Pimm, those findings served as a call to action. In 2005, he created a non-profit conservation organization called SavingSpecies, with a goal of identifying biodiversity hotspots such as Brazil's Atlantic rainforest that would benefit from habitat corridors — a kind of lifeline to the remaining forest.

"This is where the science comes together with the strategic and tactical conservation efforts," Pimm says. In 2007, his group and its partners purchased a ranch that separated a small population of endangered golden lion tamarins from a larger forested area. After the team moved out the cattle and replanted some areas, secondary forest started to grow. Last year, the researchers saw the first evidence of golden lion tamarins and cougars moving through former ranchland. "Our bet on studying forest fragments paid off," he says.

Looking forward, Lovejoy says that many crucial questions remain about the processes playing out in the fragmented ecosystems. How many of the species in the plots are doomed to extinction? How quickly and deeply will these impacts move through the fragmented forests? Will rapid shifts in insect and other animal populations drive long-term changes in seed dispersal and thus plant diversity? And what role will global warming have?

Continued monitoring of the fragments could produce some answers, but the secondary growth around the plots has undermined the viability of the experiment. The US National Science Foundation provided money for a new bout of clearing later this year, which is part of a larger $450,000, five-year grant to continue bird research there. "This grant will extend our record to nearly 40 years," says Phil Stouffer, an ornithologist at Louisiana State University in Baton Rouge and principal investigator on the grant. For Lovejoy, it is a new lease on life for the experiment.

As the project continues, long-term data from the fragments and from the larger control plot in the adjacent primary forest could be invaluable for studying the impacts of global warming, says Adalberto Val, who heads the INPA, which provides part of the half-million-dollar or so annual operating costs of the experiment. The rest comes from the Smithsonian Tropical Research Institute in Panama and various foundations. He calls the forest-fragments project a "scientific treasure".

GLOBAL SPREAD

In 1984, a team led by Robert Holt, now at the University of Florida in Gainesville, implemented one of the first follow-on studies, focusing on experimentally designed patches of secondary regrowth amid the agricultural fields of Kansas (see 'A family of fragments'). By 1990, another four projects were under way, and a survey published in 2003 identified a total of 21 fragmentation experiments of various scales and durations[4]. Andrew Gonzalez, an ecologist at McGill University in Montreal, Canada, has replicated Lovejoy's experiment at the bench- and chamber-scale with isolated patches of moss; he has used the results to inform his own work on wildlife corridors in Montreal[5].

The experiments have produced a range of results, but most of them confirmed significant impacts along the edges of the fragments that broadened over time. And the subsequent studies have reinforced the findings that habitat corridors can help to sustain the isolated fragments.

Lovejoy's latest scientific progeny — third-generation fragmentologist Ewers — initially worked in the Amazon as a 25-year-old postdoc under Laurance. Ewers first visited

Camp 41 in 2004 while conducting unrelated research on deforestation. He is now setting up a similar experiment in the state of Sabah in Borneo. Whereas Lovejoy's experiment focused on primary old-growth forest, Ewers wanted to observe the evolution of landscapes that have already been degraded and transformed by humans — something more representative of modern environmental realities. He set up fragments in logged forests and palm plantations as well as plots within forest reserves to investigate the ecological and conservation value of different landscapes.

"The general idea of Lovejoy's project was just breathtaking 30 years ago," says Ewers. "But we have new questions today, and I think we are in a much better place to make sense of these data in the long run."

His initiative, known as the Stability of Altered Forest Ecosystems (SAFE) project, is receiving some £6 million pounds in core funding over ten years from the Sime Darby Foundation in Kuala Lumpur, the philanthropic arm of one of the world's largest palm-oil producers. Forty-two plots mirroring the sizes used in the Amazon project will be located at various distances from the surrounding forests. Dozens of scientists have been surveying the sites, and the project now has data on 3,000 to 4,000 tropical species, from ants and beetles to birds, bees and trees — a database much larger than the one Lovejoy and Bierregaard were able to compile at the outset of their experiment. After a year's delay, loggers fired up the chainsaws on 4 April.

The unpublished baseline data show a landscape severely affected by development. For instance, the average amount of carbon locked up in trees in the primary forests has been estimated at 243 tonnes per hectare, compared with 49 tonnes per hectare in logged forest and just 4 tonnes per hectare within palm plantations. And yet, while many logged forests have been hard-hit ecologically, they still show pockets of remarkable biodiversity, including all five of the native cat species.

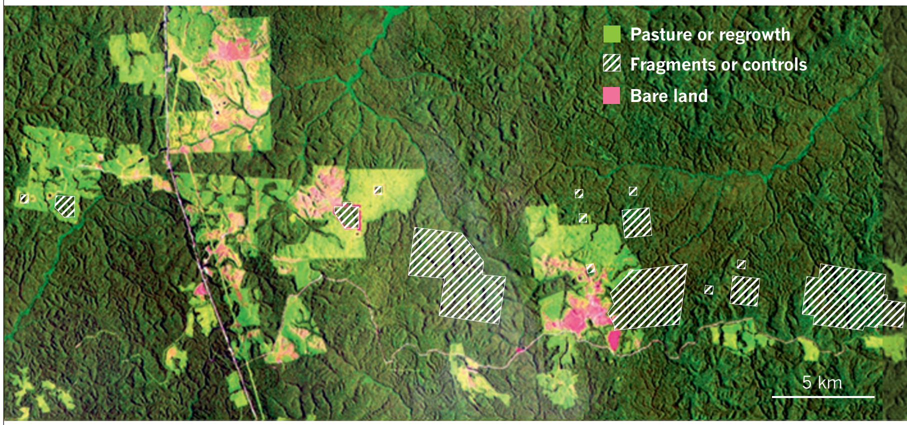
Ed Turner, an ecologist at the University of Cambridge, UK, who helped to set up the experiment, says that the project is designed to inform discussions about how to conserve habitat in a region dominated by palm-oil production. "The lessons from SAFE have the potential to have a very far-reaching effect," he says.

Another component of the Borneo project will focus on how nitrogen and other nutrients move through soils and plants, with the goal of understanding the biogeochemical processes at work throughout the forests as they are affected by fragmentation. The UK National Environmental Research Council is expected to announce in the coming months nearly £5.7 million for a series of projects focused on the relationship between biodiversity and biogeochemical cycles. For example, initial surveys have suggested that leaf litter decomposes roughly twice as fast in logged and primary forests as it does in palm-oil plantations. Once scientists have isolated fragments in each of these systems, they will be able to track changes in the decomposition rates as edge effects take hold, then relate those changes to soil nutrient cycles and impacts on plant communities.

"It's about doing fundamental science to help us understand what happens to a forest when you change it in these ways," says Ken Norris, an environmental biologist at the University of Reading, UK, and biodiversity theme leader for the UK National Environmental Research Council. "And if you are going to do ecosystems science, you need experiments outdoors at the scale at which these systems work."

Surveying the ongoing work, Lovejoy is pleased to see that his crazy idea still has legs. The project in Borneo will advance the field, perhaps leading to new collaborations and comparative studies with researchers at his own experiment in the Amazon. "I started out thinking this would be a 20-year experiment, and then I would get the answer and we would be done," he says, gazing into the rain one afternoon at Camp 41. "It turned out to be more complex. So many new questions arose."

In the end, he says that much of the project's impact — and his own — has come from broader educational and advocacy efforts that have advanced conservation initiatives in Brazil and around the world. He notes that Brazil has now protected nearly half of its share of the Amazon, more than scientists like himself could have hoped for several decades ago. He also points to the hundreds of Brazilian scientists who have moved through the project, including people such as Rita Mesquita, a researcher at the INPA who first came to the project as a student in 1985 and rose up to become scientific coordinator and an important state environmental official.



LANDSAT IMAGE COURTESY OF BDFFP

FRACTURED FOREST

The Biological Dynamics of Forest Fragments Project in Brazil has experimental plots of primary forest ranging in size from 1 hectare to 100 hectares located within cleared pastures.

Lovejoy says that the scientific value of the Amazon fragment experiment only increases with time. Basic questions about the rate of species extinctions in fragmented habitat still plague the field of ecology, and the fragments provide a unique way to explore the issue. Ultimately, he envisages raising enough money to buy the ranchland surrounding the project and then convert it into an educational facility for science and ecotourism, and he has a new advisory board that is looking into options.

"If we can get this place stabilized and institutionalized, we could do a lot of things," he says. One way or another, he seems confident that the research will continue. "Even if my plane goes down on the way to Miami, I think it will happen."

Lovejoy falls silent, and the murmur of rainfall envelopes Camp 41. After a pause, he heads for the hammocks to join his guests for an afternoon nap. Soon enough, the rains will stop and Lovejoy will once again don his safari hat and binoculars, and set off to explore the fragmented forest. ■

Jeff Tollefson *covers energy and environment for* Nature *from New York.*

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