# An Experiment for All Seasons

In probing fundamental ecology and forcing scientists of all stripes to work together, the NSF's LTER network has proved a smashing success

Eleven years ago, Mark Harmon drove deep into an Oregon forest, dug some pits, and buried 500 purse-sized mesh bags stuffed with pine needles, sticks, roots, and leaves. He wasn't the only one engaging in this bizarre behavior. At the same time, colleagues were burying similar bundles at 28 sites across the continent. Every so often, somebody exhumes one of these now-redolent bags and ships the contents off to Harmon's lab at Oregon State University in Corvallis.

An odd variation on the children's game of buried treasure? Not quite. Harmon and his colleagues are ecologists engaged in an experiment that has yielded an important result: Leaf litter in North American forests retains more carbon than anyone had expected. That discovery should lead modelers to tweak estimates of how much carbon dioxide land plants are capable of sopping up, a crucial factor in global warming predictions. Just as important, Harmon says, is the transformation he and his colleagues have undergone: "We proved that people actually would work together at this scale."

The litter-decomposition study is a product of a big-science approach to ecology: the Long Term Ecological Research (LTER) network and its grand ambition of understanding ecology's sweep through time and across space. The largest single project in ecology, involving over 1200 scientists and students, the LTER network of 24 sites includes habitats as diverse as a tropical rainforest in Puerto Rico, Antarctica's dry valleys, prairie in the U.S. heartland—even the inner cities of Baltimore and Phoenix. Findings tend to emerge after many years and require untangling short-term perturbations such as hurricanes and pest outbreaks from long-term imprints such as global warming. The LTER network "has moved long-term change of ecosystems front and center on the ecological agenda," says Stephen Carpenter of the University of Wisconsin, Madison.

**Mountain of data.** Research at the Niwot Ridge LTER in Colorado has yielded decades' worth of insights into an alpine ecosystem. In this 1953 photo, scientists collect weather data at the 3743-meter site in the Rockies.

By all accounts, the 21-year-old program has been a big hit, churning out high-impact studies on everything from the effects of global warming on Arctic tundra and Western grasslands to how a glut of nitrogen pollution is altering forest ecosystems (see table). "LTER has already paid enormous dividends," says Bill Heal, who recently retired from the U.K. Centre for Ecology and Hydrology in Scotland.

LTER has also been a huge sociology experiment. It has forced scientists to pool data, glean patterns across habitats, and forge ties between the natural and the social sciences. The megacollaboration has produced a "healthy tension" between independent-minded scientists and those who thrive in packs, says Ingrid Burke of Colorado State University in Fort Collins. As a result, the network's full potential has yet to be tapped. Still, LTER is having a lasting effect on the field of ecology, spurring it toward a new, more open culture. As Harmon says, "It's been quite a profound change."

**LTER SELECTED GREATEST HITS**

| Findings | Sites | Length of record |
|---|---|---|
| Ecosystem-based forest management | Andrews, Coweeta, Hubbard Brook | 30–40 years |
| Global warming is altering or could alter plant diversity | Toolik Lake, Bonanza Creek, Shortgrass Steppe | 10–20 years |
| Plant ecosystems diverse in species are more stable and productive | Cedar Creek | 15 years |
| Forests are becoming overloaded with nitrogen from anthropogenic sources | Coweeta, Harvard Forest, Hubbard Brook | 14–38 years |
| Grazing can enhance biodiversity, reduce exotic plant invasions | Konza, Shortgrass Steppe | 10–60 years |
| Farmland can be managed to sequester carbon, release less nitrous oxide | Kellogg | 1–10 years |
| Lake species invasions, acidification effects have long time lags | North Temperate Lakes | 7–20 years |
| Hantavirus risk predicted from El Niño effects on deer mouse populations | Sevilleta | 10 years |
| Rainfall patterns and species primarily determine biome productivity | 11 LTER sites | 20 years |
| Freeze and thaw dates of lakes worldwide indicate warming trend | North Temperate Lakes, 41 non-LTER sites | 150 years |
| Small streams contribute more than large streams to cleansing nitrogen pollution | 12 sites, including eight LTERs | 42 days |

**All together now**

The grandfather of long-term ecological research sites is Rothamsted Manor in England. Set up in 1843 as an experimental farm, the project has since blossomed into an important research effort on grassland biodiversity (see facing page). It wasn't until the next century that long-term ecology began to catch on in the United States. One influential site was Hubbard Brook in New Hampshire, where in the 1960s researchers began studying how ions moved from rainwater through land to streams in a logged watershed—findings that led to the discovery of acid rain. Then around 1970, the International Biological Program (IBP), an ensemble of studies in 44 countries, including research on five biomes in the United States, produced the first detailed analyses of what controls how nutrients such as carbon and nitrogen move through ecosystems—

CREDITS: (TOP) COURTESY TODD ACKERMAN/NIWOT RIDGE LTER

## Where the Grass Never Stops Growing

**HARPENDEN, U.K.**—A 16th-century manor house with manicured lawns and nonchalant tabby cats in the heart of rural England seems an unlikely place for one of the world's longest running experiments. But Rothamsted Manor and its ecological research station are far from ordinary. "There are no other long-term studies of this kind in existence," says David Tilman, director of the University of Minnesota's Cedar Creek Natural History Area.

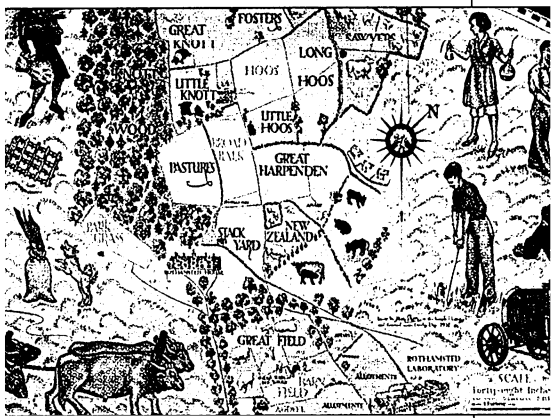
One experiment, in particular, has inspired Tilman and generations of ecologists that came before him. The Park Grass experiment, which analyzes how grassland communities respond to variations in nutrient levels, has been paying scientific dividends since the 19th century. "Any ecologist who has wandered through Park Grass in summer couldn't help but generate a whole series of novel ecological hypotheses," says Tilman.

Park Grass was the brainchild of Rothamsted's former owner, John Lawes, who had made a fortune from a patented process for producing phosphate fertilizer. He started nine long-term ecological and agricultural experiments between 1843 and 1856. While one experiment was abandoned in the late 1800s after a severe nematode infestation, the other eight have continued to this day.

Lawes divided the 2.8-hectare Park Grass plot, originally native grassland, into sections to test the nourishing effects of inorganic fertilizers such as sodium nitrate and ammonium sulfate against those of traditional farmyard manure. These treatments have remained largely unaltered since 1856, although some plots have been further subdivided and limed or have had treatments halted to assess whether they might revert back to wild grassland. Realizing that his experiments appealed to scientists as well as farmers, Lawes upon his death left a substantial endowment to keep the work going. "He was an incredibly foresightful man," says Tilman. The endowment still funds the experiments.

The fertilizers have had a profound effect on the diversity of the plant communities, says Peter Lutman, a weed ecologist at the Institute of Arable Crops Research at Rothamsted. Plots with heavy applications of nitrogen now have few species, sometimes only one or two grasses. Untreated plots, meanwhile, have maintained 50 to 60 species of grasses, broad-leaved plants, and leguminous plants.

Park Grass's longevity has taught ecologists some unique lessons. "Plenty of so-called 'long-term experiments' are in fact showing transient dynamics," says Jonathan Silvertown, a plant ecologist at the Open University in Milton Keynes, U.K.. Park Grass, on the other hand, has shown that a grassland community, after its nutrient balance is altered, takes up to 60 years to reach equilibrium. Says Silvertown, "This is very frustrating for the average researcher experiencing a normal [career] of 40 years!"




**Deep roots.** This 1932 map of the Rothamsted estate depicts Park Grass and other experiments that continue to this day.

Park Grass and other Rothamsted experiments also offer invaluable archives of dried plant material. "It's like a well that ecologists can dip into whenever they want to test a new idea," such as possible mechanisms of competition or theories on ecological stability, says Tilman. Others use archival samples as controls for studies on the accumulation of pollutants such as PCBs; much of the material was collected before such contaminants even existed.

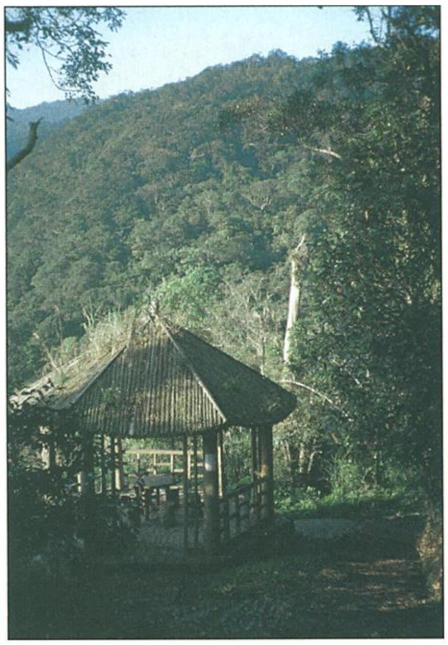
Most ecologists agree that Lawes's legacy is likely to yield many more insights—making the continuation of the experiments all the more vital. "Long-term data sets of this kind," says Tilman, "have a tendency to surprise you."

—**JOHN PICKRELL**

information still used in global carbon models. The IBP, says forest ecologist Jerry Franklin of the University of Washington, Seattle, offered "incredible lessons in the need to be able to look at responses over a long period of time."

Whereas most countries lost enthusiasm for funding such work once the IBP ended, Franklin and the U.S. National Science Foundation's Tom Callahan persuaded NSF top brass in the late 1970s to continue supporting an IBP-like effort. Their argument was that scientists would pursue long-term experiments only if they had long-term funding. NSF held several planning workshops and in 1980 christened a new network of five sites the LTER.

Each of the now two dozen sites must collect data on basics such as weather conditions, nitrogen and carbon levels, and vegetation growth measured by clipping and weighing leaves, twigs, and roots. Beyond these core tasks, the sites undertake research tailored to their regions: probing the ecology of hantavirus in the southwestern U.S. desert, for instance, or studying how increased water flow from the Florida Everglades restoration will change the region's food web.



**Going global.** U.S. ecology sites have inspired sites worldwide, including Taiwan's subtropical Fu-shan Forest.

A 10-year review chaired by Oregon State University ecologist Paul Risser urged the program to involve social scientists to probe more assiduously how humans alter ecosystems as well as search for solutions to environmental problems (*Science*, 15 October 1993, p. 334). In response, NSF added the Phoenix and Baltimore sites to plumb such questions as how neighborhoods contribute to watershed pollution and which species thrive in cities (*Science*, 22 October 1999, p. 663). Four coastal sites were also folded into the LTER program to give it more depth.

Prodded by the Risser panel, the LTERs have stepped up efforts to exploit their massive data troves. Some of the current work is aimed at developing software that can yoke together disparate databases, to eventually allow scientists to type in search terms related to topics such as climate and gather information from all the sites. The network also agreed to a policy in 1997 requiring investigators to post most data sets on the Web within 2 to 3 years. Anyone who wants to use them needs only notify the owners by e-mail and cite the source. "People had a lot of con-

CREDITS: (TOP TO BOTTOM) COURTESY OF IACR ROTHAMSTED, UK; TAIWAN ECOLOGICAL RESEARCH NETWORK cerns about whether we could do that" without scientists losing credit for having compiled the data sets or losing out to rivals who interpreted the results more quickly, Burke says. But the system seems to be working. Seeing a paper come out—without her name on it—based partly on her soil data from the Shortgrass Steppe site in Colorado took some getting used to, Burke says, but she's glad to see it help advance the science. "It's more valuable if you let it go," she says.

Perhaps the most far-reaching change brought by the Risser panel is a more panoramic view: research projects that span several LTER sites. Such projects often come at a premium, in both cost and good will. For instance, the leaf-rotting experiment, known as LIDET, gave NSF reviewers "sticker shock" because of the hundreds of thousands of dollars necessary to analyze the rotting vegetation, Harmon says. Then after the experiment got the thumbs up, he and others had to persuade reluctant colleagues to cast in on multiauthor papers. "You used to work in your own little universe. Now if it stops with your own, you're missing the boat," Harmon says. "It's a really important new way to think about ecosystems."

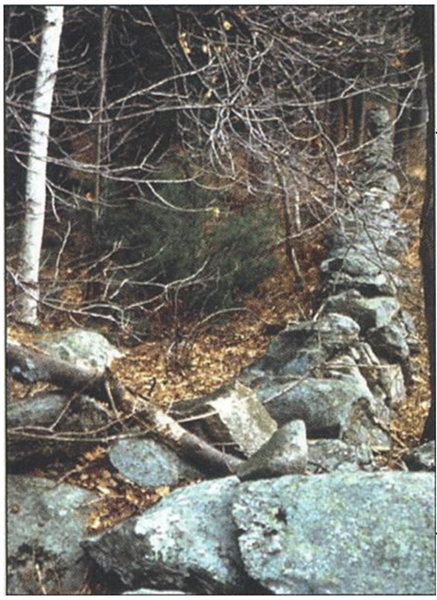
**Lonely hearts club**

The push toward collaborative research has met with some resistance. "There's a very healthy and active tension between top-down and bottom-up: how much NSF should be dictating, and how much freedom" sites should be given, says David Foster of the

## Divining a Forest's Future From Its Past

PETERSHAM, MASSACHUSETTS—Standing amid towering hardwoods and pines in a hushed upland forest, one might assume that this New England landscape looks much as it did when the Pilgrims first set foot on Plymouth Rock nearly 4 centuries ago. But subtle clues give away the epochal change this forest has endured. A crumbling stone wall reveals that this spot was once a farmer's field. And stooping beside a meter-wide pit, ecologist David Foster points to the soil, a uniform brown that could have gotten that way only by plowing. These reminders of long-gone human activity explain why white pines, not oaks, are creaking in the breeze: They're the first tree species in the area to colonize an abandoned field.

"We've come to realize you need to have a very deep sense of history and long-term processes to understand ecosystem structure and function," says Foster, who heads the Harvard Forest Long Term Ecological Research (LTER) site, part of a network supported by the National Science Foundation (see main text). The imprint of European settlers is felt in everything from the communities of beavers and moose roaming these woods to how long New England's resurgent forests can continue to sop up carbon dioxide ($CO_2$), the primary villain behind global warming.



**In a former life.** Fading signs of human habitation suggest how the Harvard Forest has been transformed since the region's agriculture industry peaked in the mid-1800s.

The Harvard Forest is a pioneering site in the emerging discipline of historical ecology. Research here started in 1907, when a group led by forester Richard Fisher "immediately began documenting the way the land was used and the history of natural disturbance," Foster says. They started with 1830, by which time 80% of the central Massachusetts old-growth forest had been cleared for agriculture. Many farmers, driven out by more profitable operations in the Midwest, then left for jobs in cities. Trees have been returning ever since.

The region's rich ecological history has many subplots that fascinate researchers. For instance, in 1938 a hurricane cut a devastating swath, spinning north from Long Island before losing strength in Quebec. Its 167-kilometer-an-hour winds flattened trees across a 100-kilometer-wide stretch of New England, where loggers then carried out the largest timber-salvage operation in U.S. history. The Connecticut and Merrimack rivers ran higher than normal for the next 5 years, reflecting the carnage wrought across the watersheds.

One of the first projects that Foster and colleagues undertook when their site joined the LTER network in 1988 was to reenact the 1938 hurricane by yanking down 250 trees in a stand of hardwoods. Instead of salvaging the timber, they let sleeping logs lie. To their surprise, toppled trees leafed out for years and seedlings sprouted, so the forest continued to evaporate water through leaves. That meant the forest's ability to return precipitation to the atmosphere didn't change much—unlike the dramatic runoff that occurred 60 years ago. The message, says Foster, is that "if you want to maintain ecosystem processes [after a hurricane], the absolutely best way you can do that is to leave the forest intact." The experiment, says forest ecologist Jerry Franklin of the University of Washington, Seattle, "made my jaw drop. ... It's just incredible how it illustrated that natural disturbance works a lot differently than we thought it did."

Other studies are sifting the shards of the Harvard Forest's ecological past for clues to future climate. A tower draped with cables set up in 1989 gauges the forest's $CO_2$ appetite by sniffing the gas wafting in and out, a project that spurred a national network of $CO_2$ towers. Elsewhere in the Harvard Forest, dish plate–sized white plastic rings embedded in the ground capture $CO_2$ venting from the forest floor. The rings are helping researchers untangle the roles of roots and soil microbes in storing carbon. Heaters beneath some plots simulate how much carbon will be released by 5 degrees Celsius of warming. At first the heated plots leaked more carbon, but after 10 years they are now stabilizing. If the study had stopped after 3 years—the typical length of a research grant—"our conclusions would be very different," says Paul Steudler of the Marine Biological Laboratory in Woods Hole, Massachusetts, perhaps painting an overly dire picture of carbon escaping from soils indefinitely.

**An Arboreal History**

| | |
|---|---|
| **early 1700s** | Homestead clearing begins |
| **mid-1800s** | Height of clearing |
| **circa 1850** | Farms are abandoned, forest regrowth begins |
| **1907** | Harvard Forest research begins |
| **1938** | Devastating hurricane |
| **2001** | 80% of New England is now forest |

This summer, the 40 Harvard foresters are hoping to complete a decade-long odyssey to state archives and town halls across Massachusetts, where they have been collecting maps from an 1830 survey that detailed land use in every township. These records will help inform which habitats are the highest priorities for conservation. "This is an arcane activity, dredging up these maps," says Foster. "Yet they become a vibrant part of conservation and ecological sciences." To a historical ecologist, the past is where many answers to tomorrow's problems lie. **—J.K.**

CREDIT: DAVID FOSTER

Harvard Forest LTER, a trailblazing project in historical ecology (see sidebar on p. 626).

Indeed, not every site leader shares the communal spirit. David Tilman of the University of Minnesota, Twin Cities, admits he shuns most network meetings and leaves collaborative studies to others at his Cedar Creek site. "I personally believe that creativity in science is more of an individual than a group effort," says Tilman, who points out that the LTERs were conceived to operate independently. Adds William Schlesinger of Duke University, a soil biogeochemist at the Jornada Basin site in New Mexico, "I'm a little old-fashioned. I came up in the ranks [of people who] did everything individually." But Schlesinger says he applauds efforts by younger scientists at the sites to join forces.

And some scientists argue that the payoff of studies performed across several sites is overblown. "I'm cautious. I just don't think that's where the science is," says John Hobbie of the Marine Biological Laboratory in Woods Hole, Massachusetts. He thinks the LTER network's greater value is to bring together scientists "with common interests" to solve problems and generate new ideas for their own sites.

A more nagging problem, perhaps, is the perception among the broader ecology community that the LTER sites get more than their fair share of attention and funding from NSF. The reality, claims Jim Gosz of the University of New Mexico, Albuquerque, chair of the LTER coordinating committee, is stagnant budgets spread thinly over many sites that scientists must supplement with other grants. Nor do all sites have the right stuff. Reviews led three sites—Okefenokee in Georgia, North Inlet in South Carolina, and Illinois Rivers—to be shut down several years ago. "The sites are being asked to do far too much," says Washington's Franklin, with requirements ranging from intense data management to precollege education programs. He's hoping that a 20-year review, headed by biologists Kris Krishtalka and Frank Harris and due out by December, will recommend a boost to site budgets.

Still, the LTERs have developed a cachet that may skew some decisions in their favor. "There's a sense that every new idea that comes along is best done at one of the LTERs"—such as integrating social and ecological science—"when there may actually be a better place," says Stanford ecologist Pamela Matson, who's not affiliated with any of the sites. She hears concerns that when new funding comes along, "doors are too easily opened" to the LTERs compared to other long-established ecological research stations such as Stanford's own Jasper Ridge. While not questioning the validity of awards won by LTERs, Matson says it's "more of a worry about how things will go in the future."

**Hands across the water**

Despite its limitations, the LTER system has inspired similar projects—and new collaborations—in 21-and-counting countries. One of the first efforts at global outreach began several years ago, when U.S. and Hungarian researchers joined forces on a study of grassland biodiversity. The pooled data revealed a correlation between aridity and fewer plant species, firming up models predicting deleterious effects of global warming on arid plant communities.

Although one aim is to collect the same basic data, not all these international LTERs are carbon copies of U.S. sites; some, such as those in the United Kingdom and Canada, are focused more on monitoring than on research. Others, including China's and Taiwan's, study problems tailored to national priorities. China secured a $25 million World Bank loan in 1993 to build its 29 LTERs, which focus on helping farmers reduce erosion and boost crop yields. Western Europe has lagged behind, although French ecologists expect 10 sites to join the international network by fall.

The LTER concept may have taken off elsewhere in the world, but it has fallen short on its home turf in one big way. The Risser report urged other U.S. agencies that run ecology sites to emulate the model. Twenty-four LTERs "are not sufficient to explain continental science," explains Gosz, who thinks that about 50 sites could make greater inroads into questions such as how ecological processes change with scale, or across several types of lakes. But the advice came with no funding, and an über-network never arose.

Long-time LTER boosters say such shortcomings should not dim the program's luster. "It was an extraordinarily innovative program when NSF began it, and it has accomplished a tremendous amount of innovative science," Franklin says. "It's been a good investment scientifically. It hasn't achieved everything people expect. But holy smokes, you can't do it all."

—JOCELYN KAISER

NEWS

# The Partitioning of the Red Sea

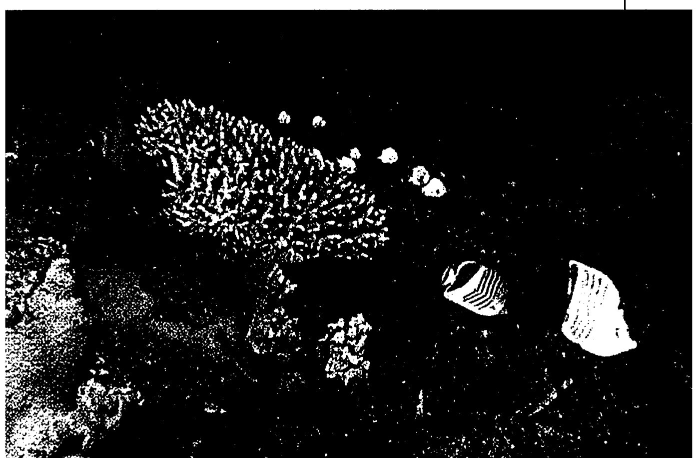
**Israeli and Jordanian researchers have embarked on a novel experiment in marine ecology—and in scientific cooperation**

For the past 2 years, marine scientists have been engaged in a remarkable new experiment in the Red Sea. While tensions in the Middle East have escalated in the wake of renewed clashes between Israelis and Palestinians, researchers from Israel and Jordan have embarked on a long-term collaborative effort to monitor coral reefs that straddle the border between their two countries.

The Red Sea Marine Peace Park aims to protect a unique but imperiled ecosystem at the northern tip of the Gulf of Aqaba. Home to 140 species of stony corals and nearly 1000 species of fish, the gulf's magnificent coral reefs are a marine biologist's delight. Particularly intriguing is why they exist at all: Nowhere else in the Indian or Pacific oceans do reef-building corals grow so far north of the equator.

Like the Long Term Ecological Research (LTER) sites (see p. 624), the young marine reserve is probing fundamental processes—such as the ebb and flow of nutrients and changes in coral cover—over many years. "There's a slew of basic science questions that this project will hopefully begin to provide some data on," says Michael Crosby, a science adviser at the Agency for International Development and the National Oceanic and Atmospheric Administration, two U.S. agencies that are helping fund and organize the park's research.

But the most remarkable aspect of the research effort is the fact that it exists at all. Although separated by only a few kilometers, the Israeli and Jordanian marine scientists had never been in contact until recently. "I remember many days sitting on the beach and



**Under siege.** Early data show that a fifth of the Red Sea reserve's corals have died off in the past 2 years.

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