Environment

taking the long view

NSF is supporting research to learn how the diverse parts of our environment—from individual species to ecosystems to global weather patterns—interact to form the world around us. A better understanding of the give-and-take between organisms and the environment is critical to the search for knowledge as well as for a healthy planet.

Although humans have been fascinated by the relationship between organisms and their environment since the days of Aristotle, ecology as a separate scientific discipline is only about a century old. Today the field is closely aligned in many minds with concerns about pollution and species extinction. The National Science Foundation began to make a serious investment in ecological research in the 1960s and in 1980 launched its pioneering Long-Term Ecological Research (LTER) program. Usually, researchers receive grants to conduct three-year studies that ask a relatively narrow range of questions. But with the LTER program, NSF has recognized that real understanding of the complex interplay among plants, animals, and the environment requires a longer and broader view. Currently more than 1,000 researchers are working at twenty-four ecologically distinct LTER sites, where studies often last for decades. The questions these NSF-funded ecologists are posing, and the answers they're getting, are emblematic of a maturing and vital discipline.

The Big Picture

A temperate coniferous forest teeming with hemlocks, red cedar, and firs. An Arctic tundra dotted with icy lakes and headwater streams. An East Coast city interlaced with deciduous trees, houses, and parks. A tallgrass prairie. A tropical rainforest. A coastal estuary. A fiery desert.

For every ecological domain on Earth, there seems to be an LTER site devoted to unmasking its secrets. Each location hosts an average of eighteen different principal investigators—often affiliated with nearby universities—who head up various studies that last anywhere from the few years it may take a graduate student to complete her thesis to the decades needed to understand the ongoing effects of, say, fire on the prairie. The sites themselves are much larger than the average experimental plot, ranging in size from the 3,000 acres under continuous study at the Harvard Forest LTER in Petersham, Massachusetts, to the 5 million acres that make up the Central Arizona/ Phoenix site.

The rationale behind the LTER program is based on conclusions that environmental scientists reached by the end of the 1970s. One conclusion is that changes in many of the most important ecological processes, such as nutrient levels in the soil, occur slowly. Relatively rare events such as flash floods have a major impact on an ecosystem, but they can only be properly studied if researchers have, in effect, anticipated the occurrences with ongoing studies. Another conclusion is that many ecological processes vary greatly from year to year; only a long-term view can discern inherent patterns. Finally, the kind of long-term, multidisciplinary databases established by LTER researchers are critical for providing a context in which shorter-term studies can be understood.

Without periodic fire, the tallgrass prairies of central North America would disappear into a woodland/shrub habitat. At the NSF-funded Konza Prairie LTER site in Kansas, researchers seek to understand the interplay of prairie and fire by subjecting sixty experimental plots to short- and long-term intervals of burning.

Although each site boasts its own array of studies designed for that particular ecological system, all studies undertaken at an LTER site must address one or more of what ecologist Steward Pickett, project director for the Baltimore LTER, calls "the holy commandments of LTER." These commandments come in the form of five questions that are fundamental to how any ecosystem functions: What controls the growth of plants? What controls the populations of plants and animals? What happens to the organic matter that plants produce? What controls the flow of nutrients and water in the system? How do disturbances affect the system?

While these five themes provide focus to individual LTER studies, they also allow researchers from very different locales to do an "apples-to-apples" comparison of their data so that even larger lessons can be learned. Clues to how an ecosystem functions are more readily apparent when scientists can compare how the same process works across ecologically diverse sites. For example, the LTER program allows researchers to observe how nutrients travel through two different types of grasslands and how grasslands differ from forests in terms of nutrient flow. To help make these kinds of comparisons, representatives from each LTER site meet formally twice a year and also communicate regularly via email and the LTER program's Web site.

Key to the success of the LTER approach, of course, are long-term funding and large-scale areas. With the proper time and space, "you can do riskier experiments," says NSF's LTER program director Scott Collins, "or you can do experiments that take a long time to have an effect, or big experiments that require a lot of space, or ones that need a certain kind of team."

Long-term studies also provide an increasingly important baseline of how the environment works—a baseline against which crucial management decisions can be measured. "As the sites are studied longer," Collins says, "their value increases [because] the findings can be applied to policy and conservation issues."

What follows is a brief tour through just a few of the LTER sites that are fulfilling the promise of long-term, large-scale environmental research. Studies at these sites have unraveled human health problems, helped to clean up the air, changed how forests are managed, exposed the effects of global change, and revealed how cities interact with their surrounding environment.

An Ecological Solution to a Medical Mystery

When young, otherwise healthy people in the remote Four Corners area of Arizona and New Mexico began dying of a mysterious acute respiratory disease in the spring of 1993, people were scared. Those who caught the disease got very sick, very quickly. Eventually twenty people died. At the time, some wondered if the disease was a biological warfare agent, a military experiment gone bad.

The Atlanta-based U.S. Centers for Disease Control and Prevention (CDC) sent scientists to the region to investigate. Tests of the victims' blood yielded a surprising result: the people had become infected with a previously undetected kind of hantavirus. The hantavirus causes Hantavirus Pulmonary Syndrome, a serious respiratory illness that can be fatal.

Named after the Hantaan River in Korea, hantaviruses were known to spread from rodents to humans but until the Four Corners outbreak, the microbes had only been seen in Asia and Europe. Moving quickly, CDC investigators asked biologists at the University of New Mexico for help in collecting rodents and insects around the homes of people who had gotten sick. A likely suspect soon appeared when the infection popped up in one particular kind of mouse.

"The CDC called us and asked, 'What mouse is this?'," says University of New Mexico mammologist and museum curator Terry Yates, who also serves as co-principal investigator at the NSF-funded Sevilleta LTER site—so-called because the site's 230,000 acres are located within the Sevilleta National Wildlife Refuge, about an hour south of Albuquerque. Yates told the CDC that the infected animal was a deer mouse, a close relative of the type of Old World mice that also carry hantaviruses and that transmit the disease through their droppings and urine.

Now the CDC knew what the disease was and how it was transmitted. But the investigators still didn't know why a disease carried by a common animal like the deer mouse seemed to be cropping up for the first time in North America. For answers, the CDC turned to what Sevilleta researcher Robert Parmenter calls "a bunch of rat trappers" who had been working on matters entirely unrelated to medical science at Sevilleta even before the site was admitted to NSF's LTER network in 1988.

The major research question at the Sevilleta LTER site was this: How do the Sevilleta's four major ecosystems (grassland, woodland, desert, and shrub steppe) respond to short-term and long-term fluctuations in climate? One way to address that question was to measure the population fluctuations of plants and animals. Climate changes affect vegetation, which in turn affects the amount and kind of food available to animals. Keeping track of the rodent populations was just one part of a multi-investigator project—but it turned out to be a crucial part of the CDC investigation.

Parmenter, who directs the Sevilleta Field Research Station, recalls being told by the CDC that "I could take all the time I wanted so long as [the rodent report] was ready by next Tuesday." He and his team of students and fellow professors "were gung-ho excited—working up the data, doing the analyses just as fast at we could."

As part of the NSF-supported LTER project in metropolitan Phoenix, Arizona State University graduate student Jennifer Edmonds collects water samples at the Salt River, east of Phoenix. The samples will be tested for nutrients and major ions as part of a project that helps researchers to better understand the relationship between urbanization and ecological conditions.

Their conclusion? The hantavirus outbreak could be blamed on El Niño, a periodic pattern of change in the global circulation of oceans and atmosphere. Parmenter's team saw in their long-term data that massive rains associated with the 1991–92 El Niño had substantially boosted plant productivity in the Sevilleta after several years of drought. A banner year for plants was followed by a banner year for rodents. Rodent populations during the fall of 1992 and spring of 1993 surged as much as twenty times higher in some places as compared to previous years. The same phenomenon likely occurred in the nearby Four Corners region. More mice meant that more humans stood a greater chance of exposure to infected rodents as the people moved among their barns and outhouses and did their spring cleaning of cabins and trailers.

Data from the Sevilleta also helped to determine that the deadly hantavirus wasn't new to New Mexico. Yates and his colleagues tested tissue samples collected from rodents prior to 1993 and detected evidence of hantavirus. In other words, the virus had been in rodents all along—it was the change in climatic conditions that triggered the fatal outbreak in humans. Such knowledge may have helped save lives in 1998, when a particularly active El Niño event prompted health authorities to warn residents of the American Southwest to be careful when entering areas favored by mice. The events of 1993 continue to be felt directly at the Sevilleta LTER, which now counts among its studies one that aims to identify the ways in which hantavirus is spread from rodent to rodent.

Yates says, "This is a classic example of basic research done for totally different reasons coming to the rescue when a new problem arises."

Contributing to a Cleaner World

LTER researchers are both medical and environmental detectives. Using many of the same skills that helped determine the cause of the hantavirus, these scientists are conducting studies that determine how pollution affects ecosystems. The results of these investigations are helping to create a healthier environment.

A case in point is the Hubbard Brook Experimental Forest, home to the longest continually operating ecosystem study in the United States. In 1955, scientists began research on the 8,000-acre site in New Hampshire's White Mountain National Forest to figure out what makes a forest tick. NSF began funding research at the site in the 1960s; Hubbard Brook joined the LTER network in 1987.

The main research aim at Hubbard Brook is suitably large scale: By measuring all the chemical energy and nutrients that enter and leave this experimental site, researchers hope to learn what makes a forest, a forest.

"The approach we use is called the small watershed approach," says Charles Driscoll, an environmental engineer at Syracuse University in Syracuse, New York, and a principal investigator for the Hubbard Brook LTER. A watershed is the whole area drained by a particular stream and its tributaries. The watersheds at Hubbard Brook span mountain valleys from ridgeline to ridgeline, encompassing the hillsides and the tributaries that drain into the streams on the valley floor. Researchers learn about the effects of both human and natural disturbances by measuring and comparing the transport of materials, such as water and nutrients, in and out of different watersheds.

The small watershed approach at Hubbard Brook has proven crucial to understanding the effects of acid rain. The term "acid rain" describes precipitation of any kind that contains acids, largely sulfuric and nitric acids. Natural processes release sulfur and nitrogen compounds into the air, where they react with water vapor to form acids. By burning gasoline, coal, and oil, humans are responsible for releasing even greater amounts of sulfur and nitrogen compounds, creating snow and rain that can carry life-stunting levels of acids into waterways and forests. By the 1970s, numerous lakes and streams in the heavily industrialized Northern Hemisphere became inhospitable to fish and other organisms. The link to forest degradation has been harder to prove, but in Europe people have coined a new word—*Waldsterben*—to describe the kind of "forest death" thought to be caused by too much acid rain.

The Birth of Long-Term Ecological Research

Today most of us take it for granted that the Earth's diverse systems, from forests, grasslands, and deserts to the oceans and the atmosphere, are interconnected. But in the early 1960s, thinking about the world as a set of interacting systems was a "totally revolutionary concept," says Joann Roskoski of NSF's Division of Environmental Biology. At the time, researchers took what the late influential ecologist Tom Callahan called a "critter-by-critter" approach, focusing on single species.

"That's fine as far as it goes," Callahan said, "but it doesn't say much about the bigger picture."

And the bigger picture is what the 1960s environmental movement was all about. During this decade, NSF helped move ecology to science's center stage by serving as the primary U.S. representative in the International Biological Program (IBP). The IBP, which was approved by the International Union of Biological Sciences and the International Council of Scientific Unions, was a controversial effort to coordinate a series of ecological projects conducted by scientific communities around the world. The program's critics charged that the IBP focus was too vague and unwieldy. Amid the controversy, NSF decided that the major aspect of the U.S. program would be large-scale projects featuring new, multidisciplinary research—specifically, systems ecology, the analysis of ecosystems by means of computer modeling, a strikingly new approach at the time. A total of five different "biomes" were studied between 1968 and 1974: western coniferous forests, eastern deciduous forests, grasslands, tundra, and desert.

The IBP helped to consolidate ecosystem ecology; resulted in a permanent increase in funding for the field; stimulated the use of computer modeling in ecology; produced smaller-scale models of ecological systems; and trained a generation of researchers. "If you now look at a lot of the leadership in American ecology today, these folks cut their teeth on IBP," says the University of Tennessee's Frank Harris, who was NSF program director for ecosystem studies in 1980.

Still, researchers and policymakers came to realize that huge projects such as the IBP ultimately had only limited applicability to the practical problems of environmental management. Attention began to turn to smaller-scale integrated projects such as the Hubbard Brook Ecosystem Study, which NSF had been funding since 1963, even before IBP. Results from Hubbard Brook, such as being able to predict how forests recover from clear-cutting and the discovery of acid rain in North America, demonstrated the power of taking an ecosystem approach to understanding the environment, but over a longer time scale than was typical of IBP projects.

Six years after the IBP ended, NSF launched its Long-Term Ecological Research (LTER) program, today's new standard for excellence in environmental science. So successful have LTER researchers been that in 1993 an international LTER program was launched after a meeting hosted by the U.S. LTER network. The international LTER effort now includes seventeen countries (with thirteen more in the wings), all of whom support scientific programs or networks that focus on ecological research over long temporal and large spatial scales.

Timothy Katz, site manager for the NSF-funded North Temperate Lakes LTER in Wisconsin, samples open-water fishes with a vertical gill net. Among the wealth of long-term data gathered from the lakes is evidence of time lags in how "invaders" affect lake communities. For example, in Sparkling Lake a kind of trout called cisco went extinct sixteen years after smelt found their way in.

Acid rain in North America was first documented in 1972 by Gene E. Likens, F. Herbert Bormann, and Noye M. Johnson at Hubbard Brook. Because Hubbard Brook researchers using the small watershed approach had long been monitoring the quality, not just quantity, of precipitation, they could tell that rainwater wasn't quite what it used to be and that the acid problem was getting worse. Their work was important in the establishment of the National Acid Precipitation Assessment Program and the passage of the landmark Clean Air Act Amendments in 1990, which mandated reductions in sulfur dioxide emissions from power plants.

Although precipitation over the United States is not quite as acidic as it was in 1972, forests are still showing worrisome signs of decline. A 1996 Hubbard Brook study determined at least one reason why: Acid rain ravages the soil's ability to support plant life.

"A lot of people thought that acid rain changes surface waters, but not the soil," says Likens, director of the Institute of Ecosystem Studies in Millbrook, New York, and lead author of the 1996 Hubbard Brook study. "This was one of the first studies to clearly demonstrate the substantial effects of acid rain on soil."

As it turned out, numerous minerals essential to life, including calcium and magnesium, dissolve more readily in highly acidic water. Thirty years of Hubbard Brook data on the chemical composition of soil, rain, and stream water showed that acid rain was and is seriously leaching calcium and magnesium from the forest soil—as rain falls, it reacts with soil minerals and washes them into the streams.

Can anything be done to bolster the soil's resistance to acid rain? In 1999, Hubbard Brook researchers set out to address this question by sending up helicopters to drop a load of calcium pellets on a 30-acre watershed that, like the rest of the forest, has been depleted of calcium over the years.

"We're going to look at the trees, the herbaceous plants, how salamanders respond, how microbes respond, and how aquatic organisms respond," Driscoll says. In a few years, the researchers may be able to report whether calcium enrichment shows any signs of helping to restore damaged soil. Such a finding would be welcome news to New Englanders in the tourism and maple sugar industries, where concern is high about whether calcium levels in the soil have something to do with the notable decline in the region's sugar maple trees. A full understanding of calcium's role in the environment will take longer. That's why Driscoll says the new study—like most Hubbard Brook studies—will continue "not just for a few months, but for fifty years."

Says Driscoll, "Once we start, we don't quit."

Solving the Biocomplexity Puzzle

Studying only one piece of the environment—even one as big as an LTER site—provides only partial understanding of how the world works. Such is the nature of what NSF Director Rita Colwell calls "biocomplexity." Eventually, all the pieces will need to conjoin in order to solve the puzzle.

One would-be puzzle master is the NSF-funded National Center for Ecological Analysis and Synthesis (NCEAS) at the University of California in Santa Barbara. NSF helped create NCEAS to organize and analyze ecological information from all over the globe, including sites within NSF's Long-Term Ecological Research (LTER) program. The center does not collect new data itself; instead, NCEAS' job is to integrate existing information so that the information is more useful for researchers, resource managers, and policymakers who are tackling environmental issues.

"Natural systems are complex, and humans are altering these systems at an unprecedented rate," says NCEAS Deputy Director Sandy Andelman. "We need to do a better job of harnessing the scientific information that's relevant to those systems and putting it in a useable form."

But gathering and integrating such information is a daunting task. There is no central repository in which ecological scientists can store their data. Most studies are conducted by individual researchers or small teams working on specific small, short-term projects. Since each project is slightly different, each data set is slightly different.

"Ecological data come in all kinds of shapes and forms," Andelman says. She adds that, in ecology, "There is not a strong culture of multi-investigator, integrated planning of research . . . . Ecology and other related disciplines have amassed vast stores of relevant information, but because this information is in so many different forms and formats and many different places, it is not accessible or useful."

Hence the need for something like the NCEAS, which is collaborating with the San Diego Supercomputing Center and the LTER program to come up with the necessary advanced computing tools. NCEAS is also developing a set of desktop computer tools that will allow researchers to enter and catalog their data into the network using standardized data dictionaries. Eventually, researchers thousands of miles apart will be able to look at each other's data with just a few clicks of the mouse.

"If people knew that their data could contribute to a larger question, most would happily make a little extra effort to put their data into a more useful format," Andelman says. "But there hasn't been that framework in place." And now, thanks to NSF, there will be.

Counting the Blessings of Biodiversity

In addition to pollution, species extinction ranks high as a concern among those interested in how ecosystems function. According to the fossil record, several thousand plants and animals have disappeared over the last ten million years; during the time dinosaurs were alive, one species disappeared about every one to ten thousand years. But as the human population has grown, so has the rate of extinction—researchers now conservatively estimate that species are dying out at the dramatic rate of one a day.

The assumption, of course, is that this can't be good. More than a century ago, Charles Darwin first suggested that more species would make an ecosystem more productive. But researchers have struggled to test the notion rigorously, not just in the lab but in the field. It wasn't until 1996 that anyone had real evidence that biodiversity—sheer numbers of different species—is critical to the planet's well-being.

In an experiment that other ecologists have described as "brilliant" and "a first," University of Minnesota ecologist David Tilman and other researchers at the Cedar Creek Natural History Area—an NSF-funded LTER site since 1982—demonstrated that plant communities with the greatest biodiversity yielded the greatest total plant growth year to year. These plant communities also were much more likely to hang on to essential nutrients that might otherwise have been leached from the soil.

Tilman's team approached the problem by constructing 147 miniature prairies within a section of the 5,500-acre experimental reserve at Cedar Creek, and planting each one with anywhere from one to twenty-four species. The burning, plowing, and planting were done by the spring of 1994. Then the researchers sat back to see which plots would end up doing best.

Actually, no one sat much. The researchers, aided by an army of undergraduates, have toiled ever since to meticulously weed the 100-square-foot plots of anything that didn't belong to what each plot was designed to contain, be it brown-eyed susans, bunch clover, or yarrow. A critical aspect of the study was that researchers randomly selected which species went into which plots. This kept the focus on the *number* rather than the type of species.

Why do more species make for a merrier ecosystem? Tilman has found that a diverse plant community uses the available energy resources more efficiently.

"Each species differs from others in a variety of traits," says Tilman. "Some have high water requirements and grow well during the cool part of the year. Others grow well when it's really warm and dry. Each one in the system does what it's good at, if you will, but there's always something left to be done." That is, conditions that are less than hospitable to some species will be readily exploited by others, leading to more lush growth overall. These processes, says Tilman, also explain why so many species can coexist in nature.

"It wasn't until we knew how rapidly species were going extinct that this issue really came to the forefront," says Tilman. Still, more work needs to be done before biodiversity's role in a healthy ecosystem can be unequivocally celebrated. That's why Tilman and other Cedar Creek researchers have added a second experiment to the mix, this time using more than three hundred bigger plots, each about the size of an average suburban backyard. The extra area should allow for a better understanding of how, for example, plots with different numbers of species handle insects and disease.

“Nobody’s ever done what they’ve done,” says Samuel McNaughton, an ecosystem ecologist at Syracuse University in New York. “It’s an enormous amount of work. Tilman would not have been able to do this without NSF funding through the LTER program.”

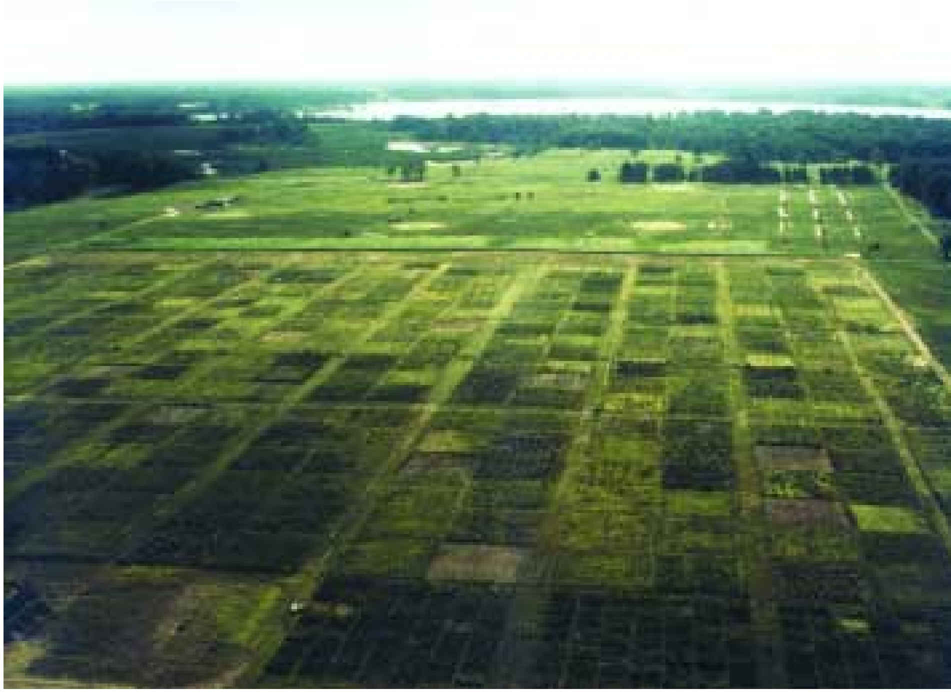
Keeping Up with Global Change

From a focus on plant communities to a broader look at global climate change, LTER research is revealing how the components of our environment interact.

Albert Einstein once said that chance favors the prepared mind. So, too, are LTER scientists uniquely prepared to learn from seemingly chance fluctuations in global climate—what LTER program head Scott Collins calls “the surprise years.”

A good illustration of this can be found among the scores of lakes that make up the NSF-funded North Temperate Lakes (NTL) LTER site in Wisconsin. A member of the network since the LTER program’s start in 1980, the NTL site is managed by researchers at the University of Wisconsin at Madison. The NTL LTER includes two field stations: one in the Yahara Lake District of southern Wisconsin and the other—called the Trout Lake Station—in the state’s northern highlands. While the area boasts hundreds of lakes that are amenable to study, the sites’ principal investigators have chosen seven to consistently monitor over the long haul.

If researchers investigate only one lake, they don’t know whether their findings are unique to that lake, says University of Wisconsin limnologist Timothy Kratz, a principal investigator for the NTL LTER. Studying many lakes exposes patterns and commonalities that are visible only when researchers investigate environmental conditions over a broad region. The seven lakes of the NTL LTER were chosen because of their representative variety in size and location.



An aerial view of a biodiversity experiment at the NSF-supported Cedar Creek Natural History Area in Minnesota. Researchers here have shown that plant communities with the largest variety of species exhibit the greatest total plant growth, one sign of a robust environment.

The number of lakes, their different sizes (ranging from quarter-acre bogs to 3,500-acre behemoths), and their distribution from lower to higher elevations, allowed Kathy Webster, then a doctoral student, and other NTL researchers in the late 1980s to conduct one of the first and most informative field studies of how lakes respond to drought.

Year in, year out since 1981, NTL researchers have measured the lakes’ chemical composition, tracking fluctuations in calcium, magnesium, alkalinity, and other factors. These persistent measurements paid off in the late 1980s, when the upper Midwest was hit by a major drought. “We were able to look at our lakes pre-drought, during the drought, and after the drought,” says Kratz. The results were surprising: Although all of the lakes lost water, only those lakes positioned higher in the landscape lost significant amounts of calcium, an essential nutrient for all organisms. The effect was all the more striking because the elevation difference between the highest and lowest study lakes was only about 33 feet.

What could explain the different level of calcium loss? Groundwater, suggests Kratz. All of the lakes in the study are fed by groundwater seeping through the rocky soil. This groundwater carries with it an abundance of critical minerals, including calcium. But the drought caused the groundwater table to fall below the higher lakes, essentially shutting off their mineral supply.

In a prolonged drought, says Kratz, lakes in higher elevations might become calcium deficient, causing a cascade of biotic effects. Animals such as snails and crayfish would be in trouble, since they require calcium to make their shells. In turn, fish that eat snails would find it harder to get enough food. The higher lakes might also become more susceptible than their low-lying counterparts to the effects of acid rain, since the calcium and other minerals from groundwater can counteract the deleterious effects of acid precipitation.

If changes in the world's overall climate result in droughts that become more frequent—as some researchers predict with the advent of global warming—the chemistry of these two types of lakes will start to diverge. Data of the kind gathered at the North Temperate Lakes LTER should help both scientists and policymakers predict and cope with the environmental consequences of global climate change.

"We didn't know the particular event of interest would be a drought," Kratz says. "But we had in place a system of measurements that would allow us to analyze the situation—whatever the event was."

Cityscapes Are Landscapes, Too

Not all LTER sites are located in remote, rural areas. In 1997, NSF added two sites to the network specifically to examine human-dominated ecosystems—in other words, cities. One site is centered in Baltimore, Maryland, the other in Phoenix, Arizona.

The Central Arizona/Phoenix (CAP) site fans out to encompass nearly five million acres of Maricopa County. While much of the site's study area is urbanized, some portions are still agricultural field or desert, and there are also a few nature reserves. CAP researchers are in the early stages of laying the groundwork for long-term studies at the site. For one thing, they're busy identifying two hundred sampling sites that will encompass the city, the urban fringe, and enough spots on the very outer edge to ensure that some portion of the site will remain desert for the next thirty years.

"One of our exciting challenges will be to take those very standard common ecological measures that people use in the forest and desert and everywhere else, and say, well, is there an equivalent way to look at how the city operates?" says Charles Redman, Arizona State University archeologist and co-director of the CAP-LTER. To tackle that challenge, Redman and co-director Nancy Grimm work with a research team that includes ecologists, geographers, remote sensing specialists, sociologists, hydrologists, and urban planners.

As a framework for their foray into the ecology of a city, the researchers are adopting a popular and relatively new ecological perspective that recognizes that rather than being uniform, an ecosystem is patchy, rather like a quilt. For example,

Wanted: A Complete Catalog of Creatures and Plants

Chytrids are not something people generally worry about. Yet this little-known group of fungi made news in 1998 when it was linked with a rash of frog deaths in Australia and Panama.

It had taken frog researchers several years to locate a chytrid specialist capable of identifying the deadly fungus, and even then the experts were surprised. “We didn’t know that any [chytrids] were parasites of vertebrates,” says Martha Powell, a chytrid specialist at the University of Alabama.

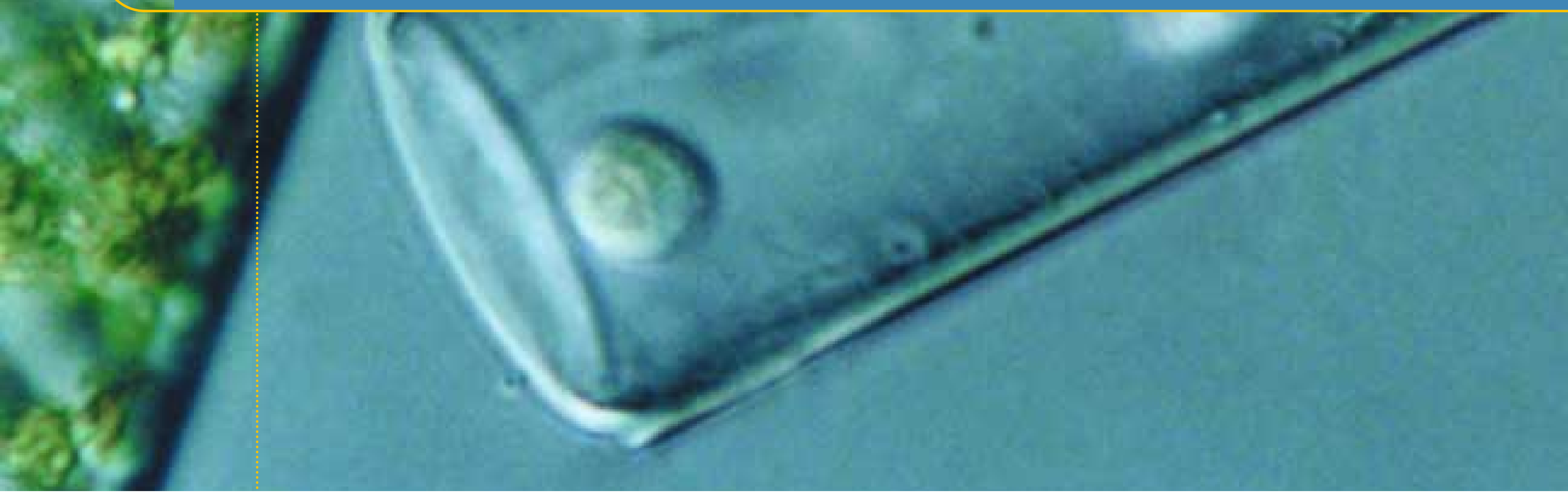
Chytrids aren’t alone in being poorly classified. Only about 1.5 million species have been identified so far out of the 13 million or so thought currently to exist (some estimates of the overall number are closer to 30 million). The gargantuan challenge of collecting and describing examples of all these unknown species falls to a steadily shrinking pool of scientists known as systematic biologists. With the advent of high-tech molecular techniques for studying evolutionary relationships, taxonomy—the science of species classification—has come to seem faintly antiquated, even though biological research collections “remain the ultimate source of knowledge about the identity, relationships, and properties of the species with which we share the Earth,” according to Stephen Blackmore, chair of the Systematics Forum in the United Kingdom, who wrote about the problem in 1997 for the journal *Science*.

But even as “the inescapable need to know more about the diversity of life on Earth remains largely unmet,” wrote Blackmore, “declining funds are limiting the ability of institutes around the world to respond . . . .” As of 1996, there were only about 7,000 systematists in the world, a workforce that Blackmore and others deem “clearly inadequate.”

Says James Rodman, NSF program director for systematics, “There are very few people studying the obscure groups” of species and many of those experts are beginning to retire.

One way the National Science Foundation is trying to address the problem is through its Partnerships for Enhancing Expertise in Taxonomy (PEET) program. PEET funds systematic biologists working to identify understudied groups like the chytrids. In fact, Powell and her colleagues are now working under a PEET grant to train at least three new Ph.D.s in the systematic biology of chytrids. Besides training the next generation of systematists, PEET projects are also making what is known about these species more widely available through the development of Web-accessible databases that contain information such as identification keys, photographs, distribution maps, and DNA sequences.

“Systematists,” wrote Blackmore, “hold the key to providing knowledge about biodiversity.” Knowing more about how the world functions requires learning more about each of the world’s parts, however small.



patches in a grassland might be recognized as areas that burned last year, areas that burned five years ago, and burned areas where bison are now grazing. Smaller patches exist within the larger patches: The bison might graze more heavily in some sections of the burned area than others, for example. There are patches of wildflowers, patches where bison have wallowed, and patches where manure piles have enriched the soil. Each time ecologists look closely at one type of patch, they can identify a mosaic of smaller patches that make up that larger patch. And if they can figure out what the patches are, how the patches change over time, and how the different types of patches affect one another, they might be able to figure out how the ecosystem functions as a whole.

Anyone who has flown over an urban area and looked at the gridlike mosaic below can imagine how easily cityscapes lend themselves to the hierarchical patch dynamics model. Still, it's a new approach where cities are concerned, says Jianguo Wu, a landscape ecologist at Arizona State University. And the patches within cities are new to ecologists.

"You can see very large patches—the built-up areas, the agricultural areas, the native desert areas," he says of the Phoenix site. "But if you zoom in, you see smaller patches. Walk into downtown Phoenix. There are trees, parking lots, concrete. They form a hierarchy of patches with different content, sizes, shapes, and other characteristics."

CAP researchers have gathered information about how land use in the Phoenix region changed from the early 1900s until today. The team has found that as the area became more urban, the patches became smaller and more regularly shaped. In the new millennium, the scientists want to see how this kind of more orderly patchiness affects ecological processes. For example, researchers would like to know how insects and other small animals move across the landscape, and how storm runoff carries away nutrients across the various patches, whether concrete or soil.

Grimm thinks that the patch dynamics model will help researchers integrate all the information they collect about the rapidly changing Phoenix metropolitan area. The model emphasizes linkages between different levels and types of patches such that researchers can design studies to ask: How might the actions of an individual eventually affect the ecology of a whole community-sized patch? If someone sells an undisturbed piece of desert property to a developer, for example, the ecosystem will change. What kind of development is built—whether there is one house per acre or a series of closely packed townhomes—will differently affect the ecological processes in the adjacent patches of remaining desert.

"Once the land use changes, the ecology changes," says Wu, adding, "What is really important is the dynamics—the impact of this patchiness on the ecological, physical, hydrological, and socioeconomic processes of the city."

Long-Term Research: A Model for NSF's Future

The LTER program has already demonstrated a remarkable return on NSF's investment. Thanks to NSF-supported research, we now have a better understanding of the complex interplay among plants, animals, people, and the environment.

In February 2000, the National Science Board (NSB), NSF's policymaking body, released a report urging that NSF expand the LTER program and make the environment a "central focus" of its research portfolio in the twenty-first century.

"Discoveries over the past decade or more have revealed new linkages between the environment and human health," says Eamon Kelly, chair of the National Science Board. "But just as we are beginning to better understand these linkages, the rate and scale of modifications to the environment are increasing. These alterations will present formidable challenges in the new century—challenges which we are now only minimally equipped to meet."

Preeminent ecologist Jane Lubchenco of Oregon State University chaired the NSB Task Force on the Environment, which was responsible for the report. "The LTER program is widely viewed as one of the outstanding successes of NSF," says Lubchenco, "and is the model for federal agencies as well as other countries for superb place-based ecological sciences. [The program is] very lean, very efficient, very productive."

The LTER program's success is one reason the task force recommended, among other things, that NSF boost its spending on environmental research by $1 billion over a five-year period beginning in 2001. That kind of financial commitment would make environmental science and engineering one of the agency's highest priorities.

And none too soon, according to Lubchenco. "We're changing things faster than we understand them," she once said in a news interview. "We're changing the world in ways that it's never been changed before, at faster rates and over larger scales, and we don't know the consequences. It's a massive experiment, and we don't know the outcome."

To Learn More

NSF Division of Environmental Biology
Directorate for Biological Sciences
www.nsf.gov/bio/deb/start.htm

NSF Global Change Programs
Directorate for Geosciences
www.nsf.gov/geo/egch/

NSF Partnerships for Enhancing Expertise in Taxonomy (PEET)
www.nhm.ukans.edu/~peet

U.S. Long-Term Ecological Research Network
www.lternet.edu

International Long-Term Ecological Research Network
www.ilternet.edu

Sevilleta LTER Project
http://sevilleta.unm.edu/

Hubbard Brook Ecosystem Study
www.hbrook.sr.unh.edu/

Cedar Creek Natural History Area
www.lter.umn.edu/

North Temperate Lakes LTER
http://limnosun.limnology.wisc.edu/

Central Arizona-Phoenix LTER
http://caplter.asu.edu/

Environmental Science and Engineering for the 21st Century: The Role of the National Science Foundation
National Science Board
www.nsf.gov/cgi-bin/getpub?nsb0022