Report on First Workshop

on the

National Ecological Observatory Network (NEON)

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Archbold Biological Station

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Introduction

This workshop was organized to provide advice to the National Science Foundation regarding the formation, organization and potential roles of a National Ecological Observatory Network (NEON). A second workshop dealing with technological infrastructure will follow in March, 2000, followed by a third workshop on network management issues later in the year. All workshops will be posted on the internet to allow for full participation and commentary by the research community. The purpose of NEON is to provide a broad integrated network of ecological research and monitoring sites that would constitute a distributed facility for researchers in environmental biology spanning all levels of biological organization from molecular genetics to whole-ecosystems at landscape and continental scales. Other disciplines such as physics and astronomy have advanced greatly with the provision of major infrastructural investments. With the increasing challenge for biologists to observe planet earth, a major investment in infrastructure is needed. Some of the background of NEON grew out of previous discussions of a proposed Biodiversity Observation Network (BON), but would represent a broader, more interdisciplinary enterprise involving ecological, evolutionary and systematic issues extending far beyond biodiversity. The workshop participants represented fields of systematics, population genetics, evolutionary ecology, population biology, microbial ecology, animal behavior, physiological ecology, ecological informatics, and community, ecosystem and landscape ecology. These researchers work in both terrestrial and aquatic environments and with organisms ranging from microbes to higher plants and vertebrates. The group was enthusiastic in its support of the overall potential of NEON.

NEON represents an unprecedented opportunity for infrastructure to address environmental questions ranging over multiple levels of biological organization and over broad ecoregions. The network will provide infrastructure that cannot be afforded in current programs and will allow scientists to systematic, evolutionary and environmental problems on a scale not currently possible. NEON will include:

- A distributed national facility of 10 centers, each with multiple sites and equipment to both monitor and conduct manipulative experiments on the structure and dynamics of populations, communities, ecosystems and landscapes. Evolutionary biology and systematics are important elements of the NEON concept. This facility will allow the opportunity to observe changes in biotic and ecological systems over several scales of space and time including changes due to climatic and anthropogenic influences.

- Comprehensive collection and archiving of data and biological samples, including molecular and genomic information and efficient data sharing and integration.

- A network that represents a national resource available to all scientists with appropriate interests.

- A substantial education and outreach component of the network is also essential.

This report summarizes discussions of the workshop and begins with an executive summary. Further information, including audio broadcasts from the meetings can be found at:

http://www.archbold-station.org/abs/neon/index.html

Executive Summary

Participants from diverse fields of environmental biology agreed on many concepts and issues and strongly supported the prospect of NEON. Different concepts of NEON arose as did varied issues and concerns about the optimal development of this network. Several key points emerged.

- NEON should address broad-scale scientific themes in environmental biology of national and international importance such as loss of biodiversity, invasive species, global change and anthropogenic influences. It should also constitute a distributed network of replicated geographical habitats to serve as a platform for many areas of environmental biology from evolution and systematics to landscape- and continental-scale ecology.

- Whether scientific themes and site guidelines should be prescribed by the NSF (possibly with an advisory board) or allowed to emerge with proposal competitions was a matter of debate. Advantages of prescribed themes were seen as insuring efficiency and broad topical and geographic coverage. However, this approach might also preclude emergence of novel ideas and constrain the flexibility of the network in the future. Other alternative schemes may also emerge with further discussions.

- Diverse geographical areas should be represented in NEON, but the degree to which these should be prescribed is an issue. Ideally, both functionally important and rare habitats as well as major environmental gradients – including anthropogenic disturbance or use -- and transition zones (ecotones) should be represented.

- NEON should provide a level of infrastructure that is currently unavailable to most researchers. This infrastructure would allow scientists to address questions at a larger scales than that are currently possible. However, in order for this infrastructure to be effective, sufficient operating funds and skilled personnel are also essential.

- Facilities for routine measurements, ranging from DNA sequencing to isotopic analysis and remote sensing might be centralized to some degree for economy of scale and efficient use of skilled human resources. In addition, state-of-the-art facilities should be developed in several areas (such as genomics and molecular analysis, isotopic techniques, sensor development and data management) to both develop new technologies and to adapt those from other fields such as biomedicine and geosciences.

- Collectioning and archiving of biological materials including classical voucher specimens, cultures, tissue samples and DNA and genomic and isotopic data

from the NEON sites are of high priority in the overall infrastructure of NEON. However, numerous issues in this area remain to be resolved in further discussions.

- The breadth of envisioned NEON infrastructure and activity will require close cooperation with existing and planned activities of museums, universities, state and federal agencies as well as non-governmental organizations. Therefore, it is essential that strong collaborations among these groups be developed and all parties be involved as NEON planning for network technologies, collections, archiving and general infrastructure proceeds.

- NEON would support the integrated efforts of researchers working at different levels of environmental biology, from molecular genetics to landscape-level problems. This brings many "sociological" and institutional challenges to attention, including accommodating and encouraging participation of researchers outside the NEON system, links among academic and non-academic institutions, data availability and professional reward systems.

- Education and outreach are seen as important components of NEON and numerous issues pertain to the development and promotion of education/outreach including on-site training, dissemination of information and experience, data access, and evaluation of effectiveness.

- A single workshop cannot resolve the complexities and issues involved with an infrastructure of this magnitude and dimension. In future discussions, including subsequent NEON workshops, many issues need to be addressed. Such issues include the nature of collections and archiving, replication and redundancy in habitats and experiments, the balance of budgeting for technology and operating, centralization of facilities, the role of the "Biodiversity Observation Network" within NEON and the degree to which scientific themes and geographical sites should be prescribed.

Workshop charge and initial assumptions for NEON

Workshop participants were asked to consider issues in the conception, development, implementation and operation of NEON. They were also asked to consider the partner institutions that would be needed, the distribution of intensive and extensive field sites, the actual infrastructure purchases that would need to be made, and how that infrastructure would be allocated among the intensive and extensive sites. Participants were also asked to consider the "sociology" of research collaboration in a large network involving disciplines ranging from molecular genetics to ecosystem- and landscape-scale studies and institutional constraints to these collaborations. A vision for an education and outreach mission of NEON was also requested.

A framework of initial assumptions for these scenarios was provided by the NSF officials for the workshop. These assumptions include:

(1) The overall goal of NEON is to develop distributed infrastructure for environmental biology, ranging from molecular genetics to landscape-level study.
(2) This distributed infrastructure should advance the study of continental- and regional-scale issues.
(3) A figure of $10 million for each of 10 observatories, each with suites of sites, was proposed as a target infrastructure budget with $1million/site/year for operating expenses. Additional funds for research would also be sought.
(4) Consortia of multiple institutions, including biological field stations, need to be developed for each site. Developing strong links with monitoring networks, field stations and other facilities of State and Federal agencies and non-governmental organizations is also encouraged.
(5) NEON sites should provide the infrastructure that would offer facilities for researchers not directly associated with the network.
(6) NEON sites should be designed to last for at least 30 years.

Participants strongly welcomed the prospect of NEON and what it might offer. At the same time this very diverse group not surprisingly had different visions and some concerns about aspects of the NEON design. As explained in more detail on the website, many of the deliberations occurred in various subgroups developing different scenarios of the NEON concept. This report attempts to capture sentiments on many of the issues and also differing views.

Conceptions of NEON

The diversity of disciplines represented at the workshop was reflected in different views of a NEON that developed during discussions.

Many participants felt NEON should be a network of replicated spatial arrays of habitat types, with the argument that funding NEON implies broad representation of the nation's habitats. However, complete coverage is neither feasible nor expected. For NEON to successfully function as a national scientific network, two major issues have to be addressed in the initial design of the network. First, it has to be able to address current major issues such as loss of biodiversity, invasive species, global change, and anthropogenic factors. There is a need to be broad enough to examine observationally and experimentally all of these types of issues across the network. Second, the network has to be flexible enough to address future major issues as yet unidentified. As issues change with scientific advances or novel challenges, the network must be large|ems are likely to be addressed within or by building upon older data sets and issues, baseline data will likely be essential in addressing new problems.

To best accomplish the above objectives, a spatial array network is required in which each observatory includes: a) the functionally important habitat types of the region (e.g., terrestrial and aquatic); b) the major gradients of the region (e.g., disturbance, stress, moisture, salinity, soils, elevation, succession and human land-use gradients from pristine to extensively modified); c) rare habitat types; and d) the major transition zones or ecotones. Observatories should be spread throughout the country to encompass the diversity of gradients and habitat types found within the United States. Emphasis is placed on structure and design of the habitat arrays to maximize statistical power.

This view holds that replication of general habitat types within individual observatories (e.g., a combination of intensive and extensive sites), and across observatories is essential for statistical contrasts and generality. By including all these habitat types in their most stable and dynamic forms (e.g., centers of abundance and edges or ecotones) we can most accurately evaluate and perhaps predict important events of both basic and applied value (e.g., conditions of greatest sensitivity to climate change or biotic invasion). One way of achieving this broad representation would be for observatories to include research sites with existing infrastructure, personnel, and data bases, such as existing research sites (e.g., Long Term Ecological Research network (LTER), Organization of Biological Field Stations (OBFS), National Association of Marine Laboratories (NAML), member organizations of the Association of Ecosystem Research Centers), the research stations of other federal/state agencies (e.g., USDA-Agricultural Research Service, Forest Service, National Park Service, Geological Service, Environmental Protection Agency, Department of Energy national labs), as well as sites associated with NGO's such as The Nature Conservancy.

Such a model may offer the greatest flexibility in allowing multiple groups or approaches to a scientific effort. For example, this model is not restrictive to either individuals or big research teams. It can capitalize on "thematic" issues advanced by the environmental biology community that might require a major

team effort. It can equally well allow individual investigators to pursue new creative efforts not previously envisioned.

Four key elements of this NEON model separate it from the LTER model: (a) NEON serves a much broader range of disciplines in environmental biology, rather than just the ecological community as is the case for LTER. (b) NEON emphasizes replicated study sites within and across regions of the nation with each observatory of the NEON encompassing the habitat variation of a region, whereas many current LTER sites are centered in specific habitat types. (c) NEON recognizes the importance of ecotone or transition zones as barometers of change. (d) As a networked array of replicated habitat types, NEON is better able to support coordinated, integrative research to critically address major current themes in environmental biology (e.g., loss of biodiversity, gene flow in nature stemming from genetically modified organisms, role of invasive species and many issues of global change), and also provides the infrastructure to address as yet unrecognized environmental problems.

Alternative models of a NEON

Different concepts for the overall thematic organization of NEON emerged in this workshop. One group proposed that themes for proposals should be specified at the time the NEON program is announced, whereas others argued for more flexibility so themes might 'bubble up' from those developing proposals. An intermediate plan suggested by some would have a set of themes as guidelines in the request for proposals (RFP), but still allow new themes to emerge from investigators. There was overall agreement that if themes were to be prescribed or used as guidelines, then substantial additional input to prescribe themes would be required from the greater scientific community.

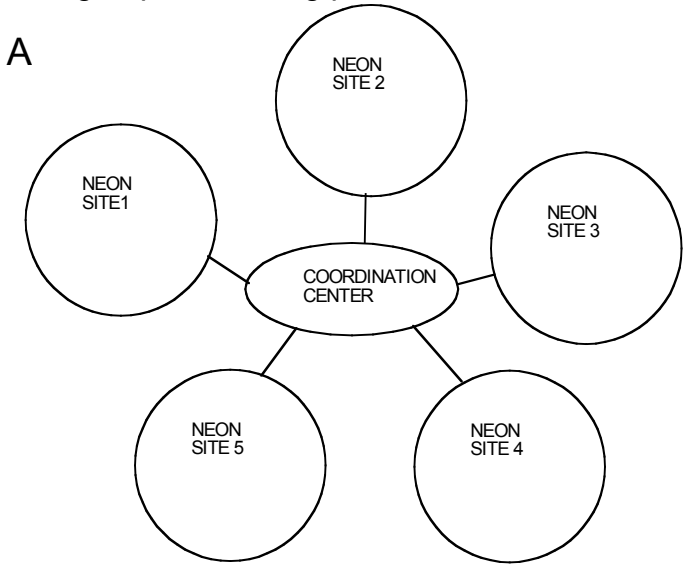
The group promoting the prescribed thematic structure also envisioned an administrative structure (Figure 1B), without the central coordinating structure that would emerge in the original NEON model (Figure 1A). Under the prescribed-theme model, the coordination of NEON would be distributed among the observatories and specified facilities associated with each observatory would serve the entire network. Funding levels would be appropriately adjusted among the observatories according to the expenses incurred by each observatory in its network wide service. Moreover, each NEON observatory would be required to set up data gathering facilities that would serve the theme of every other NEON observatory (where appropriate), so all the NEON observatories would focus together as a single network serving all the themes. Additional money would be reserved to fill in geographic coverage with additional extensive sites. This structure would ensure integration among NEON observatories without the need for a central coordinating center.

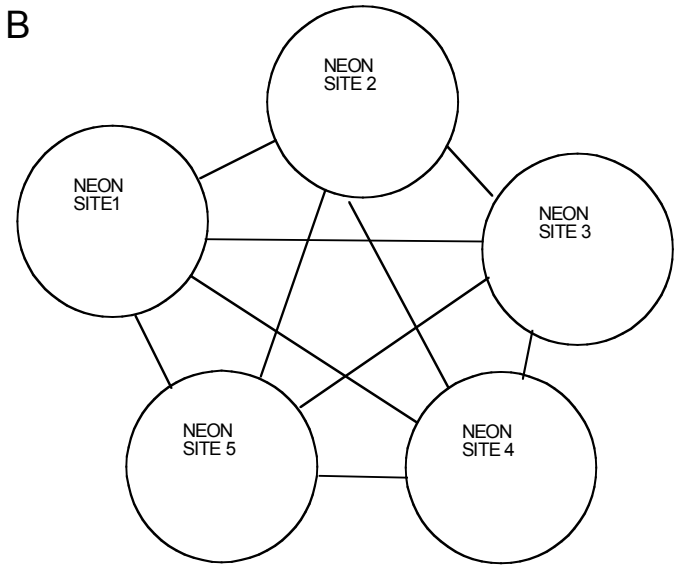
A purely illustrative example of a possible set of themes, each located at a particular NEON observatory, along with envisaged network-wide facilities associated with some of the sites follows:

(1) Biodiversity – collections coordination
(2) Ecosystem services – flux tower network, isotopic analysis lab
(3) Global climate change – GIS, remote sensing, including aircraft
(4) Population biology – genomics center
(5) Agroecosystems – chemical analysis labs
(6) Invasive species
(7) Land use
(8) Land margin
(9) Fire and other disturbance
(10) Fresh-water resources

Fig. 1. Two models for integration of research among NEON observatories. A: autonomous NEON observatories with coordination through a central administrative center (original plan). B: fully integrated, distributed network of NEON observatories.

The group advocating prescribed themes made the following points with regard to themes. This approach would ensure 1) that topical coverage would be broad, 2) that networking would be built in from the start, 3) that geographic coverage would be broad, as would the scale at which questions might be addressed, and 4) that centralized facilities would be efficient. Well-implemented planning meetings to determine the themes would ensure that there is community consensus on the themes and allow novel ideas to be incorporated within a coherent framework.





However, some participants saw potential disadvantages to the approach of specifying themes: (1) precluding novel ideas from being generated during the proposal process (2) decreasing interdisciplinary interactions (3) uneven commitments to network-wide activities, and (4) exacerbating resource conflicts between NEON and external researchers. Again, some hybrid approach for identifying themes and ensuring coordination among individual NEON observatories might be developed that would draw on the advantages of these contrasting frameworks while minimizing the disadvantages.

It was clear that consensus was not reached on this overall issue and it will need to be addressed in future discussions of NEON.

An initial exercise in designing potential NEON observatories

Four groups, each composed of individuals with a diverse range of scientific expertise, were asked to design a NEON observatory that was theme driven and regionally focused. (For this exercise, themes were not prescribed but were allowed to emerge from group discussions, thus following Model A in Figure 1.) Themes were to be composed of a series of sub-themes. Groups generally found this to be a challenge similar to that which would face potential NEON consortia. Each group agreed on a range of possible thematic topics that spanned a large breadth of disciplines and scales. Additionally, all the groups defined the types of technology that would be needed to advance the understanding of the thematic topics beyond what could be accomplished with a standard NSF grant. They also defined the necessary attributes that could allow for the formation of complementary intensive and extensive sites for research. The exercise also generated a great deal of discussion within and among groups regarding the challenges in developing a NEON program. Details of these discussions and reports from each group may be found on the website (see "Break-out Groups" A-D).

The discussion led all the groups to recognize the challenge of forming teams of interdisciplinary researchers to come together to produce a plan for a competitive NEON observatory, especially in a relatively short time frame. Consequently, some participants were concerned that previously formed groups would have a considerable advantage in responding to a request for proposal (RFP) within a short time. This led participants to recommend that NEON program planning grants to be available that would allow for new consortia to form and develop the necessary integration to plan a successful NEON observatory.

Infrastructure and technology

A prime goal of NEON is to provide an unprecedented level of infrastructure for integrated systematics and ecological research at several levels. NEON should provide a level of infrastructure that is currently not available to most researchers and allow large-scale questions to be addressed that are currently not possible. Participants were encouraged to envisage what would be desirable to this end and how provision of the infrastructure might be organized in NEON. Among the facilities and types of equipment that were mentioned by participants:

(1) DNA sequencers and microchip arrays

(2) Mass spectrometry for analysis of stable isotopes, accelerator mass spectrometry (AMS) for cosmogenic radionuclides (e.g., ^{14}C)

(3) Eddy covariance flux instrumentation to complement the AmeriFlux network

(4) Carbon-hydrogen-nitrogen (CHN) analyzers, general chemical laboratories

(5) Special aircraft for remote sensing, including hyperspectral platforms, and flux measurements

(6) Phytotrons

(7) Telemetry including microtelemetry involving new advances in nanotechnology

(8) Advanced microscopy equipment including environmental scanning electron microscopy (SEM)

(9) High speed, advanced computational and communication infrastructure

While much of this equipment does exist in some form, its availability is not widespread and available to many in the environmental biology research community. Considerable discussion developed regarding the degree to which these facilities might be centralized, either at individual NEON observatories or at the level of the entire network. Participants proposed three reasons in favor of some degree of centralization: (a) certain items are too expensive or cumbersome to be replicated across observatories, but might still be useful at more than one point (e.g., airplanes, genomic facilities). (b) Some technologies develop so rapidly that they require a high turnover, which might be less expensive if the technologies are concentrated at only one place. (c) Many of these technologies require steep learning curves, a problem that may be ameliorated by centralized expertise. However, two concerns were also raised about centralization: (a) there is a possibility that experts in one discipline will cluster at a single point in the network, which runs counter to the idea of integrating expertise across disciplines. (b) There is a concern about equitable access to each facility. Any degree of centralization at any level will raise similar problems as well as require a structure of user fees. If facilities are centralized at the network level, they might be located in a central location, or may be associated with an individual NEON observatory that would specialize in the development and application of new or specialized technologies in one area.

Systematists and ecologists often borrow and adapt technologies from other fields, such as biomedical research or geosciences. Also, given the pace of technology development, there is need to plan for infrastructure with sufficient

flexibility and opportunity for innovation in the 30-year time span of NEON. Thus, in addition to facilities for routine measurements (e.g., DNA sequencing, isotopic analysis, etc.), state-of-the art centers are envisaged that would develop and adapt new technologies, or those borrowed from other fields. For example, in addition to core DNA analysis facilities at each observatory with automated equipment for sequencing and genotyping, there would be a single central facility for genomics and molecular analysis that would develop and adapt newer and more sophisticated technologies for NEON. This central facility might also construct and screen genomic libraries for species of interest. Similarly, specialized centers for sensor development (hyperspectral remote sensing both for satellite and aircraft-borne systems), new isotopic technologies, and data acquisition, management, analysis and communication are needed. Many of these technologies will be discussed at the San Diego workshop in March.

Collections and archiving of biological materials ranging from classical voucher specimens to tissue samples, and cultures and genomic and isotopic data from the NEON sites are of high priority in the overall infrastructure of NEON. This also represents a sizeable cost and many technological and management issues. Although the need for systematic collections and archiving was widely acknowledged by workshop participants, detailed discussions of this general subject were not extensive at this first NEON workshop. The third Biodiversity Observation Network workshop held in May, 1999 at the California Academy of Sciences did involved detailed discussions concerning collections and the reader is referred to this workshop report. However, there is also need to address these issues in subsequent workshops for NEON.

The breadth of envisioned NEON infrastructure and activity necessarily overlaps considerably with existing and planned activities of museums, universities, state and federal agencies as well as non-governmental organizations. Therefore, in NEON planning for network technologies, collections, archiving and general infrastructure, it is essential that strong collaborations be developed and these other parties be involved. More on this subject appears below in the following section.

Sociological and institutional challenges associated with NEON

To create a NEON network that contributes most effectively to the benefit of greater society and also serves and supports the scientific progress of individual researchers, new institutional links and structures will need to be developed. We envision several areas in which issues arise that will require sociological rather than scientific solutions. These solutions will need to include careful consideration of incentives, rewards, and penalties, and should draw on lessons learned from past and on-going large-scale programs.

Inclusiveness and research issues:

The NEON resource should be inclusive and available to the greatest number of researchers across all relevant scientific fields. One concern is that NEON grants may go exclusively to groups that are already organized into networks, rather than to groups that might be deserving but not historically linked. One possible solution is to phase in the program over a period of 5-10 years, while providing planning grants to groups of institutions who would like to develop a viable network.

Once NEON observatories are established, strategies should be implemented to ensure access to NEON facilities by interested investigators from both within and outside the geographic area of a NEON observatory. An effort should be made to avoid an "in-group/out-group" situation. Research grants for individual researchers outside of the network to work at NEON observatories would contribute to inclusion. Observatories should also be evaluated for continued funding on the basis to which they have included scientists from outside the system (including researchers from smaller institutions). A related concern is that when large and resource-intensive equipment is placed at a single institution such as a university, that steps be taken to encourage use by and provide space for outside researchers.

Links among institutions (academic and non-academic):

NEON is an opportunity to strengthen ties between the academic community and scientists in federal, state, and private land management agencies. From the academic perspective, these include increased access to historical records, unpublished literature and other resources, coordination of data collection using national standards developed with state-of-the-art monitoring, access to a much larger network of field sites, and opportunities for training graduate students. The challenges of linking to multiple agencies is not trivial, however. The planning grants discussed above would be one avenue through which information could be gathered and stronger links between academic and non-academic institutions could be strengthened.

Once a NEON "site" is funded and assembled, coordinating the diverse assemblage of involved parties will be another challenge. Regular meetings of administrative staff as well as researchers might be augmented by seminar series or symposia and regional "working groups" focused on cooperative data analysis.

Data collection/availability and professional challenges for academic researchers:

A third category of sociological and institutional challenges involves the standardization and availability of data, and professional challenges for scientists working within the NEON framework. While these two areas appear disparate they are in fact linked, because the need for large-scale, standardized, readily-available and shared data can sometimes conflict with a culture of autonomous investigation and proprietary control over data that exists in many institutions. Thus, a proactive, network-wide policy on data sharing is needed. It is critical that the basic standardized sampling and data collection, envisioned as a major benefit of NEON, be covered by the NEON operating budget. Academic researchers should not be expected to carry it out. Similarly, NEON will present a major administrative burden that cannot be expected to fall on the individual P.I.s that design a NEON observatory. If NEON is to be effective in the long run, it will need to be designed in a way that multiplies the efforts of academic researchers in the same way it multiplies the monitoring resources of agencies. This will require a culturally savvy set of incentives and rewards, and a thoughtful consideration of downstream effects on the scientific community and infrastructure. If university faculty, especially junior faculty, are to be successfully engaged in these large-scale, interdisciplinary endeavors, then processes for evaluating and rewarding faculty must effectively incorporate this team-building mindset into tenure, promotion and salary raise considerations.

Education and outreach

The NEON initiative offers an unprecedented opportunity to convey the value and relevance of environmental biology research, and its relationship with other disciplines to a broad audience. We envision that the network of NEON observatories will communicate information about ecological/biological goals, findings, and processes to the scientific community, students (including K-12, undergraduate, and graduate), the general public and decision-makers. The RFP description should include an education component that involves:

(1) The education goals for the NEON observatory and how these link to national and regional standards for science education
(2) How environmental biology knowledge gathered at NEON observatories as well as approaches to the teaching of biology and ecology (including inquiry-based learning and portrayal of the scientific method) will be disseminated (e.g., through websites, teacher workshops)
(3) On-site training for undergraduate and graduate students
(4) Dissemination and integration of NEON information into undergraduate and graduate curricula at a broad array of institutions of higher education
(5) Integration with existing educational networks
(6) A data access policy developed for each NEON observatory to specifically address the needs of the education community
(7) An evaluation component to assess if education goals have been met

Additional issues and concerns

Some additional concerns and unresolved issues not covered above in the report follow:

Role of BON (Biodiversity Observation Network) in NEON

Participants agreed that biodiversity will be a fundamental component of NEON, but many were concerned at the prospect of simply folding BON into the new structure. A possible solution to this concern would be to develop two partially overlapping networks over time, perhaps starting with a NEON which: I) includes a biodiversity theme, and II) provides the backbone for the eventual development of a partially overlapping biodiversity network to provide additional coverage of biodiversity research. Much of the planning and thought involved in the four preceding BON workshops should be given attention in the development of NEON.

Operating budgets and maintenance of NEON infrastructure

The current vision for NEON allocates ten times more funds for infrastructure than for operating costs. While there are fiscal reasons for this, participants expressed concern that such an imbalance will greatly impair the function and effectiveness of NEON. This imbalance might also lead to a bias in favor of P.I.s at institutions that can afford to provide significant cost-sharing for operating budgets. Maintenance and replacement of the infrastructure originally acquired in the development of NEON also needs specific budgeting priority. These overall issues should be discussed in the subsequent two NEON workshops of 2000 dealing with technology and management.

Collections

Collections as defined here include both the physical materials being collected and stored as well as the archiving and retrieval of the associated information. Several participants felt there had been little discussion of the type and extent of collections that will be associated with NEON activities, and particularly of the infrastructure and operating costs associated with them. Furthermore, a concern was expressed that the planning should include a statement of the impact of new collection activity on the existing structures at museums and universities, which certainly are not be able to absorb the new load. Again, reports of the deliberations of the four BON workshops should be given attention on these issues.

Replication/redundancy/sampling

It was felt that one of the key advantages of a network conceived as NEON will be to provide enough flexibility for both statistical power of individual projects and growth in response to future and as yet unanticipated needs. This means that a solid NEON proposal has to include a detailed discussion of sampling design, including a consideration of major environmental and disturbance gradients in the region and how the proposed observatories will capture them. These and related issues are ripe for discussion at the two succeeding NEON workshops.