NEON SCIENCE CAPABILITY ASSESSMENT

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Contents

SUMMARY

The NEON data sets and services that will be provided to the scientific and educational community will enable a broad range of ecological studies over long time scales and large spatial dimensions. The real-time, continuous, well-characterized and calibrated data sets will be revolutionary in ecology, where data sets have more typically been restricted to relatively few types, been collected sporadically on local scales and thus are difficult to integrate. These characteristics have inhibited a robust understanding of ecological dynamics on regional and continental scales. Moreover, NEON infrastructure will enable new questions and lines of research that we cannot currently foresee.

The NEON Science Capability Assessment developed a framework to assess the capabilities of the NEON infrastructure, particularly at Initial Observatory Capability (IOC)[1]. The framework is based on four key questions:

1) Are the appropriate data available, including at appropriate temporal and spatial scales?
2) Where specifically are the data from (habitats/sites)?
3) What is the quality of the available data?
4) What is the availability/flow of the data, both currently and in terms of future commitment?

We apply this framework to continental-scale questions developed by the community over the course of NEON design development and conclude that only relatively simple science questions can be addressed at IOC. This conclusion is based on the restricted spatial deployment as construction proceeds, incomplete availability of the many planned data products even at sites transitioned to operations, and, perhaps most significantly, the lack of multiple time points as yet. Many of these restrictions at an early construction stage are inherent to the NEON mission and design—in particular, time is needed to obtain data streams of sufficient temporal depth. It is important for the scientific research and user communities and funders to acknowledge and understand that NEON's value for transformative science will start slowly but accelerate rapidly; operational capability will not translate linearly to scientific capability. Its full potential will not be realized even after construction is completed and the Observatory has transitioned to operations.

We expect that at IOC, the the focus of the science community on NEON science is likely to be on the last three components of the framework regarding data source, quality and availability. We expect that many will simply download NEON data at IOC to understand

[1] The infrastructure and functions of the Initial Observatory Capability will constitute the initial baseline of NEON; this platform will be scalable to the full scope of the Observatory. Once the IOC is achieved, all other project deliverables will build on the initial capability as the Observatory functions and capabilities are expanded.

the nature and quality of the available data sets. Up-front investments as planned by the NEON Project in data quality assurance and validation as well as in the cyberinfrastructure needed to deliver both the data and knowledge about the data will reduce the level of effort needed by the science community for this step. With sufficient information available about data quality and calibration, the community should be able to move effectively into aligning data sets with specific scientific questions and hypotheses.

To realize the potential of NEON, the project and the science community must be committed to an open and effective process of dialog to improve the science capabilities of the infrastructure. We recommend a suite of specific actions including:

- Open and transparent processes for rescoping and evaluation of technical changes of the infrastructure, including an assessment of the potential science impact.
- Formal, written processes for community involvement through Technical Working Groups and their successor Scientific Working Groups.
- Open and efficient approval processes by NSF for changes in data collection protocols.
- Hiring of an Observatory Science Director.
- A clear and transparent process for the transition from construction to operations and its impact on NEON science staff.
- An intense focus on data quality assurance and validation to ensure that NEON data are comparable across domains and consistent over decadal time scales.

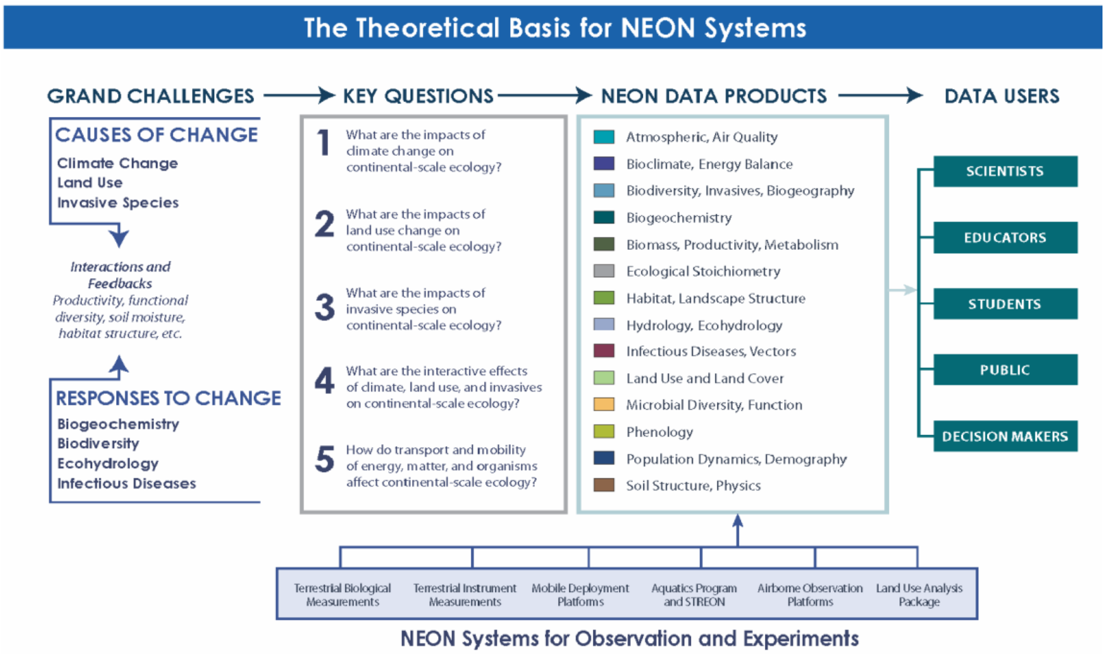
I. SETTING THE STAGE

A Overview and Charge

NEON's science scope has been developed over many years and has involved numerous activities by the scientific community and the NSF Biology directorate. The NEON observatory was designed to facilitate continental-scale ecology. Twenty domains were circumscribed, containing sixty sub-domains to serve as the main points of observation. Within and across the domains the goal is to make observations to enhance broad scale (spatial and temporal) scientific understanding in seven areas deemed as the highest priority to the future integrity of ecosystems and their biodiversity and functions across the United States. The seven areas of focus, or what have come to be known as the NEON "Grand Challenges" (left column in Fig. 1) provide foundational themes from which the observatory was designed. Approval of the architecture of measurements and collections that are planned for the observatory came in 2009. Since that time science reviews took the form of numerous independent internal and NSF-sponsored panels; the last comprehensive science capability review was in 2012 during the approval process for operations funding. On October 20 and 21, 2014, a committee was convened at NEON headquarters in Boulder, Colorado to provide the next Science

Capability Assessment (SCA) of the NEON observatory and to evaluate NEON's planned initial science capability.

Fig. 1. NEON Grand challenges (from Schimel et al. 2011; http://goo.gl/QhJaPG)



Two papers have recently discussed both the scientific and cultural impacts of NEON on the ecological community. The first by Schimel and Keller (2015) notes that continental-scale ecology will require NEON-scale infrastructure, and that issues such as requirements definition, systems engineering, and project management are essential for such large-scale projects. Moreover, standardization of data sampling and calibration are also needed to ensure comparability over large spatial and long time scales. However, complete risk avoidance may also lead to failures as well, and the science community, systems engineers, and project managers must engage in continuous and transparent dialog as the project develops. The second paper by McDowell (2015) evaluates the impacts of NEON on our understanding of continental and watershed-scale aquatic systems and processes. As with Schimel and Keller (2015), this paper notes that both science and culture will experience profound change as the result of NEON. Bringing together individual activities into the context of a larger community effort will be needed for NEON to realize its scientific potential.

The stated Committee Charge was twofold: 1) **Develop a framework that can be used to assess the science opportunitie**s that NEON's capabilities enable as the infrastructure is deployed, and, 2) **To assess the research capability and opportunities enabled by the planned initial NEON Science Capability** (or Initial Observatory Capability; IOC) that is scheduled for June 2015. This will include each NEON science sub-system scheduled of June 2015, and the Grand Challenges or transformational science that can be enabled.

The 2014 science capability assessment was established by NEON's Board of Directors (BOD). An SCA team was constituted that consisted of two members from the BOD, two members from the NEON Science, Technology and Education Advisory Committee (STEAC) and two respected members of the potential user community who had some prior knowledge of NEON's design and organizational structure. The schedule included meetings with staff scientists, science managers, project managers, system engineers, the CEO office and three NSF representatives. NEON staff assisted in developing the agenda, and securing meetings rooms, and other logistics.

B NEON Deployment

Data from the NEON observatories is becoming available on the NEON data portal (http://www.neoninc.org/data-resources/get-data). A list of the sites and their status can be found at http://www.neoninc.org/science-design/field-sites/list. In 2014, the NEON project and NSF converged on the concept of an Initial Observatory Capability (IOC) in June 2015, followed by Incremental Capability (IC) of 60% in June 2016 and 100% IC in June 2017; these documents were part of a major Cost and Schedule Review of NEON by NSF in August 2014.

C Challenges in Building NEON

The National Science Foundation, the NEON staff and community contributors have undertaken an extraordinarily ambitious program to enable the capacity for continental-level ecological and environmental sciences. Indeed, no previous MREFC project begins to approach NEON in its scope and complexity: the combination of many locations and enormous diversity of different types of measurements generate unique challenges to NSF and the NEON staff at all stages of design, construction, and operations. Thus, there are no precedents against which to judge progress and it is urgent that metrics be developed for this purpose. The framework we present is a first step in this direction, but will require refinement.

In addition to the complexities of building NEON, it is important to remember that the ecological research community also has no experience with a project of this scale. The long time period of design and construction without any data flow and the strict project requirements associated with MREFC funding means that it is easy for the larger ecological community to perceive that their expectations may not be met. Thus, transparent communication between NSF, the NEON project and the user community is essential to maximize both the science capability of NEON and its use by the community. At the end of this report, we make several recommendations to improve communication.

II. Three Perspectives of NEON Science Capabilities

We developed our evaluation of the scientific capabilities of the NEON infrastructure in the context of three perspectives: 1) science teams, 2) the project and the NSF, and 3) the broader ecological science community. Each perspective has its own needs and expectations for the assessment, ranging from the development of science proposals (scientists), to the operations of the network and long-term science program development (NEON project and NSF), to the linkages between NEON and other science-based activities, such as the LTER network (science community). Each perspective brings a unique set of metrics and expectations regarding NEON. By using these "lenses," this will set the context for a deeper analysis of NEON. These analyses in turn will allow us to develop a notional framework that could be used for future assessments of NEON science capabilities, as the network is fully deployed.

A The Individual Scientist or Science Team Perspective

For an individual scientist or science team, the first steps naturally involve the formulation of science questions or hypotheses that are amenable to analysis of NEON-provided data sets. Clearly, such a "use case" is in the purview of the scientists, but some general issues should be considered. Typically, a scientist will want to assess the availability of any "foundational" data sets, such as site characterization data, climatologies, and any other data that could be used to characterize the baseline environment of the NEON data collections and to refine the science questions and approach. Second, all of the NEON data sets will need to be characterized in terms of their sampling characteristics, quality, availability, and, where relevant, basic design elements, such as replication, stratification, and/or randomization in order to gauge their suitability for the specific scientific analyses. Moreover, scientists will need an understanding of the long-term commitments to these data sets, including any reprocessing, continued collection, etc. Lastly, scientists will need to assess the suitability of the data sets (and any ancillary information) for any planned analyses and modeling. This may require further information regarding cyberinfrastructure services, such as real-time availability, access to provisional and processed data sets, etc.

B The Agency and Project Perspective

These use cases and science scenarios will help the NEON project and NSF assess the network's science capabilities and dependencies in regards to possible operational linkages to other NSF observing and modeling capabilities (such as the LTER network or high-performance computing centers) as well as to understand the community's expectations and requirements. For example, are there dependencies between data sets or critical gaps in coverage or capabilities? How will the incremental deployment of NEON infrastructure affect the development of the science capabilities of the network? Are there new science questions that were not anticipated in the original design that will be enabled by the availability of new data sets? The use cases and scenarios will also explore the needs for non-NEON data sets and services, which could inform the potential for future additions to the NEON infrastructure either as PI-driven experiments or as upgrades.

C The Science Community Perspective

The third perspective is that of the larger scientific community. NEON is designed to be transformative for the field of ecology through its provisioning of consistent, co-registered and diverse data sets on a continental scale. These will enable a wide range of new scientific investigations of regional and continental scale ecological processes, as past barriers of inconsistently collected data, time and space gaps, etc. will be substantially eliminated. Moreover, the persistent collection of these data sets over three decades will open up the time scales that can be investigated. The scaling up over large spatial scales and scaling out over long time scales should lead to more complex questions about how ecological processes respond to and in turn impact processes such as climate change. The use cases and scenarios should demonstrate to the community the broader connections of the infrastructure to the "scaling up" in complexity of science questions and analyses. They should also help set NEON within the broader context of ecological research and observations.

The framework that we present will focus primarily on an assessment of NEON from the perspective of the individual scientist as well as the science community, although it should also help the project and the NSF with their unique needs as well. The framework will be broad in its scope, given the financial investments in NEON and its potential impact on ecology.

III. Towards a Science Framework for Assessing NEON Science Capability

A What Science?

In developing a framework to assess science capability, the first question must be "for what science?". This is not simple—NEON has an extremely grand mission—to transform the science of ecology and "enable understanding and forecasting of the impacts of climate change, land use change, and invasive species on continental-scale". While the design was focused around sets of grand challenge areas and key science questions stemming from those (Fig. 1), these are so broad as to be difficult to use in any detailed assessment of the development of scientific capability. Instead, we propose to assess NEON science capability in terms of three complementary sets of existing science questions developed as continental scale ecology has developed over the last five years, all much more detailed and hence inevitably much less complete than the Grand Challenge questions in Fig. 1. Nevertheless, they may be useful as a benchmark reflective of other questions requiring similar kinds of data and represent ways of broad sampling of science questions from the ecological research community:

1) The 12 questions cited in Schimel et al. 2011 as stemming from a special edition of Frontiers in Ecology and the Environment (Vol 6, Issue 5, June 2008) (Appendix 1).
2) The 21 "NEON Science Use Cases" described in a NEON document dated January 25, 2009 (Appendix 2).
3) The NEON data cited in the Macrosystems Biology Program grants funded by NSF to date (Appendix 3).

B Capability Framework

We propose four components that must be addressed to assess the capability of NEON to answer the science questions described above (and any others proposed from the community):

1) Are the appropriate data available, including temporal and spatial scale?
2) Where specifically are the data from (habitats/sites)?
3) What is the quality of the available data?
4) What is the availability/flow of the data, both currently and in terms of future commitment?

1) ***Are the appropriate data available*?** In addition to consideration of whether the specific data products (complete catalog available at http://www.neoninc.org/data-resources/get-data) to answer a science question are available, it is essential to know their spatial scale—data over large spatial scales are the very raison d'etre of NEON. In addition, because ecological phenomena are highly dynamic, many continental scale science questions also involve temporal changes (e.g., in climate, land use, invasions, pathogens). Thus long time spans of data collection are also an essential component. The sheer number of different data products (and diversity of type of data products) is also an essential component of NEON science capability. The NEON design is unique in the dimensionality and diversity of the data expected from each site, enabling linkages across very different organisms from microbes to birds, with different levels of organization (individual, population, community, ecosystem, landscape), and with diverse characteristics of the physical and chemical environment, including below ground, near surface, and above canopy measurements. The combination of aquatic and terrestrial measurements may also be valuable in enabling science about land-water linkages, although, unlike data within the TIS/TOS or AIS/AOS[2], the data are not necessarily located close enough that direct linkages can be inferred.

[2] TIS = Terrestrial Intrumentation System; TOS = Terrestrial Observing System; AIS = Aquatic Instrumentation System; AOS = Aquatic Observing System. See glossary for definitions.

The criticality of these three components—spatial scale, temporal scale, and data dimensionality—to answer the science questions described above means that NEON science capability will not unfold in a linear fashion as construction proceeds or even over time once construction is completed. Instead, we expect an accelerating science capability such that ***the full potential of NEON will not be realized for some time after full operations has commenced****. It is critical that the science community, other stakeholders, and funders realize and accept this initially slow unfolding of science capability.*

2) ***Where do the data come from?***

   Even in the context of continental-scale ecology, ecological questions are often restricted to particular environmental/biotic contexts that are defined by "foundational" data sets, such as site characterization data, climatologies, and any other data that could be used to characterize the baseline environment of the NEON data collections and to refine the science questions and approach. The geographical and seasonal sources of data thus are essential to defining whether NEON data are suitable for particular science questions.

3) ***What is the quality of the available data?*** To make effective use of NEON data, scientists must be able to assess the data quality along various dimensions (including sampling intensity, level of QA/QC applied, variability) to gauge their suitability for the specific scientific analyses planned. Data quality requirements will undoubtedly be specific to particular projects and so, although essential for individual projects, this component is difficult to apply in a general scientific capability assessment.

4) ***What is the availability/flow of the data?*** For many ecological questions, the mode/timing of relevant data delivery, degree of long-term commitment to data collection, degree of reprocessing, all contribute to whether or not the data enhance science capability. For example, real-time data availability could be essential in some kinds of forecasting.

C Application of the Framework to IOC

The Initial Observatory Capacity (IOC) strategy is designed to demonstrate NEON's ability to complete civil construction, collect a wide range of data at multiple temporal and spatial scales, establish data product QA/QC, and release data on the NEON portal, as well as to begin to provide data to enable scientific research. The charge of the Science Capability Team is only on the latter aspect of IOC. While 13 of the 20 domains will have completed the requirements to transition budgetary and science oversight from the NEON Project to NEON Operations, scientific capability will lag behind construction for several reasons. The most important is that, as already noted, the power of NEON comes from its large/long spatial and temporal scales and the the high dimensionality of co-registered data and data types, leading to accelerating capability as buildout proceeds. Sixty sites of terrestrial observations will be far more than twice as valuable as 30 sites; co-registered organismal plus environmental data will be far more than twice as valuable as either alone. Plant phenology plus productivity data will be more valuable than either alone. Thus, we strongly urge the research community and other stakeholders to temper expectations for the production of transformative science from NEON data for the next several years. Even after all sites are fully operational and all data products are available; the initially short duration of the data will preclude addressing many questions about the effects of environmental drivers, which rely on changes over time (as in effects of climate or invasions) or the occurrence of infrequent but extreme events (e.g., fires, storms).

In addition to the necessarily long development of NEON science capability because of the intrinsic nature of NEON questions, science capability is also lagging the site construction process because of lags in data product delivery, especially from the Terrestrial Observing System (TOS) and Aquatic Observing System (AOS). Data planned to be available on the portal at IOC are listed at: http://www.neoninc.org/data-resources/get-data/data-product-availability. As is apparent from this table, many data products will not be available even from sites transferred from construction to operations. Table 1 summarizes the number of data products and number of sites planned for IOC (June 2015) for each of the major subsystems (as of January 2015).

Table 1. Approximate number of data products and sites at which they will be available at IOC calculated from NEON working document: IOC_DP_bylocation_20150102; version from January 2, 2015. The total number of NEON sites is 106; 3 terrestrial sites for each of the 20 domains and additional aquatic and STREON sites. See glossary for definitions of subsystems.

NEON subsystem	**Total # of data products in data catalog**	**# of data products available at IOC**	**% data products available at IOC**	**# sites where data products available**	**Total sites**
TIS	67	19	28%	22	60
TOS	101	5	5%	13	60
AIS	44	4	9%	4-6	36
AOS	83	3	4%	3-7	36
STR	29	0	0%	0	10
AOP	40	10	25%	15	60

The Terrestrial Instrumentation System (TIS) and Airborne Observation Platform (AOP) have the most available data, but even that is less than 30% of planned data products; these are available for fewer than one quarter or one third of the sites. Much of the organismal data that is core to ecological questions will come from IOS and AOS and only 4-5% of those planned data products will be available at IOC. In addition, many of the data products planned for IOC are actually sets of data and the extent to which all subproducts will be available for a data product planned for IOC is not clear from the materials given to the Science Capability Team. Finally, it is not clear whether planned availability of a data product from a site at IOC means the full set of spatial and temporal replicates and planned calibration are also available. The NEON project will focus more attention on this aspect of the NEON buildout in the coming year and take steps to speed up the release of data products.

Combining the inherently accelerating value of NEON data as buildout proceeds and the proposed timeline for roll out of data products, it is apparent that nearly all NEON-based science will require at least one to two years of data to even begin to address most of the questions in Appendices I-III in a statistically robust manner and therefore cannot be addressed at IOC; many will not be answerable even at the point when the entire Observatory is transitioned to operations. The most promising source of information for transformative science in the near future are the products from the Airborne Observatory Platform (AOP).

The IOC strategy specifically included “enable the initiation of research utilizing NEON data in two important ecology gradients in the eastern United States”; a nitrogen deposition gradient and a southeastern forest management gradient, as well as a broad north-south gradient (NEON.DOC.001993; NEON Qualification Plan—Initial Observatory Capability). Although specific science questions are not posed in the IOC document, topics noted include the fate of fixed N inputs to ecosystems, processes controlling the export of N from terrestrial systems to the oceans, disturbance (fire) frequency, and urbanization.

For the nitrogen gradient, relevant available data at IOC include comparisons of canopy nitrogen from AOP across four sites in one domain and chemistry of groundwater and surface water across two sites in two domains. Terrestrial biodiversity data (plant, ground beetle, and small mammal composition) will be available across four sites in 3 domains. Thus, some basic questions on the effects of nitrogen deposition could be addressed; probably the most novel part will be the broader spatial scale and taxonomic range of community composition data as a function of nitrogen deposition level, using the meteorological data as covariates.

For the southeastern forest management gradient, relevant data at IOC include meteorological data from TIS and terrestrial biodiversity data, all available across 4 sites in 2 domains, enabling some basic assessments of effects of fire frequency on physical and community parameters, as long as the historical records of the sites will also be made available.

Thus, although some relatively simple science questions can be addressed at IOC, the focus of the science community on NEON science capability at IOC is likely to be on the last three components of the framework regarding data source, quality and availability. We expect that many projects will simply download NEON data at IOC to understand these issues. Although this might be viewed as “playing” with the data, it is an essential first step. Up-front investments as planned by the NEON Project in data quality assurance and validation as well as in the cyberinfrastructure needed to deliver both the data and knowledge about the data will reduce the level of effort needed by the science community for this step. With sufficient information available about data quality and calibration, the community should be able to move effectively into aligning data sets with specific scientific questions and hypotheses.

IV Opportunities to Enhance NEON Science Capability

NEON will be most effective where there are substantive and ongoing partnerships between the NEON Project and the science community. NEON Science Capability is a complex function of many factors, including the nature of the science questions being posed by the community, and the quality and availability of the data products and services being delivered by the NEON Project. Moreover, as we have discussed, data quality should really be considered from a larger context of data *suitability* where some data may be of high quality for one class of science questions and of negligible quality for another class because of necessary design choices made regarding sampling protocols. We cannot expect NEON to simply be a data factory that rolls out a set of pre-determined products. This does not mean that NEON is designed and operated without a strict set of requirements. Rather, there needs to be a high level of communication between the Project and the science community so that there is a common understanding of NEON science capabilities and improvements made where possible.

The need for substantive and ongoing communications between the NEON Project and the science community is clear, and it will require leadership from NSF, the project, and the science community to ensure that these conversations occur and are effectively used to guide both the project and the community's science expectations of NEON. We recommend the following to improve communication and enhance NEON Science Capability by more fully engaging the community in the following ways:

- **The processes for *any* rescoping, descoping, or technical changes need to be transparent**, and made available to all interested parties (NEON, NSF, the Board, and STEAC, and the scientific community). A shared understanding of which decisions would trigger such a process also needs to be developed.
- **Develop a process for internal review of changes during construction that could have science implications**. This process needs to go across subsystems so that tradeoffs necessitated by budget/time constraints are not restricted to within subsystems but address the totality of science products. This includes changes sample sizes/frequency of data that will be available on portal at the designated incremental capability stages because there may be critical impacts on data quality and hence science that can be done at these stages of construction and early stages of operations.

- **Formalize written procedures for community involvement through the existing Technical Working Groups (TWGs) and their successor Scientific Working Groups.** These procedures should include a) processes for filling membership of TWGs and guidelines for size and diversity (e.g., discipline, university, demography) of TWGs, b) regularly scheduled meetings/consultation with full TWGs for both consultation and updates, c) role in vetting final protocols and relevant data catalogs. Consistency in the make-up of these working groups is essential to avoid misperceptions in the community of the roles and responsibilities of the TWGs. As NEON operations begin, it is important to develop active SWGs. These groups will help to engage more of the ecological community, strengthen the interactions with NEON personnel, and build a wide network of participants.
- **Data-collection protocols need to be approved by the NSF in a more open and efficient manner**. While we understand the goal of independent review, it is unclear to the SCA team why confidential review is appropriate for protocols that underlie a community resource. Instead a process similar to public comment periods used in developing new regulations seems more appropriate, perhaps then using the TWGs for final vetting and incorporation of comments. Two months from submission to approval should be the goal. This allows early and wide-spread field-testing of protocols, as well as duplication of such protocols in other observatories, thus enhancing interoperability.
- **Hire an Observatory Science Director as soon as possible.** Hiring for this appointment will only be successful if there is sufficient budgetary authority and staff to ensure the highest quality science can be obtained from the observatory. The science position with this authority should report directly to the Chief Executive Officer, and have science staff reporting to him/her.
- **Articulate more clearly the transition from operations to construction.** Morale at NEON may suffer as current science (and engineering) *construction* staff will be confronted, in their temporary positions, by permanent staff being brought in for operations. Current construction staff deserve clarity on whether there will be opportunities to move to operations (and how those decisions will be made). The NEON Leadership needs to give serious thought as to how it will maintain needed construction staff for the duration of construction, by assessing how other successful programs have achieved this, and instituting an incentive program to retain construction staff.
- **Focus on calibration, validation, and quality assurance.** Calibration, validation and quality assurance must be embedded throughout the NEON infrastructure during its operational lifetime. Many NRC reports have repeatedly shown that long time series, such as Climate Data Records, require regular analysis and reprocessing to ensure that the best data are available for scientific studies. Moreover, interdomain comparisons are essential, and science investigations based on these continental-scale analyses will become increasingly important over the lifetime of NEON.

NEON is an extraordinarily complex undertaking, and some mistakes, and shortcomings are to be expected. We offer these recommendations not in the spirt of criticism, but with acknowledgement that in any project of this scope there is always room for improvement. The challenges associated with this project would be greatly diminished with more open and transparent decision-making and communication on all sides.

V. References

McDowell, W.H., 2015, NEON and STREON: opportunities and challenges for the aquatic sciences, *Freshwater Science*, 34, 386-391.

Schimel, D., and M. Keller, 2015, Big questions, big science: meeting the challenges of global ecology, Oecologia, DOI 10.1007/s00442-015-3236-3

Appendix 1. List of science questions related to the key questions for continental scale ecology from Schimel et al. (2011); following a series of invited papers in a special edition of Frontiers in Ecology and the Environment (Vol. 6, Issue 5, June 2008).

1. **Climate change**
    a. What is the impact of "connectivity" (local patterns and processes affecting broad-scale ecological dynamics) on the global environment? (Peters et al., 2007)
    b. How do changes in intensity, spatial distribution, and frequency of wind storms affect ecosystem attributes?
    c. How will storm damage in inland forests (soil erosion, water retention, nutrient export) affect coastal systems? (Hopkinson et al., 2008)
    d. How are pollutant source and deposition regions (connected through air and water vectors) related to patterns of land use, and how do ecosystem structure, function, and services respond to changes in pollutant loadings resulting from changing land use? (Grimm et al., 2008)
    e. How does climate change affect mean temperature and drought severity, and what influences are predicted on species interactions, phenology, snowmelt dynamics, and dust emissions? (Marshall et al., 2008)
    f. As climate change affects fuel accumulation, combustibility, and rates of ignition, how will these changes in turn impact fire regimes? (Marshall et al., 2008)
2. **Invasive species**
    a. What are the ecosystem-level causes and consequences of invasive species and infectious diseases, and what environmental measurements can predict these consequences? (Crowl et al., 2008)
    b. What societal/environmental factors can be used to forecast the spread of invasive species and infectious diseases on continental scales? (Crowl et al., 2008)
    c. What causes the variability in the success of countermeasures against invasive species? How do invasive species arrive at a new location? (Crowl et al., 2008)
    d. How does climate change affect the ability of invasive species to spread? (Crowl et al., 2008)
3. **Land use**
    a. How do climate and land use changes impact temperature and carbon cycling in lakes and streams, and what is their effect on aquatic metabolism? (Williamson et al., 2008)
    b. What are the ecological and socioecological consequences of local land use changes at regional and continental scales? (Grimm et al., 2008)

Appendix 2. List of NEON "Science Use Cases" from 2009 NEON document.

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Appendix 3. Examples of grants funded by NSF MacroSystems Biology that propose to use NEON data.

Several examples of projects recently funded through MSB illustrate some of the ways in which NEON products can benefit current and future analyses:

Microbial interactions with the environment necessarily span extreme spatial scales. A new MSB study of microbial community response to environmental changes at global scales relies on experiments in 30 grasslands spanning six continents, representing globally relevant variation in soil nutrients (28). Studies like this could not be fully supported within the NEON network, but they might still exploit portions of it. Any sites within such large networks that can be co-located with NEON can benefit from the intensive environmental and biotic data. With some sites covered by NEON data, data-collection efforts by PIs could be concentrated elsewhere. Specific NEON measurements of potential value for studies like this include all micromet, spectrometer, and canopy nitrogen data. Soil physical properties, chemistry, C and N pools, and root samples can be valuable. Soil microbe biomass, host plant composition and abundance, and phenological development could all help explain variation in microbial communities.

NEON can extend the growing number of studies aimed at relating phenology and climate. Assumptions about this relationship have important consequences in models used to evaluate the effects of climate change on terrestrial productivity. A continental-scale observational network to study relationships between phenology and climate is using digital cameras to monitor spring green up and autumn senescence across the United States (1). Similar observations being obtained at NEON sites expand this investigator-initiated network, the NEON sites bringing in more environmental observations than would be possible at other parts of the network. Here again, all NEON micromet data can help to explain rates of phenological development. Tower-based estimates of atmosphere-biosphere C and H_2O exchange at NEON sites are critical for models relating physiological stress of canopy trees, phenology and primary production.

A growing number of national networks are being used to evaluate relationships between population abundance and the environment, including breeding-bird surveys, the Christmas Bird count, and the USFS Forest Inventory and Analysis Program. A challenge in all such studies is the fact that environmental data are remote from field observations, highly indirect, or both. For example, climate products like PRISM are generated by models that extrapolate station data to a prediction grid. Temperature and precipitation from such products can depart substantially from climate experienced at field sites where population census data are obtained. The combination of biotic surveys and micromet data at NEON sites could be valuable for MSB-style studies that concern the local factors that control wildlife (11, 23) and plant population abundances (14, 15, 20), and how those local controls translate to patterns of regional biodiversity and species range limits. At least one study is examining how climate effects on plants are operating together with more direct climate effects on animals to govern extinction risks (24). Here vegetation responses to climate, in turn, alter moisture availability and the balance of latent to sensible heat. This last study requires detailed environmental data at local scales, combined with the regional climate data already available through data products such as PRISM. The biological monitoring of specific biotic groups at NEON can provide supportive information on how different groups interact in their responses to climate variation. Another MSB study is examining how tree mortality responses to climate change feedback to influence local microclimates (36). Still another considers how these relationships could lead to better reserve design (39).

NEON is expected to be at the forefront of new approaches for continental-scale analysis and forecasting of land-atmosphere exchange, across towers, plots, aircraft observation platforms and global satellite sensors. One study plans to integrate continuous, high-frequency eddy covariance measurements with satellite and aircraft remote sensing data that include disturbance, stand age, aboveground biomass, and leaf nitrogen (6). These data sources will be integrated to create gridded carbon flux estimates and to examine sources of variability in carbon fluxes over North America. Like many of the examples cited above, this MSB study plans to exploit several networks, including Ameriflux.

Thus far, MSB projects that plan to use NEON also rely on data from other sites, some represented by existing networks, others planning new data collection. Projects that rely solely on NEON for data streams may increase as the data streams are released. It is also possible that many projects will continue to exploit NEON in an opportunistic fashion, to supplement network-style studies, many of which will require sampling outside the network. One lesson from projects funded thus far could be the value of integrating NEON data with those available through other government agencies and existing investigator networks.

Appendix 4. Glossary.

Acronym	Definition	Description
AIS	Aquatic Instrumentation System	The Observatory subsystem that corresponds, in general, to the suite of aquatic measurements acquired by sensors.
AOP	Airborne Observation Platform	The Observatory subsystem that acquires airborne observations, including LiDAR, hyperspectral, digital photography, and other remote sensing data products .
AOS	Aquatic Observing System	The Observatory subsystem that corresponds, in general, to the suite of aquatic organismal and biogeochemical measurements acquired by field technicians.
BOD	NEON, Inc. Board of Directors	The Board of Directors provides overall leadership and strategic direction to NEON, Inc. The NEON Board of Directors is the highest governing authority within NEON, Inc. and ultimately responsible for the actions and performance of the organization.
IOC	Initial Observatory Capability	The infrastructure and functions of the Initial Observatory Capability will constitute the initial baseline of NEON; this platform will be scalable to the full scope of the Observatory. Once the IOC is achieved, all other project deliverables will build on the initial capability as the Observatory functions and capabilities are expanded.
MREFC	Major Research Equipment and Facilities Construction Account	NSF's Major Research Equipment and Facilities Construction (MREFC) account supports the acquisition, construction, and commissioning of major research facilities and equipment that provide unique capabilities at the frontiers of science and engineering.
STEAC	NEON, Inc. Science, Technology, and Education Advisory Committee	The Science, Technology and Education Advisory Committee (STEAC) provides high-level strategic advice to the Chair and Board of Directors on science, technology and education matters related to the NEON Observatory as well as relevant corporate initiatives.

Acronym	Definition	Description
STR / STREON	Stream Experimental Observational Network	Long-term nutrient addition and top-level consumer manipulation experiments conducted in multiple streams at selected NEON sites distributed across climate gradients that represent dominant stream hydrologic regimes.
SWG	Scientific Working Group	A successor to the Technical Working Groups that provides scientific input to the operations of the NEON.
TIS	Terrestrial Instrumentation System	The Observatory subsystem that corresponds, in general, to the suite of terrestrial atmospheric and soil measurements acquired by sensors.
TOS	Terrestrial Observing System	The Observatory subsystem that corresponds, in general, to the suite of terrestrial organismal and biogeochemical measurements acquired by field technicians.
TWG	Technical Working Group	Technical Working Groups (TWGs) comprise of science, education and engineering experts who provide input to the design of the Observatory's data collection and processing methods, including the sensors, sampling methods, and processing that will yield maximum benefit for the NEON community.