

ECOLOGY

A National Ecological Network for Research and Education

A proposal links continental-scale ecological data with education projects.

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In 1804, Lewis and Clark described nearly 300 new plants and animals from Missouri to Oregon, setting a baseline for observational ecology in the United States (1). Forty years later, Thoreau made some of the earliest field measurements at Walden Pond (2). Now, field measurements by scientists, students, and citizens are being taken to a new level as ecologists build the National Ecological Observatory Network (NEON), a continental-scale research platform, to study the nation's ecological challenges (3). Ecologists will use a distributed network of sensors linked by advanced cyberinfrastructure to predict responses of the biosphere to changes in land use, invasive species, and climate over the next 30 to 50 years. Dubbed the "ecologists' Hubble Telescope," this large-scale sentinel for environmental change is funded by the National Science Foundation's Major Research Equipment and Facilities Construction (MREFC) program. During a time of national economic downturns, NEON will foster jobs and student research opportunities at its sites and will contribute data sets to encourage "best practices" to solve environmental challenges on a continental scale.

Citizen science programs have greatly increased in recent years, in part owing to the availability of the Internet for data input and access (4). In the Jason Expedition (www.jason.org), fifth to eighth grade students have collected ecological data to share with other schools. Citizen Science Central began in 2006 as a "clearinghouse for ideas, news, and resources in support of citizen science" and developed a toolkit to facilitate that process (www.birds.cornell.edu/citscitoolkit). The National Institute of Invasive Species Science (NIISS, www.niiss.org) is a consortium of organizations that relies on citizen-science monitoring and reporting of invasive species. Project Budburst (www.budburst.org), a partner with the National Phenology Network



The future: A K–12 scenario. In the year 2020, sixth graders in Miami, Florida, grab their personal digital assistants (PDAs, handheld computers) and log into an ecology lesson. The students download a database on insect pests of subtropical forests, which they can explore as an ecosystem visually and quantitatively. They then engage in simulation "games" involving insect outbreaks that threaten the southeastern forest canopies. Students use case studies and manipulate real-time data (including forest cover, foliage production, and caterpillar population dynamics) to create future scenarios for urban and rural forests. Their PDAs enable them to exchange ecosystem and biodiversity tours that they have created with classes 2000 miles away. Science education researchers simultaneously measure the effectiveness of this combination of cyberinfrastructure, gaming, and hands-on ecosystem research.

(www.usanpn.org), engages the public in observations of seasonal events, such as first leaf, first flower, and first ripe fruit for a diverse array of plant species found in the United States.

NEON differs from other national science programs in its goals to launch ecological research and education platforms simultaneously in a way that improves ecological forecasting. Planning for NEON has taken a decade with hundreds of ecologists collaborating (www.neoninc.org/). Projected to become fully operational in 2016, the NEON national network includes 20 domain sites of matching stationary and mobile field

sensors, laboratories, archival data, synthesis and analysis centers, and education nodes, all linked through high-capacity cyberinfrastructure (3, 5–7). Each candidate site, located in a wild land area, represents the vegetation, soils, landforms, climate, and ecosystems performance of its given domain (Mid-Atlantic, Southern Plains, Pacific Northwest, and so forth). Candidate sites are located across the continental United States, including two in Alaska and one each in Hawaii and Puerto Rico. Work has already begun on a prototypic site north of Boulder, Colorado. These sites are expected to be operational for ~30 years;

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they will allow scientists to monitor ecosystems and forecast ecological changes with regard to six of the National Academies' grand challenges: biodiversity, climate change, ecology, biogeochemistry, infectious disease, invasive species, and land use (8).

Research and Education for Public Policy

NEON aims to integrate ecological research with education (3, 9) (see figure, page 1176). Over the short term, educators and cyberinfrastructure engineers will collaborate to design user-appropriate interfaces, data processing, search services, and other technologies. The plan is that ecologists, the public, policy-makers, students, teachers and other user groups will be able to benefit from and contribute to NEON data streams, products, and learning experiences.

What NEON education and outreach might look like over the next 30 years will ultimately be shaped by a staff that will include an education chief, NEON domain education coordinators, and advisory committees. As a preliminary guide, a NEON Education and Outreach Strategic Plan was released in 2007 (9). One of the goals described in that plan is to train a new generation of scientists not only to utilize NEON's cyberinfrastructure and technologies, but also to communicate better with the public, as well as with each other. NEON education aspires to serve as a test bed for the efficacy of science education linked directly to the science.

A priority in the education program is to include underrepresented groups, such as ethnic minorities, women, and first-generation college students, and to ensure both excellence and applicability of the questions addressed to the general public. NEON plans to foster a generation of researchers trained to work collaboratively with new technologies on a continental scale that integrates multiple factors over time (10–12). In NEON user workshops, graduate students and veteran researchers alike will learn novel approaches to mathematical modeling, simulation, and digital mapping of complex ecological phenomena.

For the public, NEON will bring observations about regional and national environmental changes into schools, town halls, and households, facilitating better understanding of the links between human health and healthy ecosystems. NEON education will develop links between publicly available data sets and user groups through activities such as citizen-scientist investigations, ecological field trips for students from kindergarten through high school (K–12), visualizations of near-real-time data from across the conti-

nent, and conversations between decision-makers and scientists.

Future Questions

At continental, long-term scales, NEON provides an opportunity for ecology education research. Educators will have access to data bases to study how NEON data and materials influence regional decision-makers, K–12 and college students, and ecology researchers (13–15). Examples of questions include: How do we best train graduate students to become science educators as well as researchers? What is the relation between people's knowledge of NEON forecasts and their decisions or actions related to the environment? Can the integration of child-friendly simulations, gaming, and personal technology serve to jump-start student proficiency in science? What is the appropriate balance between technological simulations and hands-on, nature-based activities?

Because NEON science and education are both enormous undertakings, the importance of their integrative capacity could become lost over time. Critical questions that will define the success of NEON education include: Will the NEON cyberinfrastructure network serve multiple audiences including

educators, citizens, diverse populations, and leaders? How can the transformational element of parallel NEON education and science platforms enhance science education in the United States?

Certainly NEON will need to collaborate with other organizations. For example, in building on the scenario envisaged in the figure below, NISS is developing a Global Organism Detection and Monitoring system (GODM) that allows users to browse, upload, download, and analyze data on invasive species of all taxa. Field data are collected by members of the public trained to follow research protocols. Together NEON and NISS could build a national program of geographically distributed "human sensors." Ecologists could then configure the data these citizen-scientists gather for use by local policy-makers. How to make such collaborations successful is another question that will need to be addressed.

NEON represents an ambitious project, much of which, especially the education component, is still on the drawing boards. Will the NEON education vision be achieved, or will it become a pile of dusty papers on a bureaucrat's desk? Only time will tell, as NEON continues to unfold. However, given the urgent environmental challenges we face as a nation, raising ecological literacy in the United States is crucial.

References and Notes

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Supplemental Online Material

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The future: Informed policy-making. Sarasota County's regional government in Florida has a problem. Pythons (first documented in 2001 in the Everglades after pets were carelessly released into the wild) are rapidly moving northward. Using the NEON database on invasive species and specifically targeting subtropical watersheds, county officials execute a risk analysis and estimate costs for controlling this new invasive species over the next two decades.