Planning of neon Moves Ahead

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Planning of NEON Moves Ahead

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Think big.

From the beginning, that's been the charge for planners working to envision the National Ecological Observatory Network (NEON), the biological sciences' first continent-spanning major research platform.

What they came up with was a 17-observatory "network of networks," to be arrayed across the nation and linked by the latest in computer networking capabilities. This network, made possible by new technologies, would continually sample the environment from coast to coast with an unparalleled array of sensors, the resulting data to be standardized and shared among disciplines in unprecedented ways. And it would involve securing at least $350 million from "the big leagues" of the National Science Foundation (NSF) budget—that portion allocated to Major Research Equipment and Facilities Construction.

Organizers have variously compared the scope of the sweeping effort to the first moon shot, the Hubble Space Telescope, or the Human Genome Project.

And now the planners have a new charge: Think bigger.

That, in effect, was the message from Congress last fall after it declined to fund NEON's first two prototype sites in favor of dedicating $6 million toward reenvisioning the network's infrastructure, as recommended by the National Academy of Sciences (NAS).

Though NAS has expressed strong support for NEON, it also said that the network's implementation plans need to be refined. One concern: Unrolling the network two sites at a time, as originally proposed, would mean "NEON would not be a truly national network of sites until all the observatories are funded and built," perhaps not for a decade. As an alternative that would bring the "nationwide network" aspect into play sooner, the academy recommended creating six continent-spanning, multisite observatories, each organized around one of six "critical environmental challenges."

It might seem as if this would put planners back at the drawing board—and in some ways it has. But among NEON's chief architects, this vision of a network that is "integrated and cohesive from the beginning" is being embraced, says Jeffrey Goldman, leader of Infrastructure for Biology at Regional to Continental Scales (IBRCS), an NSF-funded project of the American Institute of Biological Sciences (AIBS).

Between March and September 2004, Goldman and IBRCS science associate Rina Aviram hosted a series of workshops, each focusing on one of NAS's key "challenge" areas: invasive species; the ecological aspects of biogeochemical cycles; biodiversity, species composition, and ecosystem functioning; ecological implications of climate change; land use and habitat alteration; and ecology and evolution of infectious disease.

For each workshop, experts from the prospective NEON community were asked to identify the key scientific issues that could best be addressed by a distributed and integrated ecological research facility such as NEON, and to suggest corresponding infrastructure needs. Says Goldman, "Our guiding principle is to allow specific, high-priority science questions to drive other aspects of the design process." The results will help shape the ultimate design and implementation of NEON.

The idea: to come up with the kinds of overarching scientific questions that might drive the design of the national network, questions too big to be answered by existing networks—questions, in short, that only NEON could answer.

Forming a theory of invasion

Usually, researchers attack concerns about invasive species on a case-by-case basis, says Mark Hunter, associate professor at the University of Georgia's Institute of Ecology. "One minute it's the hemlock woolly adelgid," he says, referencing the Asian insect responsible for defoliating US hemlocks, "then it's the brown tree snake" (the tropical snake that took out at least a dozen of Guam's native forest birds), "and then it's some other pest of the moment. And so, because we're being responsive rather than proactive, there's no theory development," he says. "All we have are [ways] how to handle specific cases."

With a network such as NEON in place, however, Hunter, who was among those who participated in an IBRCS workshop held in Washington, DC, on 18 March 2004, sees new possibilities

What is the effective biological diversity of the United States? When it comes to biodiversity, say researchers, there are still more unknowns than knowns. Case in point: the little-understood microbial world in and around these near-boiling, silica-depositing springs in the Upper Geyser Basin of Yellowstone National Park—which could hold the key to understanding the origins of life on Earth. Photograph: Carrine E. Blank.

for creating a general theory of biological invasion that could help predict, prioritize responses to, and even prevent future invasions.

- What makes a species and a population invasive?
- What are the consequences of invasions on ecosystems?
- Are there general characteristics that make ecosystems vulnerable to invasions?

With answers to these and other questions, says Hunter, a general theory of biological invasion could someday help inform regional to continental responses at all potential stages of an invasion, whether the invaders are ants or gypsy moths or something else. It's this kind of hierarchy of answers that communities battling invasions most need.

Take the case of imported red fire ants, first introduced to the United States in the 1930s. By the late 1950s, they had moved throughout the South, and the US Department of Agriculture was waging war against the insects with a hail of insecticide pellets.

It didn't work. Today, few residents of the American South can successfully sidestep the pesky, sometimes deadly, invaders. Experts are still seeking ways to keep the ants from taking over new territory and forcing out native species. Recent government assessments indicate that the ants will most likely continue to expand their range west and north, with some already finding their way to points along the Pacific Coast in Oregon and California.

Only recently, Hunter says, did we even begin to understand the invasion's greater consequences.

"Imagine if NEON had been in place when the fire ant introduction had taken place," he suggests. "As each ecosystem was invaded by the species, if that ecosystem had been part of an integrated network, there would have been very, very good comparisons of before and after, and therefore very good predictions of what each county and each region should expect as the fire ants got there," says Hunter. "Forewarned is forearmed."

"Instead, without a network in place, every time it got somewhere new, pretty much all the research was done all over

Big questions.

This is a sampling of the questions that came out of the six thematic workshops. Complete workshop reports are available online at *http://ibrcs.aibs.org.* More information about the NEON Design Consortium and ongoing NEON planning is at *www.neoninc.org.*

Invasive species
- What makes a species and a population invasive?
- Are there general characteristics that make ecosystems vulnerable to invasions?
- What are the consequences of invasions on ecosystems?

Ecological aspects of biogeochemical cycles
- What are the physical, biological, and social processes that regulate the cycling of and interactions between carbon, nitrogen, phosphorus, water, and other materials at multiple (spatial, temporal, biological) scales?
- What anthropogenic contaminants will have important biogeochemical impacts, and how do we predict them?
- How can historic changes inform us about the critical processes involved in future biogeochemical change?

Biodiversity, species composition, and ecosystem functioning
- What is the effective biological diversity of the United States?
- How does ecosystem functioning change as biodiversity changes, and how does biodiversity change as ecosystem management changes?
- What elements are needed for predicting changes in biodiversity and ecosystem functioning and the implications of those changes for human needs?
- What are the spatiotemporal patterns regulating evolution?

Ecological implications of climate change
- How does climate change affect the genetic interactions within and among species, and ultimately the evolution of communities and ecosystems?
- What are the time–space domains of ecological variance, and how are these influenced by the spatial and temporal scales at which climate varies and changes?
- How will changes in climate influence regional ecosystem structure and function, and how will these ecosystem changes feed back to climate, hydrology, and biogeochemical cycles?

Land use and habitat alteration
- What are the past and current land-use and land-cover change patterns and trends?
- How do human population size and societal values drive land-use change?
- How predictable are future rates of change?

Ecology and evolution of infectious disease
- How many organisms that could cause disease for humans, animals, and plants are likely to exist?
- How does biodiversity affect the health of ecosystems?
- When and where in the ecosystem are disease outbreaks likely to occur?
- Can we predict the emergence and spread of disease?

again," he says, which "wastes a lot of time and resources."

Ecological aspects of biogeochemical cycles: Targeting uncertainty

"Humanity has entered a century of environmental uncertainty," begins the report of the 20–21 July 2004 workshop in Boulder, Colorado. "Changes in the biogeochemical cycling of carbon, nitrogen, phosphorus, and other key elements on Earth, and the maintenance of key biogeochemical resources such as air, water, and soil, will lie at the center of scientific, societal, and political agendas for decades to come."

It probably doesn't help, therefore, that the subject of biogeochemical *anything* is a bit arcane for the general public; moreover, the models scientists use to better understand systemwide changes can themselves be uncertain.

The problem: Current biogeochemical budgets contain gaps, unknowns that exist both because of inadequate data collection and because researchers don't yet understand all the factors driving the biogeochemical fluxes. For example, many fundamental connections be-

How will changes in climate influence regional ecosystem structure and function? In a Colorado forest, downward-pointing infrared radiators warm five 3-by-10-meter plots as part of a long-term ecosystem warming experiment at the Rocky Mountain Biological Laboratory in Gothic, Colorado. Photograph: Natalie Demong, courtesy of John Harte.

tween such factors as biodiversity and biogeochemical cycling are still largely undefined, as are the effects of direct or indirect human influence.

Nailing down such unknowns by tapping into existing measurement networks, as well as by developing new ones, would improve the accuracy of everything from climate change models to our understanding of how air pollution will impact a system, before impacts occur.

Perhaps equally important, says Lars Hedin, a professor in the Department of Ecology and Evolutionary Biology at Princeton University, more accurate models could improve the ability of scientists to communicate effectively and credibly about such change to the general public. "Underlying our questions," he says, "was this need for understanding system change and the relevance to society, and developing the kinds of models society can use."

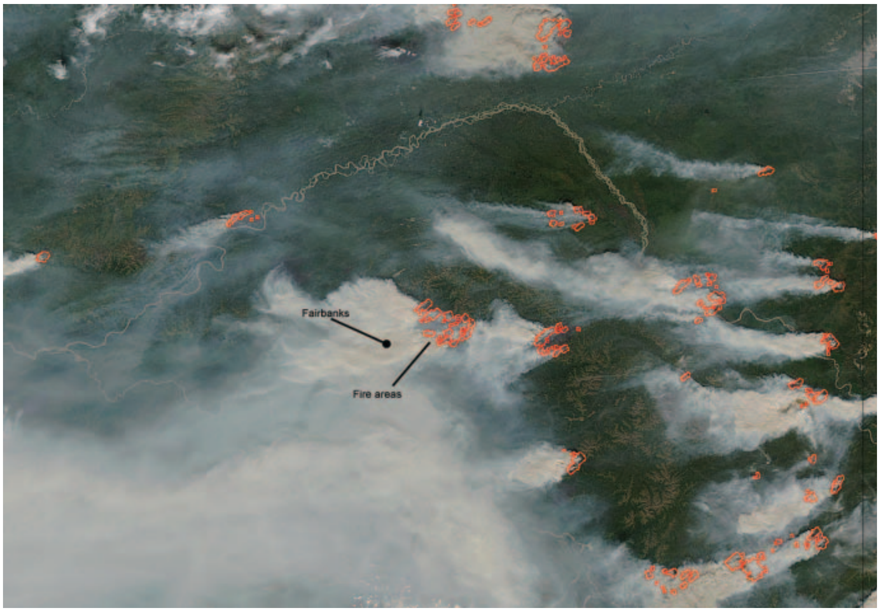
If NEON had been in place 20 years ago, says Hedin, today's conversations over climate change might be drastically different.

"You would have seen earlier the tremendous changes" in the climate of Alaska, for example, says Hedin, or the potential impacts on wine and food production in California. "There would be much more public awareness, there would be a much more coordinated and consistent view of how the environment in the United States is changing and why it's changing, what the impact will be on society, on people; and that information would be quantitative and deep enough to really influence journalists and decisionmakers. Right now, we're lacking information.

"It's not enough to say there are changes in climate. We need all the nuances as to how it will affect [the] stability of our livelihoods and environments."

To understand the effects and interactions of climate change, one change ecologists are going to have to make is to start thinking like climatologists, or at least learn to think on the same spatial and temporal scales as climatologists do, concluded workshop participants. The current mismatch has compromised researchers' detection ability, noted the report.

The group recommended leveraging existing infrastructure, such as long-term ecological research (LTER) and AmeriFlux networks, but with a focus on the regional-to-continental scale, which was lacking in previous networks.



And how will the ecosystem changes brought about by climate change feed back to climate, hydrology, and biogeochemical cycles? An unusually warm and dry summer in Alaska led to a record-setting year of wildfires in 2004, with more than 7 million acres burned (the previous record was 5 million acres in 1957). Mudslides, insect outbreaks, and invasive weeds may be just some of the consequences. There's also the possibility that widespread northern fires could contribute to further climate change. Satellite image: MODIS Rapid Response System, a program of the National Aeronautics and Space Administration and the US Forest Service.

Closing the budget gaps and increasing the predictive power of biogeochemical models, as well as learning more about environmental resilience, were among the high-priority areas identified by the work group. The report describes integrating NEON sampling efforts with a range of existing flux networks, as well as implementing regular sampling of other factors, such as sampling stable isotopes for insight into physical changes in the environment.

Another critical need, Hedin says, is ensuring the network extends into urban and suburban areas, where researchers might otherwise not sample. "We realize there are few natural systems left in the world," he says. "The leap here that's necessary—but will also be difficult—is to bring in humans, to bring in social systems into the models that define how we see our environment.

"Instead of humans outside the models, we need humans in there, as drivers."

With more data and more opportunities for analysis, Hedin says, "there would be much more information about what changes are happening, which ones are serious, which ones will affect how we will go about our lives."

Getting a sense of biodiversity

"Science really becomes powerful—and becomes science—when we can turn descriptions into predictions, into forecasts," says Leonard Krishtalka, director of the Natural History Museum and Biodiversity Research Center at the University of Kansas.

Modern, computer-assisted science has shown it can produce accurate predictions about the movement of some specific invasive species or viruses or agricultural pests entering new ecosystems. But it is only as good as its inputs. Tomorrow's challenge, says Krishtalka, is to do the same in less time and for more complex phenomena.

His work group, like the others, saw great potential in a network of sensors. "The more data you have...the closer we get to being able to model and forecast complex phenomena such as retraction of species' habitats, or perhaps their extinction, or the effects of climate change on biodiversity and, in turn, on market economies, human health, and social institutions.

"We have that capability now on a small scale. What NEON can do is give us that capability on a much larger scale, across greater areas, greater numbers of animals or plants, perhaps entire ecosystems."

Currently, the unknowns outweigh the knowns when it comes to biodiversity, says Townsend Peterson, associate professor in the Department of Ecology and Evolutionary Biology at the University of Kansas. He was a participant in the invasive species workshop, a session that also brought forward discussions of biodiversity.

"We know vertebrates. We know the easy plants and easy insects," he says, "but I kind of feel like we're looking at such a small tip of the iceberg, we don't even know what the iceberg looks like. We need a more efficient way of noticing things." And when those things are noticed, he adds, they need to be integrated into a broader information system.

Even quite basic questions remain unanswered. For example, among the biodiversity work group's hanging questions was this: "What is the effective biological diversity of the United States?" Explains the report: "We possess no national scale baseline against which changes in biodiversity caused by natural and human activities can be measured."

Suites of sensors at hundreds of sites, supercomputer centers, and 30 to 40 regional observatories would all make up the infrastructure of what some workshop members have called a "bioscope" that might help answer this and other deceptively simple questions. From real-time photos to DNA samples to sonograms of birdsongs, data would be amassed, analyzed, and shared.

The new sensor-rich network may mean not only a new way of doing science, but new ways of interacting with our environment. Better understanding of the impacts we have on our environment could even change the way we build and live in cities in the future, says LTER Network executive director Bob Waide. "It may mean our urban environment has to be modified to preserve the services provided by the surrounding natural environment. The truth is that the things that impact us are much larger than we realize."

A question-based rather than region-based approach makes sense as a way to get at such larger influences, says Waide. "One problem with the region-based approach is that our definition of regions is often somewhat arbitrary," he says. "I think there will definitely be some aspects of NEON [for which] the questions will be large enough [that] they can't be done within a given region."

"Basically, what NEON is going to enable us to do on a very grand scale is forecasting biosphere phenomena and, ultimately, planetary management," says Krishtalka. "I'm thinking that big. I don't know if my colleagues are.

"What NEON is going to allow us to do is get a lot more data at many more spots across the country, a lot more precise, real-time data, which in turn will enable us to do a lot more precise forecasting, from the local to the universal. Ultimately, all this is not only to serve science and our understanding of natural and human-managed systems, but it's to serve society and inform wise policymaking, wise decisionmaking, about sustaining our natural resources and [the] economy, protecting human health from emerging diseases, protecting our wild lands and agricultural lands from dangerous invasive species, and ensuring that nature keeps cleaning our air, water, and soil."

*What are the consequences of invasions on ecosystems? Also called the "marsh monster," purple loosestrife (*Lythrum salicaria*) takes over in wetlands, clogs irrigation canals, and can be nearly impossible to eradicate. This monotypic stand established in a freshwater impoundment at Plum Island, Massachusetts, in the Parker River National Wildlife Refuge. Photograph © 1996 Claus Holzapfel.*

Predicting disease

In 1993, no one knew of any hantaviruses in the New World that could kill humans. Then came a cluster of cases of unexplained pulmonary illness and death in the Four Corners area of the southwestern United States. The culprit was finally determined to be rodents—in this case, the deer mouse. The cluster almost went undiscovered. If not for two people who died within a week of each another, it might not even have been noticed.

For every hantavirus out there that kills, says University of New Mexico pathology and biology professor Terry Yates, "I'll bet there is an even larger number that make a huge number of people sick, but people think they've got a virus or the flu." Large numbers of pathogenic organisms remain unrecognized and uncharacterized and their modes of pathogenicity unknown, says Yates, who is also vice president for research and economic development and curator of genomic resources at the institution.

One of the first challenges of NEON would be to understand the diversity of viruses and other such organisms across the continent.

"From the infectious disease standpoint, what we'd like to be able to do is predict risk in real time so we can hopefully prevent some of these diseases," says Yates. "In public health, we wait until there's an outbreak.

"What we're trying to do is to develop a theoretical system that is sufficiently refined, and on a large enough scale, to do forecasting and predictive understanding in advance."

From high-throughput genomics to superfast computers to wireless sensing, technologies have converged to the point where developing such predictive technologies is theoretically possible. However, "with the small amount known now about pathogenic organisms," Yates says, "making accurate predictions is like asking a chemist to function knowing only 10 percent of the periodic table."

Next for NEON: Blueprint time!

In mid-September, AIBS and NSF announced a two-year, $6 million cooperative agreement establishing the NEON Design Consortium and Project Office at AIBS headquarters. The goal: to develop a blueprint for the network and a plan for implementing it that will best address the nation's most pressing ecological concerns.

Codirecting the NEON Project Office in Washington, DC, are University of Virginia professor of environmental sciences Bruce Hayden, and William Michener, associate director of NSF's LTER Network Office at the University of New Mexico. "The office is critical," says Hayden, "and it's also critical that we now have six postdocs who are helping in the process and a public relations director [who] can help us get the message out."

"There are some real benefits to having a group like AIBS do this," agrees

Michener. "In six months, we've been able to hire six full-time employees. Quite frankly, at most universities in a three-month period, we'd probably still be in the interview stage. We've been able to move quite rapidly."

Both Hayden and Michener have previous experience in NSF's Directorate for Biological Sciences Division of Environmental Biology—not to mention a history with NEON that dates to its earliest days.

The idea for the national network, in fact, can be said to have begun as a twinkle in Hayden's eye back in 1997. Shortly after the success of the Network for Earthquake Engineering Simulation in acquiring funding for a distributed network of sites, he envisioned a similar network for ecological/environmental observatories. The NEON codirectors further credit the longtime assistant director of NSF's Directorate for Biological Sciences. "NEON wouldn't be where it's at now without the real shepherding that's been done by Mary Clutter," says Michener. "She has been the one constant."

Grassroots NEON supporters—hundreds of whom have taken part in self-organized, regional groups—should not feel excluded by the most recent changes in the planning team's approach, Goldman says. He wants such groups to stay involved.

Hayden emphasizes, however, that timeliness is of the essence. "Watch the [NEON] Web pages to see what the next big activity is, because we can't go back to revisit it," he says. "We have 21 months to do a very important, extensive job, so every day it's forward. We don't look back." Calls for input and schedules of upcoming meetings are regularly being posted online at *www.neoninc.org.*

Elizabeth Blood, program director for NEON in the NSF Directorate for Biological Sciences since June 2003, agrees. "It will be really be important for the rest of the science community to participate in this and give feedback in this critical six-month period," Blood says. "This is going to be the window of opportunity to make their needs, concerns, issues known."

With eight years of conceptualization behind it, the NEON process may seem to some to have been endless, but Hayden assures it has actually been following a path not unusual for large infrastructure projects. After the next 2 years of planning and design, he anticipates 5 to 8 years of building planning and purchasing—followed by 30 years of NEON in use. He sees his own and his colleagues' involvement in the planning process as a late-career responsibility and gift to the future of the biological sciences. "For most of us who are Boomers," he points out, "it's going to be our graduate students who take advantage of it." What he and others envision is a future worth planning for: one that breaks down boundaries between disciplines and removes limitations to knowledge.

The planning process, facilitated by NEON project manager Goldman and other senior management team members, continues this year through three regular joint committee meetings that began in January.

Deborah Estrin, director of the Center for Embedded Networked Sensing and professor of the computer science department at University of California–Los Angeles, is one of nine members of the NEON senior management team, which is responsible for leading the design effort. Estrin is cochairing the sensors and sensor network subcommittee, whose job it is to imagine NEON's nervous system—in terms of which technologies are going to be most relevant and revolutionary in addressing the science questions.

Other groups around the world have also been exploring wireless and multiple arrays, she says, so "we don't have to imagine the state-of-the-art from scratch." The biggest challenge, Estrin says, will probably be "making that technology robust and deployable enough so you don't have to have a technician per node."

A "new observability" in the form of future technological capabilities will eventually mean that today's unanswerable questions not only get answers but lead to "second-generation science questions," says Estrin. "This will no longer be seen as monitoring for monitoring's sake or technology for technology's sake, but rather instruments that will shape the questions people ask," she says. "That's why Congress will end up investing in this kind of major research equipment."

For now, all aspects of NEON infrastructure are still up for discussion, says Krishtalka, another member of the senior management team. "The take-home message is that there is no preconceived notion of what NEON should look like."

He proffers this advice to colleagues: "Think big—really big—think, 20 to 30 years down the road, what do we want to understand?... Don't be prisoners of history. Don't get trapped by previous constraints.

"Nothing on this scale has ever been attempted," says Krishtalka. "In some ways it's much larger and more complex than the human genome project, and in many ways it's going to be a test of our community.

"This may be perhaps the most complex biological research and infrastructure project ever attempted in the United States. We should be bold."

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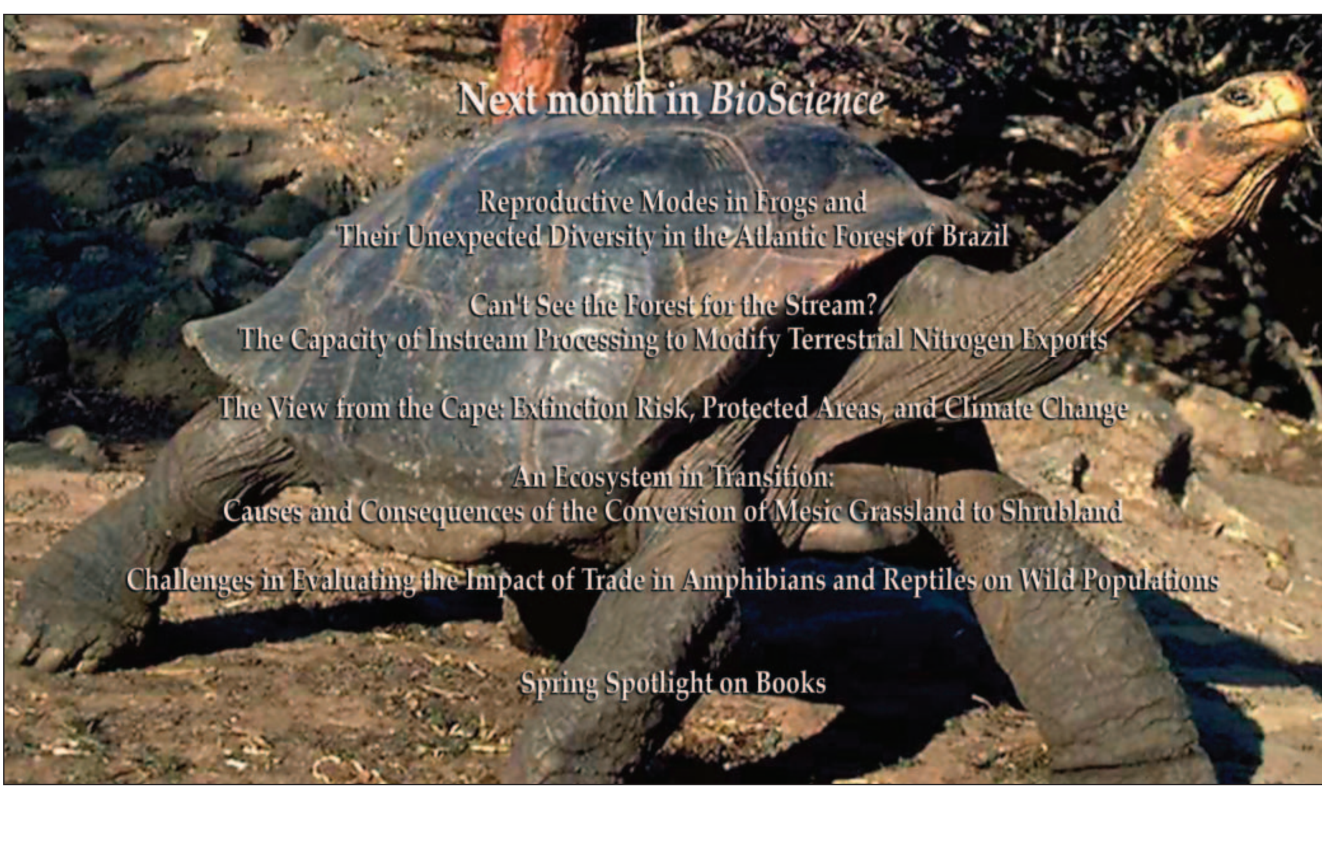
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