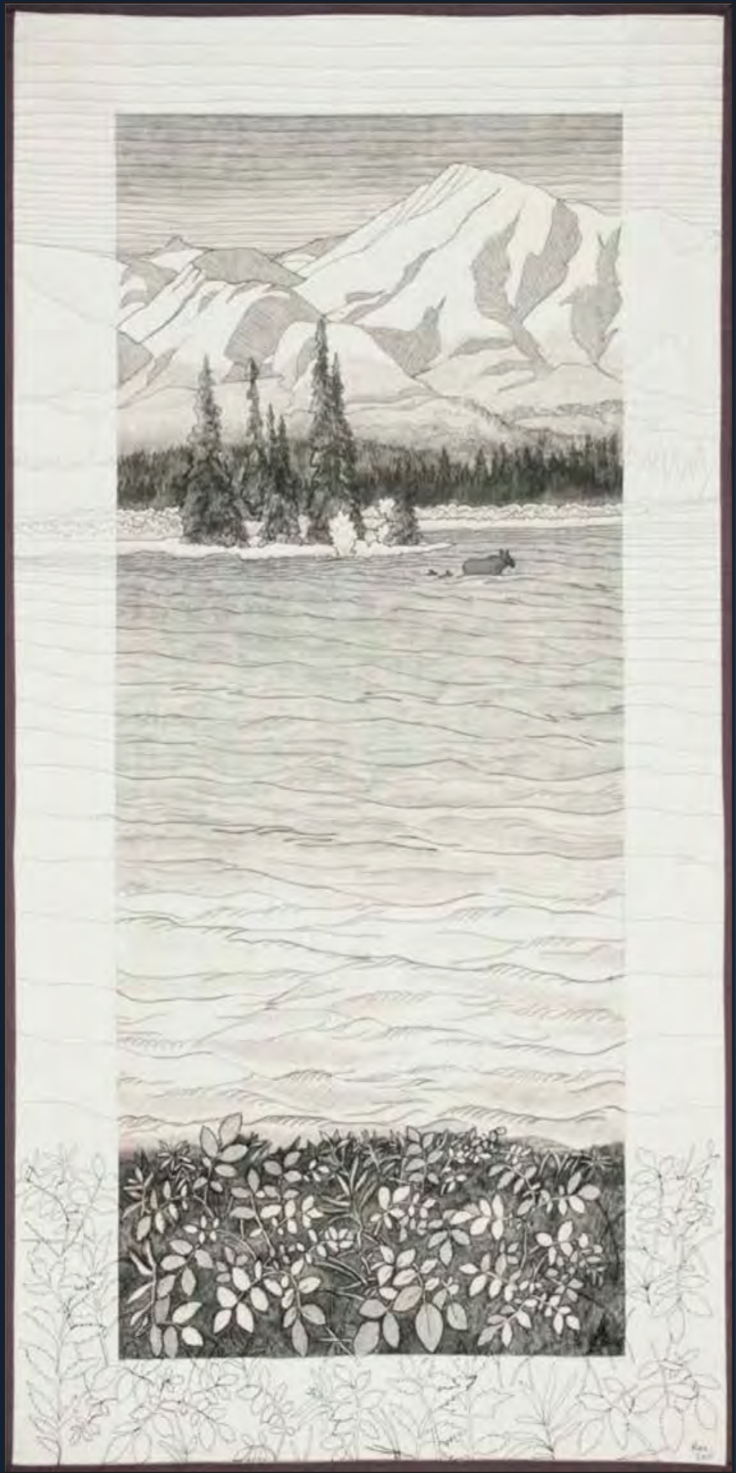
The Long Term Ecological Research (LTER) Network



LTER Discovery Articles National Science Foundation

NSF Long-Term Ecological Research Sites

- ***Andrews Forest LTER (AND)***
- ***Arctic LTER (ARC)***
- ***Baltimore Ecosystem Study (BES)***
- ***Bonanza Creek LTER (BNZ)***
- ***California Current Ecosystem LTER (CCE)***
- ***Cedar Creek LTER (CDR)***
- ***Central Arizona - Phoenix LTER (CAP)***
- ***Coweeta LTER (CWT)***
- ***Florida Coastal Everglades LTER (FCE)***
- ***Georgia Coastal Ecosystems LTER (GCE)***
- ***Harvard Forest LTER (HFR)***
- ***Hubbard Brook LTER (HBR)***
- ***Jornada Basin LTER (JRN)***
- ***Kellogg Biological Station LTER (KBS)***
- ***Konza Prairie LTER (KNZ)***
- ***LTER Network Office (LNO)***
- ***Luquillo LTER (LUQ)***
- ***McMurdo Dry Valleys LTER (MCM)***
- ***Moorea Coral Reef LTER (MCR)***
- ***Niwot Ridge LTER (NWT)***
- ***North Temperate Lakes LTER (NTL)***
- ***Palmer Station LTER (PAL)***
- ***Plum Island Ecosystems LTER (PIE)***
- ***Santa Barbara Coastal LTER (SBC)***
- ***Sevilleta LTER (SEV)***
- ***Shortgrass Steppe (SGS)***
- ***Virginia Coast Reserve LTER (VCR)***

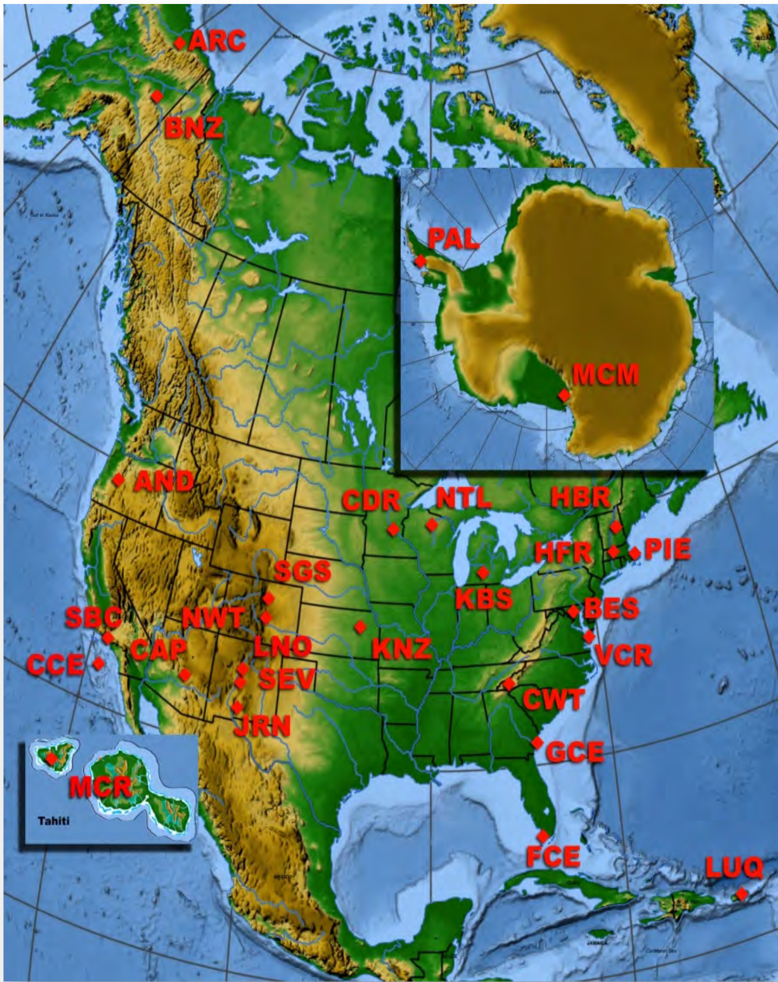


Table of Contents

Acknowledgements

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Articles written by Cheryl Lyn Dybas

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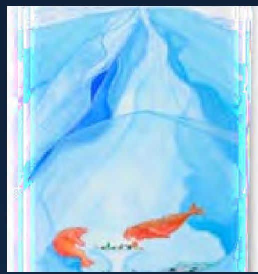
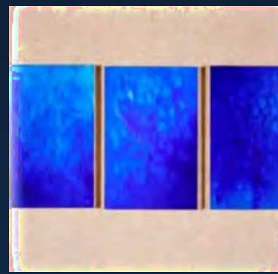
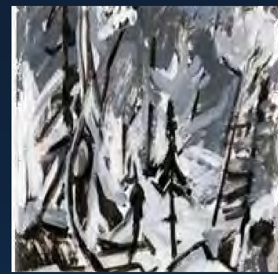
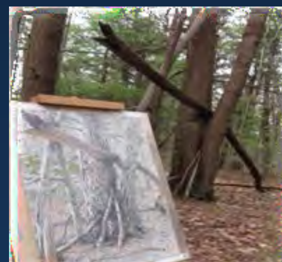
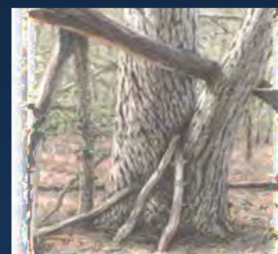
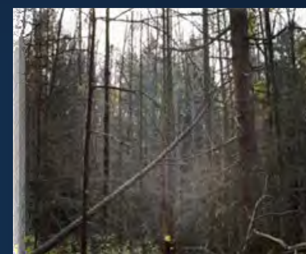
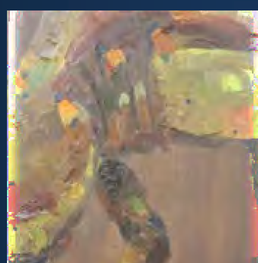
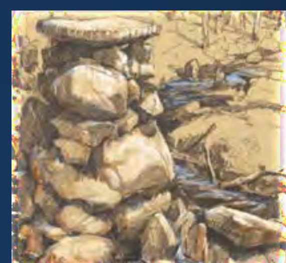
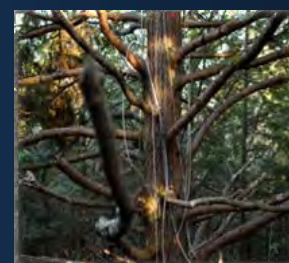
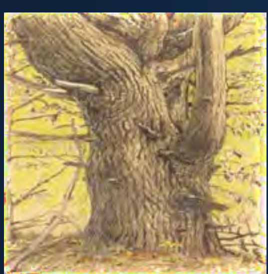
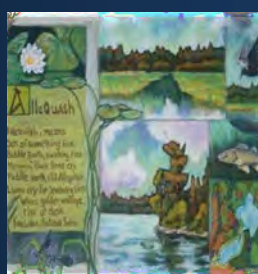
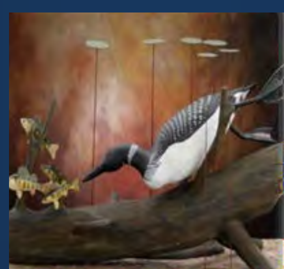






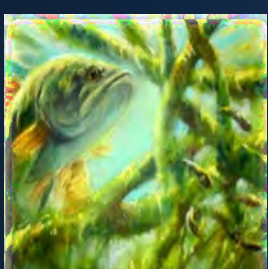




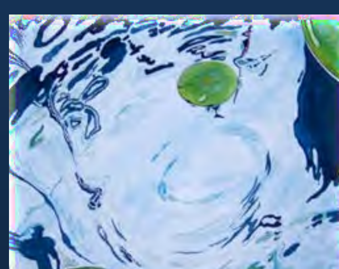
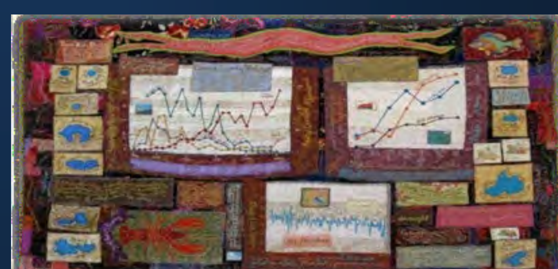
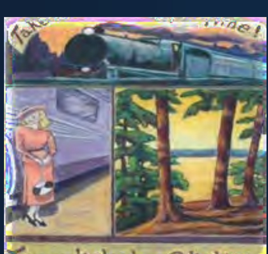


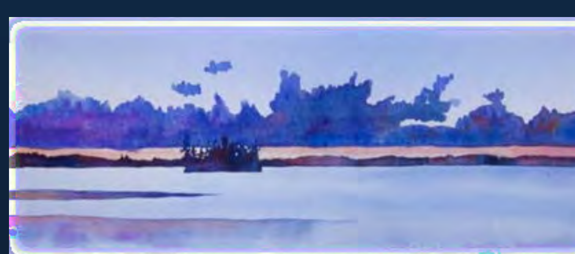
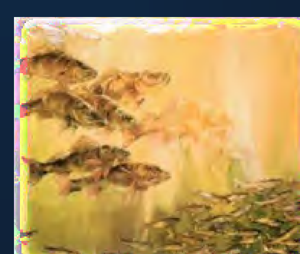








LTER Arts



Introduction: Ecological Research in a New Age: The Anthropocene

NSF's Long-Term Ecological Research (LTER) Network at the Forefront

A storytelling of ravens, as a flock of ravens is called… a copse of aspens turned shimmering-leaf-gold… and several hundred ecologists and other scientists. All were in Estes Park, Colorado, at the 2012 Long-Term Ecological Research (LTER) All Scientists Meeting, held from September 9-13, 2012.

The scientists' goal? Linking more than 30 years of National Science Foundation (NSF)-funded long-term ecological research to the questions facing us in this period of rapidly accelerating environmental change. A time many are calling the Anthropocene: an age in which the world's systems are dominated by the effects of humans.

The largest and longest-lived ecological network in the world, the LTER sites were founded with the recognition that long-term, broad-scale research is necessary for developing an in-depth understanding of environmental phenomena.

The NSF LTER Network and its 26 sites stretch across the U.S. and around the world, through deserts, estuaries, lakes, oceans, coral reefs, prairies, forests, alpine and arctic tundra, urban areas and agricultural holdings.

From Canada to Chile, from Kazakhstan to Kansas, we're witnessing a fast-changing planet.

What will it look like in the years, decades and centuries to come?

How far, and in what ways, can Earth's systems be stressed before they undergo transitions to new states—with unforeseen consequences?

How can we protect the health of the planet while achieving widespread economic prosperity?

The answer is a sustainable world, one in which human needs are met without harm to the environment—and without sacrificing the ability of future generations to meet their own needs.

Researchers from NSF's 26 LTER sites are addressing these challenges amid a storytelling of ravens and a copse of aspens turned to gold, and at myriad places across the U.S. and around the world.

Cheryl Lyn Dybas

The Colors of Fall: Are Autumn's Reds and Golds Passing Us By?

Climate change, land-use change, introduced pests and diseases altering fall foliage

25 September 2012

Autumn leaves: How long will the brightest colors be with us?

The falling leaves drift by the window, the autumn leaves of red and gold...

It was 1947 when Johnny Mercer wrote the lyrics to the popular song "Autumn Leaves." Sixty-five years ago, Mercer likely didn't think the reds and golds of fall might someday fade.

But that's what's happening in the U.S. Northeast and Mid-Atlantic regions.

Autumn colors were different there a century, or even a half-century, ago, and they will likely continue to change, says ecologist David Foster, principal investigator at the National Science Foundation's (NSF) Harvard Forest Long-Term Ecological Research (LTER) site in Massachusetts.

"The brilliant fall foliage so symbolic of New England forests was not always so, as the history of Harvard Forest shows," says Saran Twombly, NSF LTER program director.

"Today the current, rapid changes linked with climate are unpredictable," says Twombly, "threatening both the forests and our deep appreciation of them."

The changes are largely a result of human activity: land-use change, introduced pests and diseases, and climate change from fossil fuel emissions.

To date, the timing of leaf color change has stayed fairly consistent from year to year, says Foster, although out-of-sync weather conditions can advance it or hold it back.

At the start of the 20th century, much of the New England landscape south of Maine, famed for its brilliant maples, was covered by white pine forests that filled in abandoned fields and by pastures left fallow.

As the white pines were harvested, they were succeeded by broadleaf, or deciduous, trees: maples, oaks, birches and others.

Autumn color flared across the landscape.

Beautiful Harvard Pond lies within NSF's Harvard Forest LTER site.

American chestnuts, whose leaves turn yellow in fall, were common trees in these forests, says Foster. But mature chestnuts were killed by an introduced fungal disease, Chestnut Blight.

Tall American chestnut trees once dominated Massachusetts forests; many died out.

Now only small chestnut sprouts linger. “Our forests would have produced more yellows and fewer reds with chestnuts in the mix,” says Foster.

With their many sugar maples, the forests turned a striking red. The trees’ abundance in eastern Massachusetts and coastal southern New England is the result of extensive planting along roadsides during the 18th and 19th centuries.

Sugar maples provided a source of sap for maple sugar, important in the commerce of the day.

The maples are near the southern end of their range in Massachusetts. It’s likely, says Foster, that they will move north over the next century, thanks to increasing temperatures.

Massachusetts may one day seem like Virginia to the trees—and to the September and October people who come to see them.

“Over time,” Foster says, “the autumn colors of our forests may fade as conditions become less favorable for northern trees such as sugar maples.”

The result will reverberate not only through forest ecosystems, but through a region economically dependent on fall foliage tourism.

Trees that are left behind, such as ashes, dogwoods and others, may face diseases already spreading through the forest. These diseases may be exacerbated by warmer temperatures.

For some trees, however, the yellows and reds of fall appear to offer a defense mechanism. The colors may repel insects and keep them from laying eggs on leaves, reducing damage to forests the following year.

Birches’ bright yellow may be a “go away” sign to egg-laying insects: the color is a clue that the leaves are unpalatable or toxic.

Harvard Forest’s “PhenoCam” captures an ephemeral view from the forest’s highest point.

Long-term “Detritus Input Removal Treatment” (“DIRT”) plots measure leaves and soils.

Insects move on, attracted to plants without such defenses.

Deciduous trees aren’t the only ones affected by environmental change and diseases. The loss of evergreen trees may also have an effect on autumn colors.

Hemlocks—conifers common in valleys, on steep slopes and along streams—are disappearing from northeastern forests. The culprit is an introduced insect pest, the woolly adelgid.

At Harvard Forest, hemlocks are infested with woolly adelgids. The trees will begin to die over the next few years.

“It’s not clear how far north these insect pests will move,” says Foster. But as hemlocks fall, they will be replaced by black birches, whose leaves turn yellow in autumn.

Lack of rainfall in summer, such as this year’s extensive drought, also affects trees and their ability to produce the shades of autumn.

They may lose their leaves prematurely or start to turn color earlier than usual. Their hues may look dull and washed out when they should be vibrant.

Harvard Forest’s Environmental Measurements Tower rises above oaks and white pines.

If April showers bring May flowers, July and August rains lead to the bright reds and yellows of September and October.

The northeast is becoming a place of warmer temperatures, increasing droughts, changes in land use, and tree diseases and insect pests. All are on-the-march through the forest.

With them, autumn’s reds and golds may be going, going… gone.

Tropical Reefs Survive Environmental Stresses: Corals' Choice of Symbiotic Algae May Hold the Key

Corals that host fewer species of algae are less sensitive to disturbances

29 August 2012

Symbiodinium, it's technically called, but more popularly it's known as zooxanthellae.

Either way, this microscopic alga that lives inside a coral's tissues holds the key to a tropical reef's ability to withstand environmental stresses.

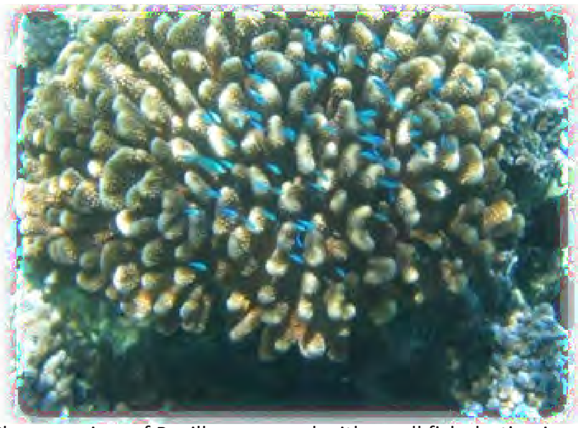
The effects on tropical corals of global warming, ocean acidification, pollution, coastal development and overfishing may come down to how choosy the corals are about these algal tenants.

Reef corals are the sum of an animal and the single-celled algae that live inside its tissues. The animal is the host and the algae are "endosymbionts."

It's a mutually beneficial arrangement. The corals provide the algae with protection in sunlit, shallow seas. The algae produce large amounts of energy through photosynthesis, which the corals use to survive and to build their skeletons.

The stability of this symbiotic relationship is critical to corals' survival. When corals lose their algae, they bleach out and often die.

Researchers at the University of Hawaii and other institutions have found that the more flexible corals are about their algal residents, the more sensitive they are to environmental change.



Close-up view of Pocillopora coral with small fish darting in and out of the reef.

In Tahitian waters, the coral Porites dominates the shallows. Shown here with Christmas tree worm.

Porites coral bommie; bommies are outcrops of coral or rock on a reef.

Coral known as *Acropora* on a fringing reef at NSF's Moorea Coral Reef LTER site.

Head of *Pocillopora* coral with small fish in a lagoon at the Moorea LTER site.

"It's exactly the opposite of what we expected," says Hollie Putnam of the University of Hawaii and lead author of a paper published in the journal *Proceedings of the Royal Society B*.

"The finding was surprising; we thought corals exploited the ability to host a variety of *Symbiodinium* to adapt to climate change."

But more is not always better, say Putnam and co-authors Michael Stat of the University of Western Australia and the Australian Institute of Marine Science; Xavier Pochon of the Cawthron Institute in Nelson, New Zealand; and Ruth Gates of the University of Hawaii.

"The relationship of corals to the algae that live within them is fundamental to their biology," says David Garrison, program director in the National Science Foundation's (NSF) Division of Ocean Sciences, which funded the research.

"This study gives us an important new understanding of how corals are likely to respond to the stresses of environmental change."

The research was conducted at NSF's Moorea Coral Reef Long-Term Ecological Research (LTER) site, one of 26 such NSF LTER sites around the globe in ecosystems from deserts to freshwater lakes, and from forests to grasslands.

Putnam and colleagues took samples from 34 species of corals at the Moorea LTER site. By analyzing the DNA from the algae in the samples, they identified the specific species of *Symbiodinium*.

The findings reveal that some corals host a single *Symbiodinium* species. Others host many.

"We were able to link, for the first time, patterns in environmental performance of corals to the number and variety of endosymbionts they host," says Putnam.

The patterns show that corals termed generalists—those that are flexible in their choice of algae residents—are more environmentally sensitive.

In contrast, environmentally resistant corals-termed specifists—associate with only one or a few species of *Symbiodinium*.

Generalists such as *Acropora* and *Pocillopora* are some of the most environmentally sensitive corals.

Conversely, specifists such as *Porites* harbor few *Symbiodinium* species and are more environmentally resistant.

The Moorea LTER site is also home to extensive lagoon reefs, pictured here.

"Coral reefs are economically and ecologically important, providing homes for a high diversity of organisms, and are necessary for food supplies, recreation and tourism," says Gates.

"The better we understand how corals respond to stress, the more capable we will be of forecasting and managing future reef communities."

It's likely that the reefs of tomorrow, says Putnam, will be shaped by the coral- *Symbiodinium* assemblages of today.

reef, *Porites* may be the clear winner. In the roulette of coral species on a tropical

Acid Rain: Scourge of the Past or Trend of the Present?

New connection between climate change and acidification of Northeast's forests and streams

25 July 2012

Acid rain. It was a problem that largely affected U.S. eastern states. It began in the 1950s when Midwest coal plants spewed sulfur dioxide and nitrogen oxides into the air, turning clouds—and rainfall—acidic.

As acid rain fell, it affected everything it touched, leaching calcium from soils and robbing plants of important nutrients. New England's sugar maples were among the trees left high and dry.

Acid rain also poisoned lakes in places like New York's Adirondack Mountains, turning them into a witches' brew of low pH waters that killed fish and brought numbers of fish-eating birds like loons to the brink.

Then in 1970, the U.S. Congress imposed acid emission regulations through the Clean Air Act, strengthened two decades later in 1990. By the 2000s, sulfate and nitrate in precipitation had decreased by some 40 percent.

Has acid rain now blown over? Or is there a new dark cloud on the horizon?

In findings published in the journal *Water Resources Research*, Charles Driscoll of Syracuse University and the National Science Foundation's (NSF) Hubbard Brook Long Term Ecological Research (LTER) site in New Hampshire reports that the reign of acid rain is far from gone. It's simply "shape-shifted" into a different form.

Hubbard Brook is one of 26 NSF LTER sites across the nation and around the world in ecosystems from deserts to coral reefs to coastal estuaries.

Has acid rain washed out of forests and streams? Or is a new threat on the way?

Co-authors of the paper are Afshin Pourmokhtarian of Syracuse University, John Campbell of the U.S. Forest Service in Durham, N.H., and Katharine Hayhoe of Texas Tech University.

Acid rain was first identified in North America at Hubbard Brook in the mid-1960s, and later shown to result from long-range transport of sulfur dioxide and nitrogen oxides from power plants.

Hubbard Brook research influenced national and international acid rain policies, including the 1990 Clean Air Act amendments.

Researchers at the site have continued to study the effects of acid rain on forest growth and on soil and stream chemistry.

A scientist collects a stream sample at the Hubbard Brook LTER site.

Long-term biogeochemical measurements, for example, have documented a decline in calcium levels in soils and plants over the past 40 years. Calcium is leaching from soils that nourish trees such as maples.

Now Hubbard Brook LTER scientists have discovered that a combination of today's higher atmospheric carbon dioxide (CO_2) level and its atmospheric fallout is altering the hydrology

A gauging station at Hubbard Brook provides new data on acidification of streams.

and water quality of forested watersheds—in much the same way as acid rain. "It's taken years for New England forests, lakes and streams to recover from the acidification caused by atmospheric pollution," says Saran Twombly, NSF program director for long-term ecological research.

"It appears that these forests and streams are under threat again. Climate change will likely return them to an acidified state. The implications for these environments, and for the humans that depend upon them, are severe."

Climate projections indicate that over the 21st century, average air temperature will increase at the Hubbard Brook site by 1.7 to 6.5 degrees Celsius, with increases in annual precipitation ranging from 4 to 32 centimeters above the average from 1970-2000.

Meteorological and precipitation chemistry monitoring at NSF's Hubbard Brook LTER site.

Hubbard Brook scientists turned to a biogeochemical model known as PnET-BGC to look at the effects of changes in temperature, precipitation, solar radiation and atmospheric CO_2 on major elements such as nitrogen.

The model is used to evaluate climate change, atmospheric deposition and land disturbance in soil and surface waters in northern forest ecosystems.

It was created by linking the forest-soil-water model PnET-CN with a biogeochemical sub-model, enabling the incorporation of major elements like calcium, nitrogen, potassium and others.

The results show that under a scenario of future climate change, snowfall at Hubbard Brook will begin later in winter, snowmelt will happen earlier in spring, and soil and stream waters will become acidified, altering the quality of water draining from forested watersheds.

"The combination of all these factors makes it difficult to assess the effects of climate change on forest ecosystems," says Driscoll.

"The issue is especially challenging in small mountain watersheds because they're strongly influenced by local weather patterns."

The Hubbard Brook LTER site has short, cool summers and long, cold winters. Its forests are made up of northern hardwood trees like sugar maples, American beeches and yellow birches. Conifers—mostly balsam firs and red spruces—are more abundant at higher elevations.

The model was run for Watershed 6 at Hubbard Brook. "This area has one of the longest continuous records of meteorology, hydrology and biogeochemistry research in the U.S.," says Pourmokhtarian.

The watershed was logged extensively from 1910 to 1917; it survived a hurricane in 1938 and an ice storm in 1998.

It may have more to weather in the decades ahead.

The model showed that in forest watersheds, the legacy of an accumulation of nitrogen, a result of acid rain, could have long-term effects on soil and on surface waters like streams.

Will sugar maples turn red in fall? Climate change and acidification of soils may tell the tale.

Changes in climate may also alter the composition of forests, says Driscoll. "That might be pronounced in places like Hubbard Brook. They're in a transition forest zone between northern hardwoods, and coniferous red spruces and balsam firs."

The model is sensitive to climate that is changing now—and climate changes expected to occur in the future.

In scenarios that result in water stress, such as decreases in summer soil moisture due to shifts in hydrology, the result is further acidification of soil and water—and the return of a poisonous miasma once thought to be long gone.

Northeastern lakes were once a witches' brew of acidifying waters that killed fish and birds. Could they become one again?

Long-term Ecological Research Reveals Causes and Consequences of Environmental Change

New insights as NSF Long Term Ecological Research Network reflects on three decades of science

6 April 2012

Scientists at the H.J. Andrews LTER site, one of 26 such NSF sites, study water resources.

As global temperatures rise, the most threatened ecosystems are those that depend on a season of snow and ice, scientists from the National Science Foundation (NSF) Long-Term Ecological Research (LTER) Network have found.

"The vulnerability of cool, wet areas to climate change is striking," says scientist Julia Jones of Oregon State University and the H.J. Andrews LTER site in Oregon.

In semi-arid regions like the southwestern United States, mountain snowpacks are the dominant source of water for human consumption and irrigation.

Research by Jones and colleagues shows that as average temperatures increase in these snowy ecosystems, a significant amount of stream water is lost to the atmosphere. The study involves more than 30 years of data from 19 forested watersheds across the country. All the study sites provide water to major agricultural areas and to medium and large cities.

But, like many long-term studies, this one revealed a surprise: water flow decreased only in the research sites with winter snow and ice.

"Streams in dry forested ecosystems seem more resilient to warming," says Jones. "These ecosystems conserve more water, keeping stream flow within expected bounds."

A range of factors can affect watersheds, from human influence past and present, to El Niño climate oscillations.

"Long-term records are finally long enough to begin to separate the effects of each," Jones says.

In contrast to most research, which spans only a few years, LTER studies are sustained over decades, documenting gradual changes and long-term variability that often can't be revealed by short-term studies.

"Each additional year of LTER data helps us to better understand how ecosystems respond to environmental change," says Scott Collins, an ecologist at the University of New Mexico and principal investigator at the Sevilleta LTER site in New Mexico.

NSF's Long Term Ecological Research Network: A ribbon of 26 land, coastal and ocean sites.

Researchers at the Harvard Forest LTER site study forests from the "Hemlock Tower."

"Such understanding provides valuable information for federal agencies, land managers and legislators who want to develop responsible policies to deal with a rapidly changing world."

The results reveal that the LTER network's diversity of long-term research approaches—including detailed observations and experiments, environmental gradient studies and complex simulation models—can contribute to new solutions in an era of unprecedented environmental change.

The NSF Sevilleta LTER site in New Mexico features a cold desert biome.

"How can we evaluate the ability of natural ecosystems to sustain critical ecological processes, and the human societies that depend on them?" asks Saran Twombly, NSF LTER program director.

"LTER research has unique and powerful insights from long-term studies and the analysis of long-term data," she says. "The results reach beyond scientists to engage the public and decision-makers."

In addition to deciphering ecosystem-level clues, LTER research can identify the biological winners and losers in a changing climate.

"The cryosphere, or the part of the Earth covered by snow and ice, has been shrinking," says scientist Andrew Fountain of Portland State University in Oregon and the McMurdo Dry Valleys LTER site.

"Populations of microbes, plants and animals that depend on snow and ice will decrease if they are unable to migrate. But life that finds the cryosphere too hostile should expand."

In shallower snow, he explains, animals such as white-tailed deer, mule deer, elk and caribou expend less energy and can more easily escape predators.

"One species' loss can be another species' gain," says Fountain.

Scientists at the California Current Ecosystem LTER site launch a monitoring instrument.

The retrospective look at the LTER network comes at a time when institutions charged with stewarding the nation's environmental health are increasingly being challenged to provide a basis for their decision-making.

An article by scientist Charles Driscoll of New York's Syracuse University and the Hubbard Brook LTER site in New Hampshire shows that LTER research has contributed to important environmental management decisions over the past decade, including new state and regional forest and watershed policies.

"LTER datasets and experiments help inform local- to national-scale decisions on climate change, pollution, fire, land conversion and other pressing environmental challenges," says Driscoll. "That creates a crucial bridge between the scientific community and society."

Demand for natural resources is increasing with the global human population, which the United Nations projects will reach at least 9 billion by 2050.

Long-term ecosystem data can help researchers simulate a region's future based on a range of possible human actions.

Adelie penguins near the Palmer Station LTER site in Antarctica; their numbers have declined.

Demand for natural resources is increasing with the global human population, which the United Nations projects will reach at least 9 billion by 2050.

Long-term ecosystem data can help researchers simulate a region's future based on a range of possible human actions.

"For example, how might forest ecosystems change if more people begin to use wood to heat their homes?" asks Jonathan Thompson of the Smithsonian Conservation Biology Institute in Front Royal, Va., and the Harvard Forest LTER site in Massachusetts.

Each year, some 2,000 scientists and students carry out more than 200 large-scale LTER field experiments to find new answers.

The resulting datasets are freely and publicly available online.

"LTER sites are providing transformative information about the causes and consequences of climate and environmental changes to ecosystems," says David Garrison, NSF program director for coastal and ocean LTER sites."They're our best hope of providing the sound scientific underpinnings needed to guide policy for the challenges of future environmental change."

Cry Me a River: Following a Watershed's Winding Path to Sustainability

New view of urban rivers, lakes, marshes: through cities

09 March 2012

Algae cover the surface of Lake Mendota, likely the result of fertilizer flowing downstream.

Cherokee Marsh, it's called, this sunken enclave surrounded by cattails and bulrushes. The marsh is a mere dot on a map of the state of Wisconsin, but its importance reaches far beyond the wetland's edge.

The Yahara River flows through Cherokee Marsh, swirling through coontail, sago pondweed, glade mallow and other plant species along the Yahara watershed. Its next stop is the twins of Madison: Lakes Mendota and Monona.

The river and its watershed provide Madison with critical "ecosystem services" such as water quality and flood protection, says Chris Kucharik, a scientist at the University of Wisconsin-Madision.

But the marsh, the twin lakes that lie downstream and the river that runs through them may be threatened by the effects of climate and land-use change.

The National Science Foundation (NSF) awarded Kucharik and colleagues a Water, Sustainability and Climate (WSC) grant to study how ecosystem services may be sustained in a regional watershed such as the Yahara, and how the watershed is affected as climate, land cover, urban areas and human demands on the environment change.

How is the Yahara faring? Lakes Mendota and Monona may be the eyes that are the windows to its soul.

Among the most urgent challenges facing the world today is how to ensure the adequate supply and quality of water, say scientists like Kucharik, especially in light of burgeoning human needs and climate variability and change.

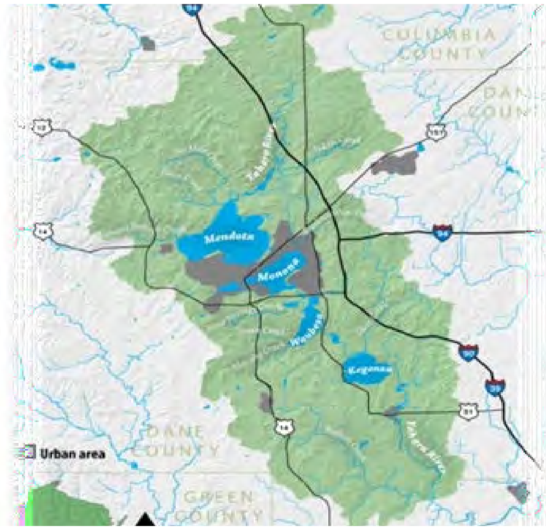
Despite water's importance to life on Earth, major gaps exist in our understanding of water availability and quality, and of the effects of a changing climate and human activities on the planet's water system.

NSF awarded 17 grants through the WSC program to better understand how Earth's water cycle works. NSF's Directorates for Geosciences; Biological Sciences; Social, Behavioral & Economic Sciences; and Engineering variously support WSC. The National Institute of Food and Agriculture also currently supports WSC.

The awards are for studies of the water system using observations at specific sites, in combination with models that allow for extrapolation to other regions and integration with different Earth processes.

"We need to determine how our 'built' water systems and our governance systems can be made more reliable, resilient and sustainable," says Tom Torgersen, NSF program director for WSC.

Aerial view of a rural farm surrounded by cornfields in the Yahara watershed.



The Yahara River watershed extends through the city of Madison, Wis., and beyond.

"They must meet diverse and often conflicting needs," says Torgersen, "such as consumption of water for energy generation, industrial and agricultural production, and other requirements."

Along with Kucharik, an agronomist and climatologist, scientists working on the NSF WSC Yahara watershed project are limnologist Steve Carpenter, ecohydrologist Steven Loheide, forest and wildlife ecologist Adena Rissman and landscape ecologist Monica Turner, all at the University of Wisconsin- Madison.

"Madison is a moderate-sized city that's growing quickly," says Kucharik. "It's one of the best examples of the issues surrounding urbanization. We have increasing water use due to a growing population; climate change happening, which is likely to foster extreme weather events; and it's in an agricultural watershed."

When you start putting all this together, Kucharik asks, what might it mean for the future of the Yahara watershed in terms of quality of life and sustainability of the environment?

"With the interplay of agriculture, cities, industry and nature across the landscape, the contribution of direct-and-obvious, as well as indirect-and-subtle, interactions determines resilience to change," says Torgersen. "This research is key to determining what needs to be done to ensure sustainability."

The Yahara watershed is largely agricultural—corn, soy and dairy products—but includes a densely populated urban area and remnant native vegetation.

A dot on a map of the United States, Cherokee Marsh in Wisconsin is central to the Yahara watershed.

A mix of urban areas, croplands, forests, pastures, wetlands and prairies makes for a complex environment.

Stresses on the ecosystem services of the Yahara watershed are typical of many agricultural landscapes.

Groundwater extraction, loss of wetlands, reduced water infiltration and increased runoff from impervious surfaces like roads alter the Yahara's hydrology and increase local and regional flood frequency.

Nitrates from agriculture contaminate groundwater, and phosphorus loads from non-point, diffuse runoff have increased well above those before widespread farming.

Pesticides and fertilizers contribute to increased "flashiness" of runoff from heavy rainfall during storms, as well as to water quality issues in the area's lakes.

"More than 35 years of data for these lakes, assembled by NSF's North Temperate Lakes Long-Term Ecological Research site, have allowed us to develop models of lake response to changes in hydrology and in nutrient inputs," says Carpenter.

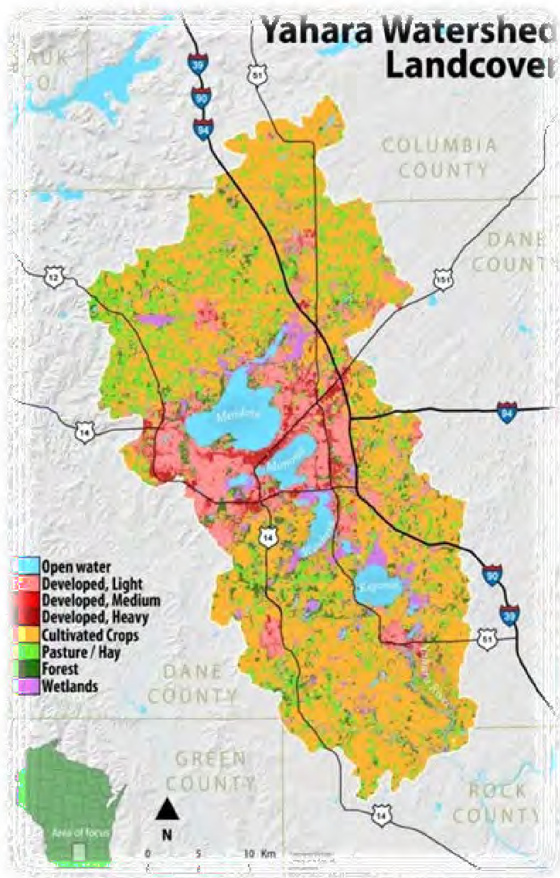
Climate change is making its presence in the Yahara watershed known. Since 1950, the number of cold days has declined.

Many species of plants flower sooner in spring. "There's an early-season 'green-up' by three to six days in the Madison area," says Kucharik.

In summer, water use by human residents increases. The city acts as an urban heat island, making temperatures even higher.

"These factors all combine to challenge the sustainability of freshwater resources and other ecosystem services throughout the region," Kucharik says.

Prairie fringes the Yahara River, which flows into Lakes Mendota and Monona.



The Yahara watershed encompasses marshes and lakes, prairies and forests.

In 2011, dry conditions in mid-summer created potential water stresses for the Yahara watershed's natural and human systems.

In the long-term, however, the region has experienced higher water tables and a rising trend in precipitation amounts.

"Historical water table elevations are being reconstructed using a high-resolution model," says Kucharik. "We're combining the results with a review of historical aerial photos of water features in the upper part of the watershed."

This rising water table may be causing low-oxygen root conditions in some farm fields. Indices indicate a decrease in corn production, for example. The plants' roots may be gasping for air.

Project scientists monitor a network of more than 160 temperature-and-humidity sensors across and beyond the urban landscape of Madison.

Combined with information from a mobile temperature-sensing unit, the results will provide a level of detail the researchers believe is unique in local climate and urban heat island studies.

"The results will advance our understanding of Earth's water resources," says Torgersen, "and with it, our predictive capability not only for the availability of water, but for the future of life on our planet."

"We have the opportunity to change management practices while the Yahara watershed is still relatively healthy," says Kucharik. "Let's not wait until its mainstem river is only a trickle."

Or until the reeds of Cherokee Marsh have dried up, scattering the watershed's heart to the four winds.

Out of Africa and Into the American Midwest

Last of the oak savannas survives at NSF Cedar Creek Long-Term Ecological Research site

6 January 2012

Oak savanna—interspersed oaks and grasses—in summer at the Cedar Creek site.

Grasses bend in the wind, their golden tips tracing arcs across fields that stretch toward the horizon. Sunwashed by a fading evening light, these reedy ballet dancers are central figures in the savanna, an ecosystem that covers some 20 percent of Earth's land area.

The largest savanna—or grassland with widely spaced trees—is in Africa.

But the American Midwest is half a planet away from the equatorial grasslands of Cameroon's East Province or Kenya's Masai Mara. Savanna nonetheless thrives there.

Savannas are found throughout the world, but their dominant trees differ. In lightly forested midwestern savanna, bur oaks and northern pin oaks take the place of Africa's acacias.

Scientists at the National Science Foundation's (NSF) Cedar Creek Long-Term Ecological Research (LTER) site in Minnesota, one of 26 such NSF LTER sites across the globe, study a mixture of trees and grasses called oak savanna.

Oak savannas were once widespread in the U.S. midwest, according to Peter Reich, an ecologist at the University of Minnesota who conducts research at Cedar Creek.

Early travelers across the northern tier states remarked about the "park-like" character of the region's vegetation. "They may have been the last to see unbroken miles and miles of oak savanna," says Reich.

Experimental plots where prairie meets forest at Cedar Creek.

"Conversion of oak savanna to agricultural land, changing deer and bison numbers, differences in fires and rainfall, and fluctuating nitrogen deposition and atmospheric carbon dioxide levels are all threatening this important ecosystem," says ecologist Elizabeth Borer of the University of Minnesota. Borer is also affiliated with the Cedar Creek LTER site.

Today oak savannas are among the rarest plant communities on Earth. Cedar Creek is home to one of the last of these savannas.

Bur oaks are mainstays of oak savanna ecosystems in the north central U.S.

By their definition, oak savannas foster open-growing oak trees. When a single tree grows away from other trees, it doesn't face competition for light from its woody neighbors. Its branches are able to spread out and become very large. Oak savannas sprout up in an already open area; in the north-central U.S., that's usually a prairie.

"Oak savannas here are found in a zone that's at the dividing line between forest and prairie," says Reich.

In Earth's warming climate, that prairie/forest line may march toward the northeast. "It's one of the reasons we're working to understand how the parts of this ecosystem fit together," Reich says.

In any story of the oak savanna, the primary characters are oak trees and prairie grasses.

Or so biologists thought.

Reich, along with researchers Rebecca Montgomery and Brian Pelc of the University of Minnesota, discovered that low-growing and oft-forgotten shrubs also play important roles. They reported their results in the journal Forest Ecology and Management.

"Savannas are globally important ecosystems maintained by a balance between species interactions and natural disturbances," says Saran Twombly, director of NSF's LTER program.

"The response of shrubs to disturbance in oak savannas has important implications for management of these endangered ecosystems."

Indian Grass and other prairie plants bend in Minnesota breezes.

Before European settlement, the oak savanna was part of a larger "fire ecosystem." Fires, set by lightning or by Native Americans, ensured that savannas didn't become forests. Only trees with a high tolerance for fire, such as bur oaks, survived.

Homesteaders eventually cleared much of the oak savanna for agricultural uses. By removing tinder-box grasses, they suppressed the fire cycle. The pockets of savanna that remained became forest or thicket.

For oak savanna to flourish, growth of the shrub American hazel must be kept in check.

Oak savanna conservation and restoration efforts began in earnest in the 1970s. Controlled burns, such as those at Cedar Creek, have become a primary means of maintaining and restoring oak savanna. Woody shrubs that would otherwise overtake grasses and form thickets are weeded out by the scorching heat.

Unburned plots in Cedar Creek "burn areas" illustrate the effect of fire on savanna plant communities. Bur oaks with lichen-covered, wide-spreading limbs still thrive; they're evidence of a more open past.

But the absence of fast-burning fires has allowed the plots to brush up with hazel, sumac and blackberry, eliminating most echoes of the true savanna.

One tract of bur oaks is threatened not by loss of fire, but by cattle grazing that took place until the 1970s. The cattle ate everything but unpalatable juniper bushes that grow in the area.

Junipers eventually dominated the understory to the exclusion of all other species. "The 'juniper savanna,' if one could call it that," says Reich, "may be interesting to look at, but all is not well there."

Many shrub species, such as American hazel, have adapted to disturbances like fire by vigorously resprouting afterward, says Montgomery. "How fast they resprout influences the size and density of individual shrubs, and can alter the structure of the entire plant community."

"Shrub expansion has become a problem for management goals in some disturbance-dependent ecosystems [such as oak savannas] where natural resource values, habitat quality, plant diversity, abundance of economically-desired species and/or ecosystem function have been altered by increases in shrub abundance," the scientists write in their paper.

To find answers, Reich, Montgomery and Pelc measured the growth of individual American hazel shrubs in response to the frequency and timing of stem clipping in both open and shaded conditions.

In their experiments, clipping substituted for the effects of fire and was tested because of its use as a management and restoration tool.

In the 12 weeks after a spring clipping, American hazel shrubs in open oak savannas recovered 82 percent of their lost stem biomass, showing why a single fire or clipping treatment may not work to reduce shrubs like hazel.

It's a management challenge for those working to preserve savannas, says Reich.

"More importantly," he says, "timing had as significant an effect on resprout potential as the number of clipping events." Even small differences were important.

Plants clipped in mid- and late June and in July regrew 57, 17 and 8 percent as much biomass, respectively, as those clipped in early June.

The results have much to say about fires set to maintain oak savannas: Fires that burn later in summer (compared with those in spring) would have a greater effect.

"If peak biomass production in American hazel occurs in June and early July, a typical prescribed burn in late spring may have little inhibitory effect on resprout vigor," says Reich.

The limited resprouting of American hazel later in the year could be of value to oak savanna restoration. "Many degraded sites need both thinning of tree canopy layer and understory [shrub] management," says Montgomery.

The last oak savanna may depend not on oaks or grasses, but on shrubby, on-stage interlopers. Without fire—or clipping that replaces fire—that enters the scene at the right time, oak savannas could be long gone.

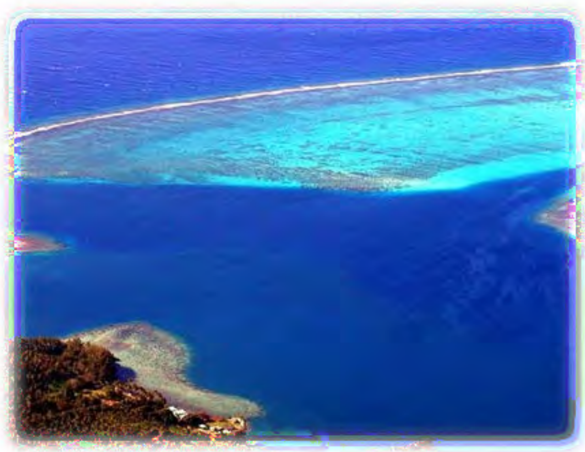
Out of the American Midwest and into an English thicket.

Winter in the oak savanna at NSF's Cedar Creek Long-Term Ecological Research site.

Trouble in Paradise: Ocean Acidification This Way Comes

Sustainability of tropical corals in question, but some species develop survival mechanisms

4 January 2012



Something wicked this way comes: Ocean acidification arrives in paradises like Mo'orea.

Double, double toil and trouble;

Fire burn and cauldron bubble.

—-Shakespeare, *Macbeth*

Mo'orea, it's called—this isle in French Polynesia that's been dubbed the most beautiful island in the world.

Here, Tahitian breezes dance across crystal blue waters. Beneath tropical seas lies a necklace of coral reefs that encircles Mo'orea like a string of brightly colored jewels.

Extensive reefs of corals named Porites and other species form atolls, or reefs that ring Mo'orea's lagoons.

Porites are colonial corals, also known as Scleractinians, found in shallow, tropical waters throughout the Indo-Pacific and Caribbean regions. Think tropical reef and your mind's eye is likely seeing Porites.

These corals and other calcifying marine life, such as coralline algae, are also the world's primary reef-builders. And therein lies the trouble.

The seas in which these calcifying species dwell are turning acidic, their pH slowly dropping as Earth's oceans acidify in response to increased carbon dioxide (CO2) in the atmosphere.

As atmospheric carbon rises in response to human-caused CO2 emissions, carbon in the ocean goes up in tandem.

Underwater office: Researchers obtain information on Mo'orea's coral reefs.

Marine life that depends on calcium carbonate can no longer form shells or, in the case of coral reefs, skeletons. Such marine life is found in waters that are more basic with a higher pH rather than a lower pH, which is more acidic.

Marine scientists study how Mo'orea's corals and other species respond to more acidic seas.

Porites reefs, say scientists Peter Edmunds and Robert Carpenter of California State University at Northridge, are among the most sensitive of all corals.

Carpenter and Edmunds are two of the lead scientists at the National Science Foundation's (NSF) Mo'orea Coral Reef Long-Term Ecological Research (LTER) site.

Mo'orea is the only coral reef site in NSF's LTER network.

To study the effects of ocean acidification on corals and other calcifying organisms, the biologists have been awarded an NSF SEES (Science, Engineering, and Education for Sustainability) Ocean Acidification grant.

We need to understand the chemistry of ocean acidification and its interplay with other marine processes—while Earth's seas are still hospitable to life as we know it, according to David Garrison, director of NSF's Biological Oceanography Program.

Carpenter and Edmunds hope to learn how fast—and the specific mechanisms by which—ocean acidification is affecting Mo'orea's corals and calcified algae, before the island's pristine reefs join dead and dying corals lining tropical coastlines around the world.

"Is there a way of sustaining healthy coral reefs when our oceans are acidifying?" asks Edmunds.

"Marine animals and plants from pteropods—delicate, butterfly-like plankton—to hard corals and coralline algae are affected by ocean acidification, as are the microbes that fuel ocean productivity and influence the chemical functioning of seawater.

"Corals like Porites, with their extensive distribution in tropical waters, may be ocean 'canaries in the coal mine.'"

Mo'orea's corals form the backbone of a reef ecosystem that supports many other creatures.

At the current rate, he and Carpenter believe, coral reefs could disappear by the turn of the next century.

“The loss of biodiversity,” says Carpenter, “would be devastating to the world’s oceans—and to all of us. Tourism and fishing, in fact, entire economies, depend on coral reefs.”

The scientists’ recent findings are cause for hope, however. Porites, it turns out, may be developing an ability to counteract the effects of ocean acidification.

When Edmunds exposed Porites to different water temperatures and pH levels, and to plankton called brine shrimp as a food source, he found that increasing the amount of plankton in the coral’s diet reduced the effects of ocean acidification.

The results are published in a recent issue of the journal Limnology and Oceanography.

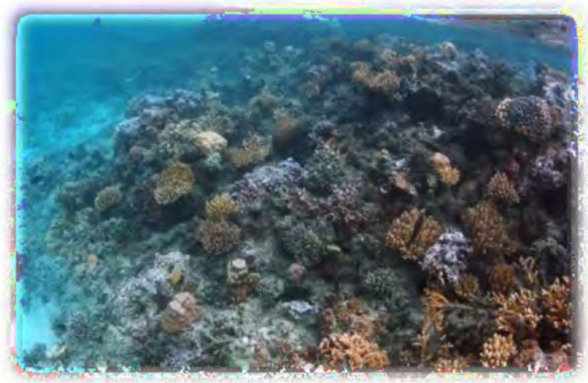
“It’s an intriguing mechanism,” says Edmunds. “As seawater became more acidic, the corals continued to deposit calcium carbonate [new hard skeleton]. Although ocean acidification reduced the overall ability of coral tissue to calcify, the corals responded to more food by adding more tissue.”

Edmunds thinks the extra food may allow the coral to “bulk up,” thereby changing its internal structure and increasing its ability to manufacture skeleton even in acidifying waters.

“It’s an important finding that corals can mitigate the effects of ocean acidification,” says Garrison. “It will be important to uncover the specific mechanism, and to establish whether other species have this ability.”

And whether, says Edmunds, it might allow Porites to survive in the more acidic oceans of the future.

Edmunds and Carpenter found that the response of tropical reefs to ocean acidification may be species specific, with some species of corals and coralline algae affected more than others.



Beautiful coral reefs that ring the island of Mo’orea are affected by acidifying ocean waters.

They’ve also discovered that more acidic oceans may lead to changes in patterns of biodiversity in a high-CO2 world.

If the tropical seas cauldron continues to bubble with waters turning to acid, the scientists say, it will indeed lead to double, double toil and trouble—for the most beautiful island in the world, and for coral reefs around the globe.

Ultimately, it will affect the sustainability of life on a planet that—made up of 70 percent ocean—might better be called Water than Earth.

Alligator Commuters: Gators' Travels Link Freshwater and Marine Ecosystems

Florida alligators travel upstream and downstream between marshes and the coast

23 June 2011

An alligator lazes on the bank of the Shark River.

'Gators. They're everywhere in freshwater areas of the southeastern U.S.

Now, scientists have found that American alligators also swim into the brackish waters of estuaries—places where rivers meet the sea—out into the coastal zone and back again.

In a study at NSF's Florida Coastal Everglades LTER site, Adam Rosenblatt holds an alligator.

These "commuter" alligators connect different habitats, creating links among marine, estuarine and freshwater food webs.

"Alligators need frequent access to low-salinity freshwater because, unlike crocodiles, they don't have glands that can excrete salt," says scientist Adam Rosenblatt of Florida International University (FIU).

"However, that doesn't keep them from making use of saltier environments."

Rosenblatt and Michael Heithaus, also of FIU, conducted a study of alligators' movements between freshwater and saltwater habitats in South Florida. They published their results in the Journal of Animal Ecology.

In their study, which took place in Florida's Shark River estuary in the Everglades, alligators moved long distances between freshwater marshes and the estuary's mouth.

Florida's Shark River: home to many alligators, key parts of the aquatic ecosystem.

The estuary is part of the National Science Foundation's (NSF) Florida Coastal Everglades Long-term Ecological Research site.

"Alligators are 'ecosystem engineers' because their burrows, nests, and trails create unique local habitats," says Saran Twombly, program director in NSF's Division of Environmental Biology.

"This research tells us that alligators also may regularly 'engineer' nutrient transfers over large distances between habitats in coastal wetland ecosystems."

An acoustic transmitter is attached to the tail of an alligator.

Rosenblatt and Heithaus used the movements of individual American alligators as a model system to investigate whether top predators link food webs in habitats some distance apart—and whether individual alligators' movements might be an important part of the transfer of nutrients between these locales.

"Alligators in the Shark River are almost always alone," says Rosenblatt. "They appear to spend their time foraging and traveling, then resting between these two activities."

Estuaries are critical habitats for many species with recreational, commercial and ecological importance, Rosenblatt and Heithaus write in their paper. "They serve as 'nurseries' for many fish and invertebrates."

Species with broad salinity tolerances are thought to connect estuaries with other coastal ecosystems. They feed in productive estuarine waters, then ferry nutrients along as they move into coastal waters.

For example, female blue crabs feed in estuaries, then swim to the mouths of these estuaries to release their eggs during spawning.

"The role of larger predators, like alligators, in doing the same thing has been largely overlooked," says Rosenblatt.

He and colleagues searched for alligators at night from an 18-foot boat. They used high-powered spotlights to find and capture alligators, then weighed and measured them. Ultimately the 'gators were fitted with acoustic transmitters to track their movements.

"Commuting" alligators, Rosenblatt and Heithaus found, make frequent trips between differing salinity zones, and vary widely in the amount of time they spend in downstream or upstream regions.

Downstream-commuting alligators traveled between the mid-estuary and the sea; upstream commuters between the mid-estuary and freshwater marshes.

Unlike species with less mobility or smaller body sizes, "mobile large-bodied species like American alligators are buffered against short-term stress by their size," says Rosenblatt. "They have the staying power to remain in different habitats for longer periods of time."

Researchers weigh an alligator using a spring scale.

Scientists measure the length of an alligator.

Downstream commuters, for example, move into saltier waters to feed; it's thought that they then move back into fresher waters to recuperate from the trip.

If these alligators consistently haul out or bask at locations upstream, "they could create nutrient 'hotspots' in the mid-estuary zone," says Rosenblatt.

All this commuting leads to a chain of habitat interconnections.

"Nutrient 'translocation' by highly mobile predators like alligators," Rosenblatt says, "may be important to the entire coastal Everglades ecosystem."

A long commute, at least for American alligators, and likely for the habitats in which they live, has its rewards.

New View of Undersea Giant Kelp Forest "Canopy"—From Satellites Above

Marine scientists discover wave disturbance, nutrient levels affect California giant kelp growth

25 May 2011

Marine scientists have a new view of giant kelp in the Pacific Ocean—through a scuba mask and a satellite's "eye."

Forests of giant kelp, or Macrocystis pyrifera, are found in temperate coastal regions—and are among the most productive ecosystems on Earth.

In a melding of data from the beneath the waves and the skies above, researchers have developed a method for studying how environmental factors affect kelp forests.

The results have allowed scientists to look at changes in giant kelp across hundreds of square miles in California's Santa Barbara Channel over 25 years, from 1984 through 2009.

The findings are published in the journal Marine Ecology Progress Series.

Obtaining a quarter-century of imagery from the same satellite, in this case the Landsat 5 Thematic Mapper, is unprecedented, says David Siegel of the University of California at Santa Barbara (UCSB), one of the paper's co-authors.

"A satellite mission that goes on for 10 years is rare," says Siegel. "One that continues for more than 25 years is a miracle."

Until recently, the high cost of Landsat images limited their use in research. Then in 2009 the Landsat image library was made available at no charge.

Landsat image of transects at the Arroyo Quemado and Mohawk kelp forests.

"In the past, it wasn't feasible to develop long time-series using Landsat images," says Kyle Cavanaugh of UCSB, the paper's lead author. "Once these data were released free of charge, however, we could access hundreds of pictures that show an area over time."

Images from the Landsat 5 satellite provided the researchers with a view of how giant kelp forests change across a broad geographic region.

"Giant kelp forms a dense floating canopy at the sea surface that's distinctive when viewed from above," write the scientists in their paper. "Water absorbs almost all incoming near-infrared energy, so the kelp canopy is easily differentiated using its near-infrared reflectance signal."

Underwater view of the giant kelp canopy in the Santa Barbara Channel.

In southern California, giant kelp is found primarily on shallow rocky reefs distributed in patches. The plants' numerous fronds extend upward in oceans and bays, forming a canopy at the surface.

The kelp grows to lengths of more than 100 feet, at a rate of up to 18 inches per day.

Giant kelp provides food and habitat for many ecologically and economically important near-shore fish and other species, says David Garrison, program director in the National Science Foundation's (NSF) Division of Ocean Sciences, which funded the research along with NSF's Division of Environmental Biology.

An underwater canopy: kelp plants grow toward the sea surface on strong, flexible stipes.

The kelp is also an important source of food for many deep-sea species. Giant kelp that's uprooted from the seafloor is transported offshore into deeper waters, where it sinks and fuels deep-sea ecosystems.

The scientists found that giant kelp growth in exposed areas of the Santa Barbara Channel is mostly controlled by large waves.

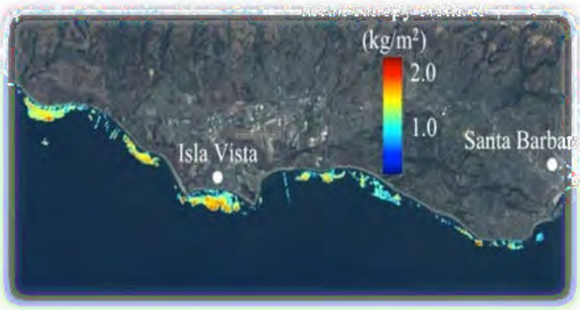
The kelp's growth in more protected areas, however, is limited by low nutrient levels.

During winter months, storms in the north Pacific Ocean create large swells that enter the Santa Barbara Channel. Waves breaking during and after these storms are a major source of giant kelp death in this region.

Scuba diver measures giant kelp biomass in permanent long-term underwater research plots.

Giant kelp is particularly sensitive to changes in climate that alter wave and nutrient conditions.

Using Landsat data, the researchers discovered that most years had a seasonal kelp cycle, with minimums in the winter followed by rapid growth in the spring and early summer. This growth in turn led to maximum amounts of kelp in late summer and early fall.



Giant kelp canopy biomass off Santa Barbara measured by Landsat 5 satellite from 1984-2010.

"We know from scuba observations that individual kelp plants are fast-growing and short-lived," says Cavanaugh. "The new data show the patterns of variability that are also present within and among years at much larger spatial scales. Entire kelp forests can be wiped out in days, then recover in a matter of months."

Information collected by scientists at the Santa Barbara Coastal Long-Term Ecological Research (LTER) site was added to the satellite data.

Dan Reed of UCSB, a co-author of the paper and principal investigator of the Santa Barbara Coastal LTER site, has spent many hours as a scuba diver studying giant kelp.

"The kelp occurs in discrete patches," he says, "but the patches are connected genetically and ecologically. Species that live in them can move from one patch to another.

"Having this satellite capability allows us to look at how the different patches are growing, and to get a better sense of how they're connected," says Reed. "We can't get that information through diver plots alone."

Continued large-scale and long-term observations are needed, he says, to understand how ecosystems—including giant kelp forests—might behave in a future climate.

Aerial view of the canopy of giant kelp floating offshore near the city of Santa Barbara, Calif.

Life Underground Critical to Earth's Ecosystems

Scientists travel 'down the rabbit hole' for new view of subterranean biodiversity

29 July 2009

"I wonder if I shall fall right through the Earth!" mused Alice-in-Wonderland as she tumbled down the rabbit-hole." How funny it'll seem to come out among people that walk with their heads downwards! The antipathies, I think ..."

Alice's experiences in a below-ground world, written about by Lewis Carroll in 1865 in his famed Alice's Adventures in Wonderland, were fiction.

Or were they?

If the work of biologist Diana Wall of Colorado State University (CSU) in Fort Collins is any indication, life indeed imitates art.

Wall, who studies life beneath the surface, is using DNA-based methods to discover the extent of the biodiversity under our feet. Soil, it turns out, provides habitat for millions of species, an array of animals every bit as varied and strange as those Alice encountered.

"You have roundworms, or nematodes, the lions of the underground," says Wall. "These animals rule the Kingdom of Soil."

For example, some 89 nematode species are found in little more than 90 cubic centimeters of soil below a tropical forest in Cameroon.

"The unseen, and mostly underappreciated, realm beneath us is teeming with life," says Wall. "Earth is really brown and black, not green."

Spruce trees cover a hidden world at the Bonanza Creek LTER site.

Increasingly, soils are recognized as one of the most species-rich habitats on Earth, according to Matt Kane, a microbiologist and program director in the National Science Foundation (NSF)'s Division of Environmental Biology, which funds Wall's research.

Researchers collect soil samples at the Arctic LTER site.

"Soil animals and their interactions with microorganisms influence many ecosystem processes," says Kane, "including decomposition, nutrient cycling, carbon sequestration, plant community dynamics and the soil structure itself."

An understanding of the biodiversity of soils is critical to maintaining the "ecosystem services" from which humans benefit.

"All above-surface organisms ultimately depend on soil biodiversity for food and habitat," Wall says. "Human health and national economies are largely based on benefits derived from soils.

"What some call 'plain old dirt' in reality provides fertile ground for our food, whether crops on land or fish and crustaceans from freshwater and marine sediments [soils]."

Scientist Ed Ayres studies animals below-ground in tundra above the Arctic Circle.

Soil biodiversity, she says, is also crucial to controlling human, animal and plant pathogens; floods and erosion; waste-processing; and water purification.

Some regions on Earth "have high-fertility soils, like the Nile Delta region," says Henry Gholz, a program director in NSF's Division of Environmental Biology. "Others are underlaid by permafrost, or are very shallow and less productive."

Researchers Johnson Nkem and Jamie Hollingsworth take samples from the boreal forest.

Global changes have led to degraded soils through desertification, droughts and floods; many places are losing once-fertile lands.

A nematode worm is extracted from tundra soil near Toolik Lake.

How do soil biologists uncover what's usually obscured by roads, lawns, and golf courses, or by forests and meadows?

"Soil animal biodiversity has only been researched in a limited number of ecosystems," says Wall.

This dearth of information results partly from a lack of methods to rapidly and easily measure biodiversity below-ground, she and colleagues state in a paper published in the journal Soil Biology & Biochemistry.

Current ways of studying the biodiversity in soils are based on traditional morphological identification (looking at animals under a microscope and "keying" them out).

With that in mind, scientists Wall and Ed Ayres at CSU, along with Richard Bardgett of Lancaster University in the U.K., and Jim Garey and Tiehang Wu of the University of South Florida, conducted research on the below-ground biodiversity of two Alaskan ecosystems using DNA sequencing.

Boreal forest stretches across mid-Alaska; NSF's Bonanza Creek LTER site is located here.

Bonanza Creek winds through miles of forest; beneath is a thriving underground world.

"It's the most comprehensive molecular analysis of soil fauna to date," says Wall.

The biologists studied life beneath the surface at two of NSF's 26 LTER sites: the Bonanza Creek and Arctic sites in Alaska.

Bonanza Creek is in interior Alaska southwest of Fairbanks, below the Arctic Circle; the Arctic site, above the Arctic Circle, lies in the foothills region of the Brooks Range on Alaska's North Slope. Bonanza Creek is mostly boreal spruce forest, while the Arctic site is largely flat, open, heath-like tundra.

Wall and colleagues found that nematodes were the dominant soil animals, whether under boreal forest (60.9 percent) or tundra (69.8 percent). Rotifers, microscopic wheel-shaped animals, made up 26.1 percent of the soil animals in the Arctic tundra and 18 percent of life beneath the boreal forest.

Arthropods such as spiders comprised some 19.4 percent of the boreal forest underground, and 2.6 percent of that of the tundra. Tiny tardigrades, better known as water-bears, were rarer, at 1.3 percent and 1.5 percent of boreal forest and tundra, respectively.

"A molecular approach [DNA sequencing] to 'gazing through the looking glass' provided new information on what lives below the surface, at least in two ecosystems in Alaska," says Wall. "It adds to our understanding of soil animal biodiversity, especially in locations rapidly affected by global warming."

NSF's Arctic LTER Site (ARC) and Toolik Lake field research station are on Alaska's North Slope.

Climate change is happening faster in Alaska than almost anywhere on Earth.

"Life beneath the surface at the Bonanza Creek and Arctic LTER sites is already showing changes," says Gholz. "It's imperative that we know what's there now, to better plan for the future."

In Lewis Carroll's century-plus-ago tale, Alice finally reached bottom on her long fall down the rabbit-hole. Landing in unfamiliar surroundings, she wondered whether it was warm there.

A century hence or sooner, the answer to her question might be "yes"—even above the Arctic Circle.

For Alice, the White Rabbit led the way. For the denizens of Earth's soils, scientists like Diana Wall are shining light on underground darkness.

"How late it's getting!" cautioned the White Rabbit. "There's not a moment to be lost."

Diana Wall might sound exactly the same alarm.

Appendix I: Image Credits

The Colors of Fall: Are Autumn's Reds and Golds Passing Us By?

1. David Lee
2. John Burk
3. David Foster
4. NSF Havard Forest LTER Site
5. David Foster
6. David Foster

Tropical Reefs Survive Environmental Stresses: Corals' Choice of Symbiotic Algae May Hold the Key

All Images: Hollie Putnam

Acid Rain: Scourge of the Past or Trend of the Present?

All Images: NSF Hubbard Brook LTER Site

Long-term Ecological Research Reveals Causes and Consequences of Environmental Change

1. NSF HJ Andrews LTER Site
2. NSF LTER Network
3. David R Foster
4. NSF Sevilleta LTER Site
5. McOwiti O. Thomas
6. Zena Cardman

Cry Me a River: Following a Watershed's Winding Path to Sustainability

1. UW Madison
2. Michael Forster Rothbart, UW-Madison
3. Blake Draper
4. City of Madison, Wisconsin
5. Sam Zipper
6. Blak Draper

Out of Africa and Into the American Midest

1. NSF Cedar Creek LTER site
2. Elizabeth Borer

Images 3-6: NSF Cedar Creek LTER site

Trouble in Paradise: Ocean Acidification This Way Comes

All Images: NSF Mo'orea Coral Reef LTER Site

New View of Undersea Giant Kelp Forest "Canopy"—From Satellites Above

1. NASA; SBC LTER Site
2. Stuart Halewood
3. SBC LTER Site
4. SBC LTER Site
5. NASA; SBC LTER Site
6. Jeff Jones

Life Underground Critical to Earth's Ecosystems

1. Ed Ayres, Colorado State University
2. Ed Ayres, Colorado State University
3. Johnson Nkem, Colorado State University
4. Ed Ayres, Colorado State University
5. Grace Li, Colorado State University
6. Diana Wall, Colorado State University
7. NSF
8. NSF

Appendix II: LTER Arts Credits

From left to right:

Artist	Name of Piece	Dimensions	Media
Nancarrow, Ree **(Front Cover)**	Deneki Lakes: Then	37x43	Fiber, quilt
Nancarrow, Ree **(Front Cover)**	Deneki Lakes: Now	37x43	Fiber; quilt
Ranzen, Karin	Red Winged Blackbird	25x20	Silk dupioni, Acrylic paint
Freer, Fred	Thin Ice	30x15	Acrylic painting
Glendenning, Terry	Fire Below: A Methane Gas Bubble Triptych	12x36	Multiple layers of paint and polymer acrylic medium on prepared wooden substrate
Hedden, Jessie	Burn Composition 3	11x14	Acrylic on paper
Klass, Margo	Glacier	10x30	Concertina binding, Somerset paper, gouache, bookcloth, Japanese paper; Technique: Pochoir
Carol Glelvin-Reymiller	Metaphor for the Future: Hoping for Well-Adapted Children	18x16x3	Wooden shoe lasts, Wolf unlnae, lynx claws, glass beads, buttons, babiche, acrylic paint
Yates, Douglas	Mountains Rising	22x25	Digital capture, archival paper, ink jet print
Kaspari, Debby	Hemlock and Chestnut	24x36	Pastel
Hirsch, John		24x36	Photograph
Hirsch, John		24x36	Photograph
Bryant, David	Red eft - dark	12x12	Oil on board
Bryant, David	Red eft - light	12x12	Oil on board
Kaspari, Debby	Sanderson Tannery	24x36	
Hirsch, John		24x36	Photograph
Kaspari, Debby	Wolf Pine	24x36	Pastel
Daulton, Terry		30x42	Pastel
Ramsdell, Jim	Chase Scene	44x24x20	Sculpture
Daulton, Terry		30x42	Pastel
Schnell, Mindy	Gimme Shelter	24x31	Watercolor
Singsaas, Ann	Lake Impressions	30x34	Watercolor
Singsaas, Ann	Little Ripple	22x28	Watercolor
Peterson, Bonnie		52x72	Quilt
Daulton, Terry	Trout Lake Station	30x42	Pastel
Daulton, Terry	A Sunday Afternoon on the Shore	30x42	Pastel
Singsaas, Ann	Trout Lake	12x18	Watercolor

NSF 13-083