Land Use and Habitat Alteration

Report from a NEON Science Workshop

August 25–26, 2004
Baltimore, MD

National Ecological Observatory Network
American Institute of Biological Sciences
IBRCS
Infrastructure for Biology at Regional to Continental Scales
A community resource by AIBS

The IBRCS Program

The Infrastructure for Biology at Regional to Continental Scales (IBRCS) Program, an effort by the American Institute of Biological Sciences (AIBS), launched in August 2002 with support from the National Science Foundation. The following are the program's goals:

- Help the biological and the larger scientific community—within and beyond the AIBS membership—to determine the needs and means for increased physical infrastructure and connectivity in observational platforms, data collection and analysis, and database networking in both field biology and other more general areas of biology and science.
- Provide for communications within this community and with NSF regarding the development and focus of relevant infrastructure and data-networking projects.
- Facilitate the synergistic connection of diverse researchers and research organizations that can exploit the power of a large-scale biological observatory program.
- Disseminate information about biological observatory programs and other relevant infrastructure and data-networking projects to the scientific community, the public policy community, the media, and the general public.

The program is led by a working group comprising biologists elected from the AIBS membership of scientific societies and organizations and appointed from the scientific community at-large. It is assisted by a variety of technical advisors. The program has a special focus on the National Ecological Observatory Network (NEON), which is a major NSF initiative to establish a national platform for integrated studies and monitoring of natural processes at all spatial scales, time scales, and levels of biological organization. Jeffrey Goldman, PhD, is the Director of the IBRCS program. He and Richard O'Grady, PhD, AIBS Executive Director, are co-principal investigators under the grant. Additional information is available at *http://ibrcs.aibs.org*.

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About the American Institute of Biological Sciences

The American Institute of Biological Sciences is a non-profit(c)(3) scientific organization of more than 6,000 individuals and 86 professional societies. AIBS performs a variety of public and membership services, which include publishing the science magazine, BioScience, convening meetings, and conducing scientific peer review and advisory services for government agencies and other clients.

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Photo compilation created by Robert Wu. Ground photo collage documenting land cover change from 1902 (desert grassland) to 2003 (Prosopis-Opuntia desert scrub) on the Santa Rita Experimental Range in southeastern Arizona. The image is a collage of photos taken on 3 dates at Photo Station 233 in the Santa Rita Experimental Range Repeat Photography Collection (http://ag.arizona.edu/SRER/photos.html).

NEON Workshop Series

The National Ecological Observatory Network (NEON) is a major initiative proposed by the National Science Foundation (NSF) to establish a continental-scale platform for integrated studies on natural processes at all spatial scales, time scales, and levels of biological organization. NEON is anticipated to provide the resources and infrastructure for fundamental biological research that will enhance our understanding of the natural world, improve our ability to predict the consequences of natural and anthropogenic events, and inform our environmental decision-makers.

The previous two years of NEON-related activity have revealed several steps that the scientific community must take along the path to the creation of NEON. Prior work showed that in order to develop a detailed description of NEON's physical design, an important milestone for NEON, the scientific objectives and targets of NEON must first be defined. With this in mind, as part of the NSF-funded Infrastructure for Biology at Regional to Continental Scales (IBRCS) project, AIBS, in partnership with experts from the prospective NEON community, convened a series of workshops between March and September, 2004, focused on the following ecological themes, which have been proposed as guideposts for the design of NEON:

- Ecological implications of climate change
- Land use and habitat alteration
- Invasive species
- Biodiversity, species composition, and ecosystem functioning
- Ecological aspects of biogeochemical cycles
- Ecology and evolution of infectious disease

The goal of the workshops was to highlight urgent scientific questions that NEON can address, define science requirements associated with those questions, assess the state of currently available infrastructure, and discuss needs for future infrastructure development. The recommendations that grew from these meetings, as captured in this report and others in the series, will guide subsequent NEON planning.

This workshop series opened up the NEON planning process to a diverse group of scientists from academia, government, and the NGO community. In total more than 120 scientists participated in these meetings—some were previously involved in NEON activities, while others took part in a NEON effort for the first time.

Introduction

The magnitude and intensity of change in the Earth's biosphere resulting from habitat loss and the increased intensity of land use are of grave concern (NRC 2001). These changes are having a direct, immediate, and significant impact on species diversity (Lindborg and Eriksson 2004), exotic species invasions (Vitousek et al. 1997, McCay 2001), water quantity and availability (Meyer and Turner 1992, Goetz et al. 2004), and ecosystem productivity and biogeochemical cycles (Osher et al. 2003, Williams et al. 2004). The long-term consequences are difficult to assess, but it is becoming increasingly evident that landscape change may also alter our climate (Copeland et al. 1996, Stohlgren et al. 1998, Pyke 2004) and promote the spread of new diseases (Langlois et al. 2001).

The need for "improved information on and understanding of land-use and land-cover dynamics [in order for] society to respond effectively to environmental changes and to manage human impacts on environmental systems" has been identified as one of six grand challenges for NEON to consider (NRC 2003). AIBS organized a series of workshops to consider questions and organizational issues associated with each of these challenges in the formation of a network of NEON observatories (IBRCS 2003). The objectives were to develop criteria to prioritize research questions (Table 1), identify key research questions that NEON is uniquely able to address (Table 2), and recommend infrastructure (Table 3) necessary to examine these questions.

Table 1. Criteria for prioritizing NEON research questions

Intellectual merit

- Maximizes contribution to knowledge
    - enhances understanding, leading to general principles
    - addresses critical areas currently with insufficient data
    - increases ability to predict and manage problems
- Promotes studies at local to continental scales
    - integrates and synthesizes information
    - assesses broad impacts of ecological change
- Considers previously impossible problems
    - develops new methods and infrastructure
    - requires synoptic analysis and synthesis
    - establishes consistent and comprehensive data sets
- Responds to new needs, methods, and technologies, providing linkage and synergism with existing research

Broad relevance

- Provides a sound basis for land-use management, enabling effective long-term policy and planning
- Educates and informs all aspects of society
- Develops and improves the infrastructure for the study of the consequences of landscape change

Questions and Issues of Concern

A long list of essential needs and critical questions concerning the effects of LULC change was identified at the workshop. The diversity of landscapes, the complexity of ecosystem processes that occur within these landscapes, the intensity and extent of current and historical change, and the many uncertainties associated with landscape studies made the prioritization of these questions a challenge. However, the combined use of the criteria in Table 1 and arrangement of the overriding issues in a hierarchical framework provide an overview of the issues to be considered by NEON (Table 2).

The first of these questions deals with the determination of rates and patterns of LULC change (Table 2, topic I). In itself, documenting land use is a difficult task, and, therefore, much of the work to date has focused on land cover. The accelerating rates and broad impact of LULC change require that careful, accurate, and complete documentation be produced at local, regional, and continental scales. Numerous data sets are now available for assessing contemporary patterns (Table 3), but insufficient effort has been devoted to reconstructing historical trends (Foster et al. 2003). Understanding these trends, and possible lagged effects associated with LULC change, is critical for making useful and reliable projections across temporal and spatial scales (Table 2, question IIIb). The assembly of LULC records in a consistent format, the analysis and evaluation of the sufficiency of such data, and the verification of our ability to extrapolate across scales are sufficient reasons for the establishment of NEON.

Human activity is an essential factor affecting LULC change (Table 2, topic II)

Table 2. Critical questions concerning the pattern and rate of LULC change

I. Describing rates and patterns of LULC change
- a. What are the past and current LULC patterns and trends?
- b. How do natural gradients of biophysical drivers (e.g., topography, weather, natural disturbances) affect current and future patterns of land-use change?
- c. Are responses to LULC change subject to significant lags and/or thresholds that complicate analysis and prediction across spatial and temporal scales?

II. Identifying the causes of LULC change
- a. How do human population size and societal values drive land-use change?
- b. How do local policies (i.e., building permits, conservation easements, etc.) affect regional land-use patterns?
- c. How have past patterns of LULC affected current patterns of land use (legacy effects)?

III. Predicting the consequences of LULC change
- a. How does LULC change affect a spectrum of ecosystem properties, including nutrient cycling, biodiversity, invasion of exotic species, water resources, and net primary production (NPP)?
- b. How predictable are future rates of change based on current regional attributes?
- c. How do human societies respond to LULC change and alter future land-use practices?

and probably the most challenging to understand and predict (Turner 1994). Growth in human populations, changing perceptions and societal values (Table 2, question IIa), and governmental policies and actions (Table 2, question IIb) establish trends and induce patterns with far-reaching consequences (Lambin et al. 2001). Because the ability to predict requires an understanding of complex interactions between humans and the landscape (Table 2, question IIIc), a strong linkage between the disciplines of economics, sociology, and environmental sciences is required for NEON to be successful in this important activity.

The third topic concerns the prediction of the consequences of LULC change (Table 2, topic III). The linkage between LULC studies and other grand challenges (Table 2, question IIIa) makes our ability to project the effects of change of central interest to all ecologists. However, the assessment of these effects must be done within the context of simultaneous changes in the physical drivers (Table 2, ques-

Table 3. Data resources and activities needed to assess land cover and land-use change

Theme	*Example Data Sources*[1]	*Initial NEON Activities*
	LAND COVER	
Current Land Cover (CLC)	LANDSAT NLCD/MRLC, MODIS, and other NASA products	Assemble and evaluate accuracy and resolution of alternative classification schemes
Historical Land Cover (HLC)	Diverse, local records, including aerial photographs	Assemble records, digitize and assess usefulness and validity for representative sites
Land Cover Change (LCC)	Comparative analysis of multiple data sets, including ED	Analysis of trends of change and their association with environmental and land use drivers
Environmental Drivers (ED)	Climate and weather, soils and geology, stream flow, atmospheric inputs, and disturbance agents	Collate information from diverse sources, identify new monitoring needs; distinguish change in condition from change in cover type
	LAND USE	
Human Population & Demography (HPD)	US Census TIGER	Assemble and integrate data with CLC and land-use records
Commerce and Transportation (C&T)	USDOT, state and municipal agencies, USGS, Dept. of Homeland Security	Digitize existing records for an entire region, assess temporal and spatial trends
Urban/Suburban Structures (USS)	Contemporary aerial photography, ground surveys, and databases	Assemble and verify; assess accuracy of information (e.g., errors of resolution); assess spatial and temporal trends
Land Value and Ownership (LVO)	Local historical records and property tax databases	Assemble historical records, digitize and assess validity for representative sites
Socioeconomic Surveys (SES)	Specially constructed	Assess drivers of and response to changing patterns of land cover and land use

[1]Acronyms and information sources: NLCD, National Land Cover Dataset; MRLC, MultiResolution Land Cover Characterization Consortium; MODIS, NASA's Moderate-resolution Imaging Spectroradiometer; TIGER, Census Bureau geographic database; USDOT, United States Department of Transportation; USGS, United States Geological Survey.

tion Ib) if understanding and predictability are to be achieved. The alteration in human land-use practices as a result of increased understanding of the consequences of LULC change is an important, but poorly understood, component of managing and mitigating to reduce adverse consequences (Table 2, question IIIc).

Embedded in all of these questions is the essential problem of scale (Levin 1992, Veldkamp et al. 2001). The challenge for NEON will be to define the resolution and extent of LULC data required to assess effects at local, regional, and continental scales (NRC 2003). This definition will require adoption of an approach that translates information across scales. Although LULC change is a primary factor affecting ecological change (e.g., net primary productivity, biodiversity, biogeochemistry), the extent to which new studies are required to fully understand the ecological consequences of LULC change have not been adequately addressed.

Recommendations

The vital importance of understanding and predicting LULC change, its linkage with the other grand challenges (NRC 2003), and the complexity of assessing and predicting change as a consequence of a spectrum of human and environmental drivers resulted in wide-ranging discussions of the role of NEON in these important activities. Recommendations fell into three broad areas:

Assessing LULC change

Satellite monitoring makes the routine reporting of land cover possible (Table 3), but the current infrastructure supporting this task is insufficient for the long-term goals of NEON. The MultiResolution Land Cover Characterization Consortium (MRLC; Loveland and Shaw 1996) has produced the widely used National Land Cover Dataset (NLCD; Vogelmann et al. 2001). A second edition of these data is now being developed (Homer et al. 2004). However, it is uncertain that timely, continuous reporting of LULC change will continue. Furthermore, current data are not capable of identifying intensities of land use nor the causes of LULC change. Hence, data fundamental for predicting future patterns at regional and national scales are lacking.

NEON must seek to develop all aspects of remote sensing and data analysis infrastructure so that historical trends can be produced, the sociopolitical and environmental drivers of change understood, the reliability of scale-dependent predictions quantified, and reliable data efficiently provided to the scientific and public sectors. The development of such infrastructure will require a significant effort and must include:

- A network of research centers devoted to monitoring, mapping, analyzing, and reporting of LULC change
- Close affiliation with existing agencies, data and analysis resources (e.g., US

Department of Agriculture, US Forest Service, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, the Census Bureau)
- Enhanced support of detailed, high thematic resolution land-cover datasets (e.g., Ikonos and Digital Ortho Quarter Quads satellite imagery)
- Investment in analysis and prediction methods that will allow the determination of the local sociopolitical and environmental drivers that are determining rates and patterns of change

Relating LULC change to ecological effects

A landscape-based sampling plan must be developed by NEON to satisfy two critical needs:

- To establish a clear understanding of the linkages between drivers of landscape change (e.g., climate change, sociopolitical and socioeconomic factors, environmental disturbances) and observed LULC patterns
- To determine the effect of LULC change on biodiversity, invasive species, biogeochemistry, infectious diseases, and climate change

Establishing a network of sites that will satisfy these multiple research objectives is a daunting task; previous efforts have met with limited success (Andelman and Willig 2004). Nevertheless, a network of sites must be selected to represent the characteristics of each region and the local factors responsible for producing change.

Sampling efficiencies within a region may be gained by selecting sites across significant environmental and land-use gradients. Sites experiencing rapid changes in land use will be attractive locations, but consideration must also be given to those locations with extensive data records (e.g., land-use and paleoecological data) and ongoing studies [e.g., NSF microbial observatories, NSF Long-Term Ecological Research sites, US Army Corps of Engineers Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP) sites, and NSF's Consortium of Universities for the Advancement of Hydrologic Science (CUASHI) sites]. The use of a hierarchically nested sampling design should be developed to explicitly address scaling issues related to landscape change.

All selected sites should record a broad spectrum of routine environmental, ecological, and sociological data. These measurements should be immediately available to the general public in two forms: as raw data for distributed analysis by NEON and non-NEON participants, and as derived data providing synoptic information on the ecological implications of LULC change. A subset of sites, stratified by land-use type, should be further instrumented to address the specific issues raised by the other five grand challenges of NEON. This commitment to advanced technologies will be significant and should be driven by scientific questions directed at determining the causes and consequences of LULC change.

Outreach, education, and training

Because LULC change is affected by and, in turn, affects human activities, it is essential that NEON develops an infrastructure that will:

- Collaborate with local and national experts who supply critical data and utilize technical products arising from the analysis of LULC change
- Supply timely information to the economic and political sectors requiring LULC information
- Ensure the education of all sectors of the society regarding the consequences of LULC change

Although a significant effort must be made to make NEON resources available to the general public, it is not presently clear how this should be done. Because most decisions regarding land-use change occur at local rather than regional scales (Haeuber and Hobbs 2001), efforts should focus on facilitating the rapid retrieval of geographically relevant information. Partnerships with expertise in communication and information dissemination must, therefore, be an immediate priority within the emerging structure of NEON. This partnership will employ a variety of communication tools (e.g., web pages, online databases, brochures), train scientists in communicating the consequences of LULC change, forge explicit linkages between research scientists and educators, and seek innovative approaches for the education of all sectors of human society.

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