National Ecological Observatory Network
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Research Design Basis for the NEON Relocatable Systems

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NEON Inc has derived a research design and deployment strategy for the network's relocatable systems. The design is based on the scientific questions that were outlined in the ISEP, refined by the outcomes of the RFI responses and the Sioux Falls workshop. NEON Inc implemented these ideas in developing the preliminary design, also considering basic principles of experimental as well as logistical and financial constraints. The preliminary design team was driven by the following considerations:

1. Acted to create a national observing system,

2. Implemented the scientific objectives developed through the preliminary design process, and focused on the Grand Challenge (GC) questions,

3. Incorporated a rigorous experimental design,

4. Preserved the human and financial resources necessary to implement measurement of the biological response variables (FSU) as well as instrumental measurements at all sites,

5. Estimated the workload demands on NEON and university staff implied in the design, and

6. Considered theoretical perspectives related to the GC questions such as observing connectivity in space, revealing immediate responses to ecosystem stressors and understanding the interplay of human and natural systems.

The preliminary design integrated these opportunities and constraints. It is consistent with criteria from previous design discussions but-—as is typical of a synthesis—is enriched by integrating multiple sources of input into a synthetic design that is different in structure from the earlier suggestions of NEON Inc and the community.

The research approach is guided by a set of principles that are essential to a scientifically-rigorous design. These are to:

1. Ensure that the continental network is an ecologically focused network with a strong emphasis on maintaining the resources to measure biological response variables. This decision implies that the financial and human resources to conduct the FSU protocols must be available for at all sites, which consequently led to a conservative sizing of the number of relocatable systems.

2. Ensure that effects of land use change on ecological responses were a major focus of the preliminary design. It is one of the three main foci of the NEON goal statement. Unlike climate change and invasive species, land use and its effects are necessarily not captured in the deployment of the National Wildland Core Sites (described in the previous NEON announcement at www.neoninc.org).

3. Create replication or density of sampling along gradients. In order to sample an effect quantitatively, especially a nonlinear effect, it is desirable to sample as many points along the gradient as possible.

4. Create planned contrasts. To do this, we generally sought sites that contrasted with the core wildland site in one or a small number of factors, but were otherwise in similar environments. Some designs span gradients and create cross-domain contrasts.

5. Replicate contrasts across domains. In order to derive generality from a given contrast, that contrast should be replicated across eco-climatic regimes.

These principles led to a rigorous but constrained preliminary research design of the NEON relocatable systems. The first principle leads to a conservative number of sites. The second principle leads to more rather than fewer sites per planned contrast. Within any fixed number of relocatable systems, the fifth principle suggests fewer rather than more questions (to allow for multiple replicate contrasts). Collectively, these principles imply:

1. Fewer sites with more measurements per site to ensure that resources are available for the full suite of biological and physical observations are made at each site (Principle 1).

2. Dense sampling of contrasts related to a few questions, rather than sparse sampling of many questions.

3. Because the sites include a wide range of measurements, (sensors plus FSU) most of the response variable areas identified in the ISEP (biodiversity, biogeochemistry, ecohydrology, invasives, disease) are observed at all relocatable sites.

In specific response to maximizing the number of measurements per site, the current relocatable systems are based on the FSU and towers equipped with meteorological instruments, basic air quality measurements, soil respiration, physical and canopy measurements. Depending on the science question and location, the relocatable system may be equipped with any combination of four instrument packages: eddy covariance instruments, advanced air quality instruments, aquatic sensors, and dust sensors. This design is in response to the measurement requests in the RFI responses. Biological response variables are measured at the relocatable site via the FSU. The relocatable system provides a comprehensive set of measurements of the physical and chemical drivers and biological characteristics. The relocatable systems are intended to be deployed for 3-5 years and then moved. Requests for longer deployments will receive serious scrutiny and approval from NEON Inc and NSF. In the construction phase, NEON will build the infrastructure for two cycles of deployment by building the “pads” for the first and second cycle sites. When the major hardware is moved after a deployment, the unoccupied sites will have a basic meteorological capability, and soil and canopy arrays will remain.

Logistical constraints significantly shaped the NEON design. Salaries of staff to operate field sites are the largest long-term expense for NEON. Moreover, these costs are not part of the construction budget. At the minimum, maintaining a NEON sensor suite requires several technicians and a CyberInfrastructure (CI) specialist. The sensor and CI staff will need to visit each NEON installation approximately once per week. During the field season the FSU activities are likewise intensive. Conducting the FSU requires expertise in a number of taxa and a significant field team during sampling periods. It is not generally feasible to duplicate this staff within domains to support remote installations.

These logistics play into the research design in two ways. First, conducting the FSU at all sites is necessary to cover the full range of GC scientific questions and leads us to scale the overall number of sites to the human resources available for the FSU. Second, travel time has to be controlled as it directly competes with time to maintain instruments and conduct field work. In early documents, a 100 kilometer spacing was suggested. In the network design meeting, we relaxed this significantly to three hours. We recognize that this makes much of some domains “inaccessible” and we are working hard on approaches to fill this gap. This will include the use of the mobile laboratories (which are not restricted to a three-hour radius) and airborne observations. NEON recognizes the difficulties these logistics create and will work with NSF on creative solutions.

In designing specific deployments, NEON Inc adopted the GC question format used in the Sioux Falls workshop, and noted that the questions fell into three groups that suggest generally similar deployment strategies. These groups were: Land use, biodiversity-invasives-disease, and climate change-ecohydrology-biogeochemistry. We designed replicated spatial contrasts to address each of these areas.

In addition, we considered the overarching theoretical question of connectivity. Connectivity—the linkage of ecological processes across space—is relevant to all of the GC questions. For example, climate change occurs in spatial patterns that affect large regions similarly because of atmospheric dynamics. Invasive species create connections by their migration. Atmospheric transport of dust and pollutants links source and sink regions across space. Aquatic systems create connectivity through flows of rivers and streams at all scales. The NEON preliminary design addresses this. The domain structure capturing climate and airmass movement creates an ideal observing system for connections linked to atmospheric transport and climate teleconnection patterns. Within the experimental design, specific mesoscale connectivity issues are addressed through alignments of sites along aquatic, atmospheric, and invasive species flowpaths.

Specific themes for relocatable systems (land use, biodiversity-invasives-disease, and climate change-ecohydrology-biogeochemistry) were refined into more specific issues. Synthesis of the RFI responses highlighted urbanization and exurban development, agriculture, and forest management as key land use drivers of ecological change. We proposed replicate contrasts for each of these drivers in strongly contrasting ecoclimatic regions, allocating a significant portion of the relocatable resource to this with the core sites serving as the wildland anchors. We also noted that these patterns of land use change are important drivers of biodiversity, invasion, biogeochemistry, and most other ecological processes and so this set of contrasts is important for all the other GC questions.

Within the climate change-ecohydrology-biogeochemistry theme, we identified sampling regions of rapid climate change as crucial. We were able to identify several areas where observed climate change rates have been high, and theory suggests that high rate of change should continue. We also identified connectivity as crucial in this theme and suggested deployments to address transport of pollution (the N deposition gradient), dust (deployments in the Colorado Plateau and Great Basin), and in river networks that experience major precipitation pulses (sites along the Tombigbee waterway). Sites on the West Coast will have instrumentation that will help to identify inputs of Asian dust and associated atmospheric pollution.

Within the biodiversity-invasives-disease theme, we identified several distinct deployment strategies. First, by scaling the entire relocatable infrastructure to allow FSU measurements, the observations of biodiversity, invasive species, and diseases will be made at all sites in the network along gradients of many drivers. Second, by systematically sampling large-scale biogeographic gradients, the Wildland Core sites are designed to observe the nation's land scale patterns of biodiversity. Third, some relocatable contrasts were specifically allocated to paired invaded-noninvaded sites, or along environmental gradients that influence invasion. Finally, a significant number of relocatable systems were allocated to a Before and After Control-Impact-type design, where systems will be located near the current or likely near-future location of a biological invasion. The research sites would then observe ecological responses to the invasion as it progresses. This invasives-focused deployment strategy requires a well-developed collaboration between ecological forecasting (to identify sites) and observations and thus will force the development of this partnership.

This preliminary research design of the NEON relocatable systems ensures rigorous science within an equally rigorous framework of financial and logistical discipline. The contrasts replicated across domains approach allows for efficient use of resources within a rigorous research design. The preliminary design is now clear enough to carry out the required costing and engineering design for the next stage of the NEON review. However, before the NEON "baseline" and design are finalized and final costs are determined, there is a lot of room for creativity and collaboration. NEON Inc staff will be working with all the domains to refine this preliminary design, and invites comments, suggestions, and concerns. Please contact the CEO or NEON Inc staff with suggestions, ideas, or potential improvements to the research design for the NEON relocatable systems.