

Report of the Fourth Workshop on the Biodiversity Observation Network (BON)

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I. Introduction

This report describes the results of the fourth workshop sponsored by the National Science Foundation to assist with the development of a Biological Observation Network (BON). The mission of the BON program is to advance knowledge of the biological, physical and social determinants of biological diversity, its environmental consequences, and its role in determining biocomplexity. The first workshop on the BON program, held at the Blandy Experimental Farm, University of Virginia, in September 1998, dealt with the conceptual framework for the network, the proposed characteristics of individual BON sites (including the "minimum standard installation" criteria), the core research areas to be addressed, and the possible role of a coordinating center for the network. This workshop's final report can be viewed on the Internet:

<http://www.vcrlter.Virginia.edu/biodwrk98/BIOWRK98.htm>

The second workshop, held at the National Center for Ecological Analysis and Synthesis, Santa Barbara, California, in January 1999, contributed additional insights to the BON concept, including the potential contributions to cross-disciplinary research, enhancements to biodiversity infrastructure (including museum collections and field stations), descriptions of observatory characteristics, potential contributions to educational activities, and identification of potentially important core taxa to be sampled. In addition, the workshop participants began to outline the procedures and research activities to be conducted at BON sites, and developed initial estimates of funding requirements to adequately operate BON sites. This workshop's final report can be viewed on the Internet:

<http://www.vcrlter.Virginia.edu/biodwrk99/BON99a.htm>

The third workshop, held at the California Academy during 6-7 May, 1999, dealt with the topic of museum collections and their role in the BON Program. This workshop's final report can be viewed on the Internet:

http://research.calacademy.org/bon/BON3_Final.html

In the course of the earlier workshops, the mission of BON was defined as elucidating the composition, spatial and temporal patterns, ecological and evolutionary processes, function and human dimensions of biodiversity. The mechanism envisioned was (1) a set of 50 sites, known as biodiversity observatories, equipped with advanced instrumentation and the resources necessary to collect comparable data on the diversity of multiple taxa; (2) cross-observatory networking infrastructure; (3) a technological coordinating facility; and (4) funding to promote investigator-driven cross-observatory research. During the workshop, the participants were informed by NSF that the National Ecological Observatory Network (NEON) will be developed initially as a program to enhance infrastructure for all of field biology. Essentially, NEON will create consortia of field biology research activities. In response to this new NSF strategy, the workshop participants recommended that, as a mechanism to ensure that biodiversity research be an explicit component of these NEON consortia, the BON sites be established prior to the development of NEON for the study of the spatial and temporal dynamics of biodiversity. These BON sites should then be included in NEON consortia where appropriate.

With the proposed development of NEON, there is now less need for BON to provide centralized technology as envisioned in earlier workshops. Thus, BON can be implemented by providing (1) site-level funding for each of 50 observatories and (2) cross-site funding for biodiversity research. Site-level funding would support personnel and facilities for data acquisition and management (GIS/GPS service and equipment) and field and museum technical support for repeated samplings of core taxa. These two elements would be the subjects of two calls for NSF proposals: BON site proposals, and BON research activity proposals.

The importance of a BON program is evidenced by the large number of conceptually important questions that could be addressed by a continent-spanning network of BON sites. If high-quality, extensive data sets on species richness and abundance could be assembled in a standardized format, numerous ecological and systematic hypotheses could be tested. The following comprise only a sampling of such questions:

- Are large- and small-scale gradients in biodiversity correlated to abiotic variables (precipitation, temperature), and if so, are these relationships linear or non-linear?
- Across large-scale gradients, are there nodes or inflection points of rapid species change, and with what environmental variables are these points related?
- How is biodiversity at any one locality shaped by the spatial structure and heterogeneity of the surrounding region, at multiple spatial scales?
- Are there predictable relationships between spatial turnover ("beta diversity") and geographic or environmental distance?
- Over time, are large-scale relationships between local and regional diversity more stable than local diversity?

- Are biodiversity patterns associated with inter-site corridors? E.g., in aquatic ecosystems, is plankton biodiversity higher in lakes that are connected to other lakes via stream networks than in isolated lakes?
- Is biodiversity within one environmental stratum (e.g., tree canopy, supraterranean, subterranean) indicative of biodiversity in other strata at the same location?
- How does biodiversity respond to climate change, and does the degree of change correspond to geographic, abiotic or biotic antecedent conditions?
- How do the population dynamics of different cosmopolitan taxonomic groups vary over large environmental gradients, and to what environmental variables might these dynamics be correlated?
- To what extent do changes in ecosystem process rates reflect changes in species diversity, or in abundances of particular species?
- Is variability in ecosystem process rates correlated with species diversity (i.e., across sites [or times] with contrasting diversities)?
- How resilient are components of biodiversity to disturbance, both anthropogenic and natural?
- What is the relative contribution of local and regional disturbance on sustainability of biodiversity?
- How is biodiversity affected by the mobility of organisms (fauna) or their propagules (plants)?
- What abiotic and biotic factors facilitate the invasion of exotic species into specific habitats and ecosystems?
- How do the invasive species in one biological group (e.g., plants) influence the diversity of that group, other groups (e.g., pollinators), and ecosystem processes (e.g., productivity)? Can we predict cascading effects?
- How does body size scaling within a taxonomic group or trophic level vary over large scales?
- Do changes in scaling relationships provide insights into the co-evolutionary dynamics of competitors?
- Given that the methodology for measuring biodiversity continues to evolve, what are the statistical challenges involved with designing and implementing large-scale monitoring and inventorying programs?
- What indicators are best suited for determining the health and sustainability of ecosystem processes?

Given the shift in scope of the program goals, with the more focused mission of the Biodiversity Observation Network, the objective of this fourth workshop was to develop some of the detailed logistical and operational aspects of the BON sites, and the processes by which biodiversity researchers could utilize the network in an efficient and productive manner. Specifically, we were charged to envision the organizational structure of a BON site, including various distributions and types of field study sites, and to develop guidelines for structuring both field sampling activities and coordination among BON Site personnel and visiting BON researchers.

In this report, we address logistical aspects of a "typical" BON Site, including, at the finest scale, the responsibilities of Site P.I.s and staff, and the roles of visiting BON researchers in developing biodiversity databases and specimen collections for the BON Sites. At the broadest scale, we address the concept of a coordinated sampling design for the BON program, and provide advice to NSF as to how "biodiversity" can be measured across a network of sites in a statistically meaningful fashion, so as to maximize the long-term usefulness of the data and specimen-based

collections. This question lies at the heart of the network's mission and scientific value, as observations of the wide variety of taxa (from microbes to vertebrates) must be integrated both qualitatively and quantitatively across space and through time to address current and future questions on the role of biodiversity in the functioning of Earth's ecosystems.

II. BON Site Descriptions

A. Site attributes. As described in the earlier BON workshops, the individual BON Sites will have a number of attributes that will promote biodiversity research, including (but not limited to) field study sites with long-term security from unplanned land-use change or development (although urban/suburban study sites could be included in BON), access to both terrestrial and aquatic habitats, on-site facilities (field stations or other laboratory/housing buildings), vehicles for site access, Internet computer connectivity, GIS/GPS instrumentation, meteorological data (preferably on-site stations in close proximity to field sampling sites), on-site reference collections of local flora and fauna, and site personnel to assist with BON visiting researcher activities. All BON sites should be affiliated in some fashion with a research museum, which would archive and curate specimens collected from its associated BON site(s). It is also anticipated that BON sites could consist of multiple partners and collaborating personnel, organizations and/or institutions.

B. Site personnel. The Principal Investigator (PI) of individual BON sites will provide the coordination of all BON activities at the site, and will arrange the activities of site personnel and facilitate the visits of BON researchers. Each site will have a designated BON data manager/GIS manager who will work with all visiting BON researchers to ensure data quality assurance, quality control (QA/QC) and data sharing, and proper GPS site location collections and archival in site GISs for field sampling sites. Site PIs and data/GIS managers will coordinate across sites to ensure standardization and compatibility of all databases. Specimen data access also will be the responsibility of the BON site data/GIS manager, in conjunction with museum curatorial staff. Finally, each site will be responsible for repeated sampling of certain "core" taxa (see below); as such, a team of field biologists will be funded at each BON site to collect biodiversity data on these important taxa. The composition of the field team will be at the discretion of the Site PI, and could include faculty, research staff, graduate students, and undergraduate students. Training and supervision of the field team would be the responsibility of the Site PI and collaborating researchers.

C. BON GIS/GPS/Data Management. The BON research mission requires that each site be equipped with a minimum set of capabilities for data collection and management. The following list provides some details for these capabilities.

1. Georeferencing. All field data should be georeferenced to a scale of spatial precision that is consistent with the sampling protocol. A template of surveyed permanent sample locations will facilitate georeferencing of some types of sample collection, whereas others will require that georeferencing data be collected simultaneously with biological data, using differentially-corrected GPS measurements or other surveying techniques. Site personnel should be available to assist biological researchers with field georeferencing.

2. *GIS and Informatics.* Sites should have Geographic Information Systems (GIS), including digital data layers for basic site characteristics, and the capability to generate data layers on an ongoing basis with species distribution data that are collected on site. Basic site characteristics include, but are not limited to: topography (bathymetry), hydrography, soils, vegetation, human structures, land use/ownership, and the location of previous studies and manipulative experiments. Remote sensing and aerial photo collections that can provide a broader perspective of the site's relationship to its surroundings and a longer-term perspective of gross vegetation and land use changes are also desirable. Each site should have informatics and communications capabilities, Internet connections, and a data management scheme for backing up and archiving digital data.

3. *Metadata, QA/QC.* Quality assurance/quality control (QA/QC) measures should be developed for data entry, data processing, and data custody. Metadata that describes georeferencing and GIS methods should accompany each data layer, using standard tools provided by the Field Biology Consortium.

D. BON "Core" Taxa. Conceptually, the network of 50 BON sites will support a large and diverse assemblage of researchers interested in biodiversity patterns. The NSF would provide competitive funding to scientists through question-based BON research grants, and in the aggregate these grants would cover a wide range of taxa. However, the BON concept cannot rely on a serendipitous distribution of research proposals to cover all major taxa at all sites during all years. Many of the BON research proposals would rely on certain taxa's being measured simultaneously with the "target taxa" of the research proposal; for example, an entomologist wishing to study the diversity of hymenopteran pollinators across 10 BON sites might need to have diversity estimates of the flowering plants at each site, but might not have the expertise, time and resources to sample the plants at every site each time a site visit is made. Thus, the entomologist would have to rely on other BON researchers to provide those data (this would clearly fall under the multi-disciplinary, data-sharing concept of the BON Program). However, if some sites (by chance alone) do not have research groups working on flowering plant diversity during the year the entomologist is sampling, there would be no data available for comparative purposes.

The solution for this problem will be to require each NSF BON Site to support a small field team to collect annual diversity data on core taxa, and make these data available to all visiting researchers. The list of core taxa has not been determined at this time, and the formulation of such a list was beyond the scope of the current workshop. However, we strongly recommend that specified core taxa be sampled at each BON site. Routine sampling of the distribution and abundance of particular organisms will provide baseline information to contribute to and integrate with other BON research activities. Core taxa at a particular site might include organisms that are already routinely sampled at that site and organisms that have been deliberately selected to maximize overlap across multiple BON sites. Where possible, interdisciplinary teams should be used to collect data on multiple biological groups of core taxa, soils, climate, hydrology, and topography to produce multiple layers (themes) of biodiversity for the ecosystem. For example, data on native and exotic plant diversity could be collected with data on soil chemistry, pollinators, and soil organisms. In streams and ponds, data on fishes, amphibians, water quality, and primary producers could be collected simultaneously.

Rather than dictate what types of organisms should be the common core taxa, we recommend that these taxa be chosen by either (1) the first group of BON awardees at their initial meeting, or (2) a separate working-group of ecologists/taxonomists during another BON-planning workshop. In these discussions, the scientists involved should consider taxa from multiple habitat types (freshwater, marine, wetland, terrestrial) and multiple trophic levels (producers, consumers, decomposers). Collaborative efforts, such as roving teams with particular taxonomic expertise, should be encouraged.

Once the core taxa are designated, additional workshops should be held to develop common sampling protocols for each taxon. These meetings would bring together statisticians and field biologists with the dual goal of ensuring statistically valid designs and maximizing comparability of data across sites.

Although our group believes that the development of core taxa recommendations is beyond the scope of our workshop, we strongly affirm their importance to the eventual success of BON. The future of BON and NEON programs depend on the routine and consistent collection of data for a select group of core taxa with common protocols designed and tested to ensure comparability of data across a wide range of biomes and habitats. Core taxa, identified in previous BON reports, might include vascular plants, selected aquatic or terrestrial invertebrates, mammals, fishes, birds, and soil organisms. Initial requests for proposals from NSF will likely be specifically written to maximize cross-site data comparability for a subset of core taxa. Addressing hypotheses about broad-scale patterns of biodiversity is problematic without highly comparable data sets.

E. BON Reference Collections and Research Museums. Species lists and availability of properly preserved, identified and curated specimens for each site are essential for attracting research on particular taxa, for biogeographic analyses, and for assessment of biotic responses to environmental gradients in space and time. Site PIs must have or obtain necessary permits for general collection and storage of specimens and should ensure adequate support for taxonomic services for core taxa. Collected specimens of core taxa must be properly identified, georeferenced, archived in an appropriate museum or reference collection (as arranged with museum personnel), and made accessible to researchers using the site. Site personnel are responsible for standardized taxonomy and updated nomenclature of core taxa. Site PIs should develop a policy, or work with researchers using the site, to determine numbers of specimens of each taxon that will be retained in local voucher collections or deposited in other research collections. Numbers of specimens of each taxon, their spatial and temporal referencing, and their storage location must be maintained in the site database and be accessible across the Network.

F. BON Sampling Designs. In an effort to make the data from all taxa in all years across all BON Sites as comparable as possible, the participants of this workshop discussed at length various strategies for implementing "standard" field sampling procedures.

During these discussions, a "top-down" (= NSF-imposed methods) versus "bottom-up" (= investigator-driven) design was a central issue. All participants acknowledged the desirability of collecting similarly structured data on a common set of organisms at all BON sites, to promote cross-site comparisons within and among taxa. However, we concluded that three factors militated against a predominantly top-down design: the specialized knowledge required to devise the best

sampling protocols for each taxon; the enormous heterogeneity of environmental conditions among potential BON sites; and the modest budget envisioned for BON, which precluded hiring legions of data collectors to conduct standardized sampling protocols.

We recommend instead that standardized sampling be accomplished primarily by giving incentives to Principal Investigators. First, we recommend that the PIs of BON sites be asked to demonstrate that their site would use standardized protocols for data management and field sampling of core taxa. Standardization of data management (data file formats, taxa nomenclature and codes, etc.), as well as the selection of core taxa and appropriate sampling methods, should be undertaken by another pre-BON workshop, or meetings of PIs and data managers after BON site proposals are funded. Site PIs would therefore be responsible for ensuring that (1) comparable data for multiple core taxa at multiple BON sites are being collected using mutually agreed-upon standardized methods at all sites, (2) data collected among various taxa within any BON site are integrated spatially and temporally, coincident with measurements of abiotic variables and processes, and (3) that the data sets are consistently managed within and among all BON sites. Site PIs also will be responsible for coordinating field site selection with visiting BON researchers, with the goal of overlapping the sampling of as many taxa as possible on core study areas within the BON Site.

Second, we recommend that the PIs of BON research proposals be asked to show that their data are collected using best available protocols, that the completeness (or sampling-effort dependence) of the data be assessed (see below), and that integration across taxa and across BON sites be advanced by the proposed study.

Third, we discussed in detail the potential spatial layout of sampling sites within a particular BON field site. We first considered a systematic grid system of sample points, that could be scaled up or down to reflect appropriate sample sizes for different taxa (e.g., soil microbes vs. birds). The workshop group felt that rigid systematic sampling carried considerable risk of bias (due to possible unknown underlying systematic dispersion patterns of certain taxa), and if a site were to utilize a systematic sampling scheme, then some additional precautionary sampling effort should be dedicated to evaluating potential bias. We next considered a hierarchical sampling strategy, in which stratification of sampling in field sites (based, for example, on different ecosystem types, soil texture/moisture gradients, topography, etc.) would be incorporated into the BON Site design. This approach was favored by the group, due in part to the greater chance of sampling "rarer" habitats containing unique species assemblages. Randomized sampling sites located within strata could then be arranged, with high-resolution GPS coordinates taken to record the exact locations for comparisons with samples from other taxa. In all cases, the BON sampling designs would be evaluated through the NSF review process for statistical rigor and appropriateness to the taxa and ecosystem being addressed.

III. Integration of research activities at BON sites

Once a network of BON sites has been established, resident and visiting researchers will be using these sites for field sampling of their specified taxa based on the questions proposed in their individual NSF BON research proposals. It is critical to the BON network concept that these studies be integrated and coordinated at the site level to ensure maximum use of the data can be attained, and that the data and specimens meet appropriate QA/QC, metadata and storage/archival

standards. While standardization of sampling protocols, measured variables, taxonomies, and data quality are to be encouraged, we recognize that flexibility is needed to allow the BON Site P.I. and the visiting research P.I.s to operate efficient and cost-effective research programs. In this regard, we envision the following site activities to be undertaken for each BON research project:

A. The researcher P.I.(s) will coordinate with the BON Site P.I. to select appropriate study sites and dispersion of field sampling locations. Where applicable, the sampling designs should be compatible with those from other BON sites on similar taxa, and should maximize statistical comparability of results. Within each BON site, the P.I.'s should, whenever practical, overlap sample sites among studies so as to maximize the biodiversity data bases of selected sites and sites hosting ongoing experiments. Preferential use of the areas where BON core taxa are being sampled should be promoted. This decision process can be assisted with the use of the GIS data layer (described above) of previous/existing study areas at each BON site.

B. As study sites are selected and sampled, the BON Site P.I. will provide GPS services (instruments and technician field/lab support) to the visiting researchers to incorporate the sample site locations into the site's GIS. These locations should be determined with maximum accuracy, preferably sub-meter resolutions using Differential Corrections of GPS data. Permanent site markers can be installed at the discretion of the BON Site P.I. The purpose of acquiring highly-accurate site locations is to allow for future resampling of exact study sites for temporal comparisons of biodiversity changes.

C. Whenever possible, reference specimens collected from the sample sites will be added to each BON site's reference collection, to be archived in an appropriate museum collection. Site-specific reference collections can be enhanced through this process as well, as negotiated among the Site P.I. and the visiting researchers. The number of reference specimens provided for each collection should be determined by the researcher and the BON Site P.I.

D. The visiting researcher should make every attempt to evaluate the "completeness" of the sampling effort in determining the true species richness and abundances of their target taxa. This may include constructing species-area curves, plots of species richness vs. sample numbers or unit effort, etc. These relationships will then be used across taxa and sites to more accurately evaluate and compare biodiversity patterns and trends. BON proposals providing comparable data across multiple BON sites would be of greater value than more detailed studies at a single site, and proposals that provide for both intensive and extensive studies would have higher priority than those projects limited to one or the other. In addition, where possible, the researcher should provide an evaluation of the degree to which each BON site represents a larger geographic region with respect to the taxa under study.

E. The BON site PI and the visiting research PI should ensure that data collected on the BON site are incorporated into the BON databases as soon as logistically possible. The site's data manager will have the responsibility of ensuring the data QA/QC in collaboration with the visiting researchers. Reprints and databases derived from the BON sampling should be distributed to the entire Network in a timely fashion, generally following publication by the research PIs.

Respectfully submitted by:

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