Report from the NSF BIO Advisory Committee Subcommittee on NEON Scope Impacts[1]

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A. Introduction and scope of document

The National Ecological Observatory Network (NEON) is designed to be a continental-scale research platform for understanding and forecasting the impacts of climate change, land-use change, and invasive species on ecological processes. With funding and oversight from the National Science Foundation (NSF), NEON is currently under construction, expected to be fully operational in 2017. The Observatory is an ambitious and unique large-scale project; as the first of its kind, arising in a rapidly advancing science and technology landscape, it is unsurprising that design modifications would be needed over the course of construction that began with Major Research Equipment and Facilities Construction (MREFC) funding in 2011. During summer 2015, the most substantial NEON design changes to date were proposed in order to stay on target and within budget. Accordingly, NSF has asked this Subcommittee to review the suggested modifications and determine whether they will significantly reduce NEON's capability to enable transformational research (Appendix 1; BIO AC NEON Subcommittee Charge).

B. Background

Ten years in planning by the ecological science community, NEON is the first major infrastructure designed for ecological research at a continental scale. The vision is to transform ecology and allied disciplines by supporting scales of research that not only deliver more data than previously possible but also, importantly, require investigators to engage in new, more expansive ways of thinking than have been traditional. Five questions frame NEON, inspired by the National Research Council 2001 report *Grand Challenges in the Environmental Sciences* (ISBN: 978-0-309-07254-0): 1) What are the impacts of climate change on continental-scale ecology?, 2) What are the impacts of land use change on continental-scale ecology?, 3) What are the impacts of invasive species on continental-scale ecology?, 4) What are the interactive effects of climate, land use, and invasives on continental-scale ecology?, and 5) How do transport and mobility of energy, matter, and organisms affect continental-scale ecology?

NEON construction was funded in FY 2011 for $433M, to be expended over a 6-year construction schedule. Now approximately 50% complete and with $268.4M spent, unexpected delays and expenses motivated the recent proposal to cut future costs. Such changes must not compromise NEON's ability to transform ecology through enabling continental-scale understanding of the five central questions.

[1]Report discussed and approved by the Biological Sciences Advisory Committee on December 18, 2015.

C. Process of this Subcommittee

This Subcommittee was constituted at the request of the NSF Directorate for Biological Sciences (BIO) Advisory Committee (AC), following the recommendation made by a group involved in a 14-17 July 2015 Scope Management Meeting at NSF, including members of the NSF staff from the NEON Program, NEON project staff, members of the NEON Board of Directors and Science Technology and Education Advisory Committee (STEAC), and domain scientific experts from the community. The Subcommittee was appointed by the NSF BIO AC Chair, Dr. Katherine Gross, in consultation with other members of the NSF BIO AC and NSF BIO's Assistant Director (AD). Our charge was delivered in September 2015, by NSF BIO AD Dr. James Olds. The Subcommittee met in virtual conference on 9 October, 14 October, 22 October, 28 October, and 4 November 2015 to discuss and evaluate the eight major classes of "descoping" that have been proposed by NEON leadership (Appendix 2; NSF Letter-7-31-15 Scope Management), and to base this discussion and evaluation only on materials that were available at the time of the July Scope Management meeting. The central goal is to determine the degree to which each of the proposed changes, and their interactive or cumulative effects, will jeopardize NEON's ability to enable transformative research relative to the original NEON plan (Appendix 3; NEON_DOC_000001-Observatory_Design) and in the context of the current research environment.

D. Summary of proposed descoping actions

In order to reduce future NEON construction costs, NEON leaders have proposed to strategically 1) reduce management costs, 2) remove relocatable sites in Hawaii as well as 3) all urban sites, 4) reduce instrumentation at all sites, 5) eliminate 6 relocatable sites, 6) halt all STReam Experimental Observatory Network (STREON) activity, 7) deliver lower-level data products during construction, and 8) move targeted staff costs from construction to operations budget.

E. Descoping actions described and evaluated

1. Management budget reductions

The budget reductions in the management category come from four separate sources: a reduction in Indirect Cost (IDC), reduction in contingency, reduction in staffing, and a reduction in flights for the Airborne Observatory Platform. In two of these cases, this Subcommittee has been provided with insufficient data to assess impact. The reduction in Indirect Cost, of $26M, or approximately one-fourth of the entire descoping process, was justified in the plans as simply "NEON incorrectly estimated indirect costs to complete construction". Given that NEON Inc.'s primary activity is the NEON project, indirect costs may provide critical infrastructure necessary to keep the organization running. Details of how IDC is spent and the source of the "incorrect estimate" would be required to determine potential impact. Similarly, the 5% staffing reduction was described as being "implemented by each team", but this Subcommittee has no information on what the current staffing levels are in each area, or what positions will be eliminated, which makes an estimate of impact impossible. Presumably more detailed information on these projected activities either has been provided or is being prepared by the project team, but was not available for this Subcommittee.

The reductions in Airborne Operations stem from a "lean qualification" procedure that reduces the number of flights to determine the readiness of the platform. Assuming this process will still result in a safe and functioning platform, this change would not impact the scientific capabilities of the Observatory. Finally, the reduction in contingency is essentially an expenditure of the contingency funds to mitigate cost overruns to date. As the purpose of contingency funds is to meet unexpected expenses, it is reasonable to reduce these funds as construction progresses. The stated reduction seems appropriate and also would not impact the scientific capability of the Observatory.

2. Hawaii relocateable sites removed
Biological invasions and susceptibility to invasions were identified as a grand challenge addressable through NEON, and several paired sites were identified in Hawaii, the Southern Great Plains, and the Mid-Atlantic to provide data useful in addressing this challenge. NEON leaders propose to eliminate the relocatable Hawaii sites. The two relocatable sites in Hawaii were originally chosen because they differed in their invasion status, which would facilitate comparisons. Unfortunately, conditions at the sites have changed such that the intended scientific objectives for the sites cannot be achieved. The fact that invasion status changed so rapidly is itself an illustration of the inherent challenges in both predicting invasion susceptibility and characterizing the community and ecosystem impacts of invasions in a rigorous, controlled manner.

Although the two Hawaii sites are to be eliminated, there are other remaining paired sites in the continental United States that can provide high-quality data enabling evaluation of the science questions to be addressed. Thus, while comparisons of invasions and susceptibility to invasions between island and continental communities, or tropical and temperate communities, may no longer be achievable, the remaining sites will generate empirical data that can be used to achieve the basic objective at the continental scale.

3. Urban sites removed
According to NEON planning documents (Appendix 3; NEON_DOC_000001-Observatory_Design), urbanization, as "perhaps the most ecologically intense and least studied of land uses" was originally designed to be examined in two transects, humid sites on the Eastern Seaboard and Puerto Rico and dry sites in the Southwest and intermountain West, and was to be investigated in the context of other land uses (e.g, urban vs agricultural). The descoping proposal eliminates all seven sites aimed at study of urban ecosystems. Design, safety and permitting issues presented insuperable barriers to completing construction in a timely manner. NEON will, however, retain the infrastructure already developed for these sites and plans to use this infrastructure as appropriate in the next planned deployment of relocatables.

That said, in terms of descoping impacts, elimination of urban sites will restrict NEON data to mostly non-urban landscapes. Although grand challenge questions can

still be addressed in remaining sites, with a shift in focus to other forms of land use (agriculture, forestry), this limitation will reduce the utility of NEON as a source of data for answering specific ecological questions (e.g., connectivity as relating to urbanization). The Subcommittee notes that some of the remote sensing products from the NEON Land Use Analysis Package (LUAP) work could be used for comparative studies of urban and wildland sites, an activity that may not be needed during construction but may provide future insights in the absence of urban data directly generated by NEON. In addition, the Department of Energy may develop urban research sites, Integrated Field Labs, that could provide complementary data (http://science.energy.gov/~/media/ber/berac/pdf/20150226/Draft_BERAC_Feb_IFL_workshop_report.pdf).

4. Instrumentation removed

Proposed descoping includes elimination of various instrumentation – MiniRhizotrons, the Biogenic Gas Measurement System (BGMS; formerly known as the Air Quality Monitoring System), and five Mobile Deployment Platform Systems. The MiniRhizotron system was included in the original scope in order to capture below ground images of roots that would enable estimations of below ground biomass, changes in fine root production, and below ground net primary productivity as part of the overall ecosystem productivity assessment. Other measurement systems were designed with the expectation that MiniRhizotron data would be available, such that estimates of ecosystem carbon cycling are affected by the delay or loss of these data. The rationale for eliminating the MiniRhizotron system from construction is that there is not yet a suitable technology that can be deployed within the construction timeline, but there should be post-construction opportunities for strategic testing and validation that may allow future integration of MiniRhizotron instrumentation into NEON sites. Given that ecosystem-level properties are regularly estimated without MiniRhizotron systems, our assessment is that NEON can accommodate the deferral of this instrument's deployment without substantially compromising NEON's broader scientific value. The BGMS was designed to measure fluxes of ozone, methane and nitrous oxide. A history of difficulties with design and deployment, combined with the need for cost savings in areas with relatively low overall impact on NEON, appears to have motivated the suggestion to eliminate the BGMS. The BGMS measurements are included in a variety of non-NEON monitoring although certainly the coordinated monitoring focused on NEON sites would have had advantages over those external data. The Mobile Deployment Platform Systems provide rapid response capability for observing sudden events such as hurricanes, floods, and wildfires. In addition, they enhance NEON's ability to deliver valuable scientific products on short time scales (< 1 year), and their availability provides a valuable mode of engagement with individual researchers who may request the mobile platforms for scientific observation of unusual or societally important phenomena. The suggestion to reduce the number of mobile platforms seems to be primarily motivated by financial concerns, rather than specific difficulties in their construction. With five other mobile platforms remaining within NEON, this reduction does not appear to substantially reduce the scientific value of NEON overall.

5. Multiple relocateable sites removed

The relocatable sites are envisioned to collect data to address questions that could not be fully addressed by core wildland sites. Typically, they are located in areas expected to represent conditions on a gradient (e.g., an urbanization gradient) or to provide comparative data (e.g., wildland vs. managed). Six sites (Table 1) appear to present permitting or other logistical problems, such that implementation on time is not considered feasible by NEON leadership. Sites that would be deferred or eliminated in this plan include two addressing Climate Impacts, one in Invasive Species, two in Urbanization (Land Use), and one in Forest Management (Land Use). Overall, the deletion of these sites primarily threatens the potential for NEON data to address questions associated with Land Use, a category of questions already affected by the proposal to remove all urban sites from NEON construction. The removal of an Invasive Species site further reduces the potential to address Invasive Species questions. Capability to address change associated with Agriculture as a Land Use class is still relatively strong, particularly given recent moves by USDA and its partners to build a Long-Term Agroecosystem Research Network, which will complement both NEON and the existing Long-Term Ecological Research Network funded by NSF. Removal of the Fraser site reduces the number of sites on a potentially influential dust and nitrogen gradient (Figure 12, NEON Observatory Design). Deletion of Poker Flats, the Taiga Climate Impacts site in this list, is unfortunate given the rapid changes in permafrost that are affecting this domain but we also note that the Climate Impacts siting otherwise remains comparatively intact. A rationale for removing Fraser and Wichita was not provided in available documents. This Subcommittee finds this set of proposed changes to be difficult to evaluate with the information at hand, given the range of analyses it may affect.

Table 1. Relocatable Sites proposed for removal from NEON.

Site	Domain	Science Theme
D19R2-Poker Flats	Taiga	Climate Impacts
D13R2-Fraser	Southern Rockies	Climate Impacts
D11R2-Wichita	Southern Plains	Invasive Species
D12R2-Paradise Valley	Northern Rockies	Land Use (Urbanization)
D15R2-Red Butte	Great Basin	Land Use (Urbanization)
D16R1-Thayer	Pacific Northwest	Land Use (Forest Management)

6. STREON removed

STREON was envisioned to be the first experiment within NEON. The goal was to use experimental manipulation to assess how streams respond to two increasingly pressing human threats - nutrient loading and the loss of top consumers (e.g., fish). STREON would provide novel long-term insight on these issues, as well as an exemplar of designing and implementing experimental work within NEON, useful for the scientific community as it envisions future investigator-led experimental work within NEON. Permitting and other logistical problems have plagued implementation, such that NEON leaders consider it infeasible to construct STREON on schedule in a manner that meets original scientific goals. This Subcommittee

considers the removal of STREON from construction to be relatively low impact for NEON in the sense that STREON was planned to be a stand-alone experiment complementing the upstream NEON aquatic observations. STREON's removal does not substantially reduce the value of those planned observations. Moreover, it is possible to fund and implement large-scale experiments of this type through other mechanisms, ideally led by external investigator teams who collaborate with NEON in their execution. However, STREON presented the clear opportunity for near-term discovery, and NEON will need to identify new modes for rapid scientific returns if STREON is removed. Although the financial investment in STREON to date has been small, the intellectual investment by the scientific community has been large, and it is encouraging to see NSF leaders quoted (e.g., Mervis 2015, DOI: 10.1126/science.aad4620) as being supportive of using other mechanisms to fund STREON-like activities. STREON was to be the first of the "NEON Experiments". With its removal, this Subcommittee urges the project to identify alternate "experiments" that demonstrate use of NEON for high-impact, near-term discovery.

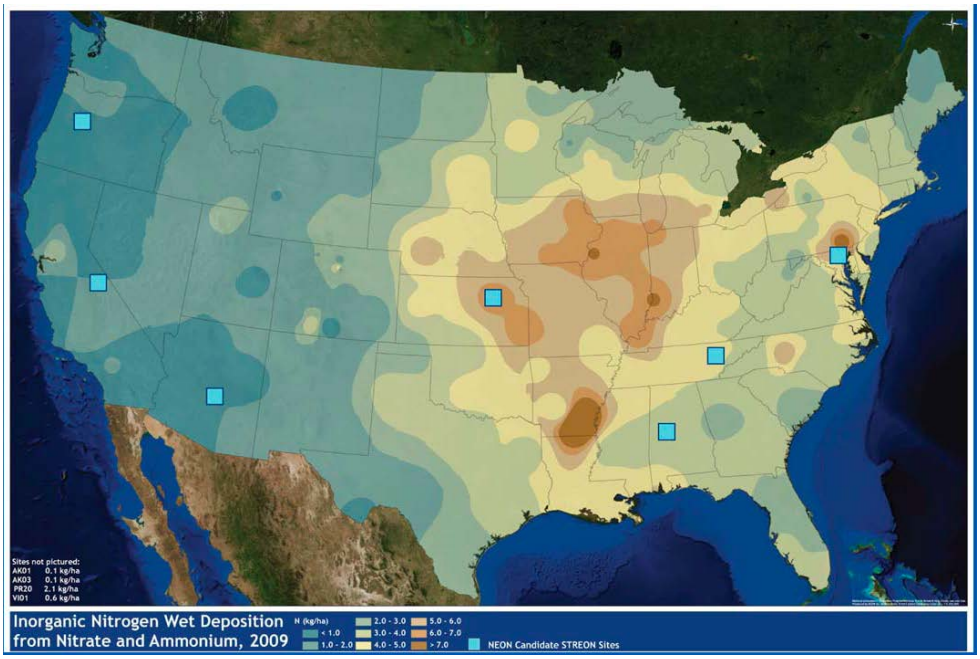

Figure 1. STREON site locations (blue squares) across a nitrogen deposition gradient. All STREON sites were to be downstream from NEON aquatic sites that would serve as control. All STREON activity is proposed to be excised from NEON construction.

7. Data products reduced

The data descoping now planned for NEON has a number of components. The most direct is simply elimination of data products from cancelled facilities, such as the Urban sites and the STREON experiment. Other reductions include higher-level data products (primarily Levels 2-4), as well as LUAP data, both described further below.

The new descoping plans for reduction in data products during the construction phase (Appendix 4; NEON DPS_072Reduced Scope Proposal) focuses NEON effort on lower-level data products (see Table 1 for definitions). The proposal maintains a relatively high commitment to Level 1 Data Products (81% of original plan), with

reductions in Level 2 (23% of original plan) and Level 3 (62% of original plan), and no Level 4 products.

Table 1. A major science data system like that planned for NEON has an array of data products that are often characterized as Level 0-4 (from p. 56 of Appendix 5; NEON_DOC000026_Scope_20150612Final.pdf).

Data Product	Description
Level 0	Raw data; usually in machine/sensor units; no calibration or QA/QC applied
Level 1	Calibrated data products, generally from a single measurement stream; physical units; QA/QC applied
Level 2	Derived data products from a single measurement stream; includes temporally interpolated measurement streams and processing to biogeophysical units; for AOP, may require additional data sets to develop algorithms
Level 3	Level 2 products remapped, re-gridded, mosaicked or resized; includes spatially interpolated data, such as vertical/profiles and horizontal/mapping
Level 4	Derived data products from multiple measurements streams, multiple instances, or produced from models; inputs include L1, L2, and/or L3 data products, occasionally combined with external data

Lessons learned from the successful NASA Earth Observing System Data System (EOSDIS) suggest that the proposed data prioritization is appropriate. The entire scope of data products should be planned at the outset, as NEON has done; data volumes, processing loads, latency, storage sizes, and distribution demands need to be planned for the whole system. However, final implementation of sequentially produced data, such as Level 1-4 derived products, need not happen together. Instruments come on-line producing level 0 data and then undergo Level 1 processing. At this point, the instrument should be considered operational. Level 2, 3, and 4 products derived from these Level 1 data cannot be finalized until the Level 1 processing is stable, or else considerable reprocessing will be required. It seems that NEON is now adopting this logic for the Data Product descoping, which this Subcommittee considers appropriate.

The LUAP was intended to provide integrated, interoperable information to extend models to continental scale. The proposed descoping action in the LUAP activity is to leverage existing data, repositories and freely-available mapping tools. Instead of duplicating the storage, discoverability, and accessibility of these data sets, NEON will work with the external agencies to develop APIs that support users in finding and manipulating data directly from original sources (p60, Appendix 5).

The LUAP activity is an essential part of NEON, actually providing complete national datasets, not simply a set of point measurements. NEON has consistently branded itself as a continental-scale research platform, and the LUAP is a critical part of

turning core site data into continental scale data. That said, other agencies, particularly NASA and USGS have invested significant resources in producing, archiving, and distributing these datasets. NEON can provide a valuable user gateway to these datasets for the NEON community that will be very helpful without redundant archiving and distribution activities already done by other agencies.

In summary, while these changes to the data production plan seem reasonable, it is important to emphasize that commitment for the final Level 3 and 4 datastream should not waver. Most of the high-impact science, such as for the NEON Grand Challenges, will use Level 3 and 4 data. It is inefficient and redundant for multiple groups to do Level 3 and 4 processing. Also, virtually all of the educational and outreach material will use Level 3 and 4 products.

8. Moving staff expenses from construction to operations
NEON construction (MREFC) costs are viewed as distinct from operation and maintenance (O&M) costs, where construction is considered to be a single investment in building the Observatory and O&M funds will be needed to maintain high-level Observatory functioning over its lifetime. Currently, the MREFC funds support a number of staff whose duties will continue throughout operations – cyberinfrastructure production, field operations, collections and laboratory analysis, and education. The rationale for their costs being carried within MREFC has been that their activity is part of the construction phase until the Observatory is operational. However, as NEON sites transition into operation, the rationale for their costs remaining within MREFC becomes less clear. The proposal is to move targeted staff costs from MREFC to O&M when physical construction at sites is complete, not only to repurpose these funds toward other aspects of NEON construction but also to reduce the complexity of moving NEON into operation. This Subcommittee appreciates that designating a NEON site as "operational" is a matter of perspective, and that physical construction is not the only criterion by which NEON sites' progress toward "operational" may be assessed. Our charge is not to resolve this potential debate but to determine the degree to which this proposed change jeopardizes NEON's ability to function as a platform for transformative research. The primary threat posed by this specific proposal is a prospective delay or failure in delivery of data or other products from sites once they are designated as operational and costs move to O&M. However, given that NSF will have continued oversight of NEON's O&M stage, we consider this potential risk to be minimal. A remaining question then would be what activities cannot be supported with the O&M funds when they are diverted to the proposed activities, but this Subcommittee did not have the information that would allow us to evaluate that potential impact.

F. Conclusions
Although most of the proposed changes are regrettable and many will likely degrade NEON's capabilities relative to the initial vision, based on the information at hand our assessment is that NEON can still deliver on its major scientific goals. In the case of the proposed management budget changes to IDC and the 5% staffing reduction, we have

insufficient information to evaluate impact and anticipate that NEON and NSF leadership have rigorously investigated the feasibility of this plan. The proposed changes to Airborne Operations seem relatively low-impact and the reduction in contingency funds is appropriate. The proposed reduction of instrumentation appears logical and without major negative effect. The elimination of sites overall is difficult to evaluate but appears to have highest impact for questions involving urban gradients and those that would benefit from tropical extremes. On the positive side, we do see opportunities for NEON and independent investigators to capture some of these gradients through the use of complementary public data (e.g. through LUAP activity), prospective new programs (e.g. DOE's proposed Integrated Field Laboratories), and mobile NEON capabilities. Removal of the STREON experiment will limit the potential for near-term discovery that 1) capitalizes on the already substantial investment of the scientific community in its design, and 2) provides an exemplar of using NEON as a platform on which to build future experimental work. We are encouraged to see signs within the documentation that NSF will support STREON-like work through other funding mechanisms. Future NSF support of investigator-led work on continental-scale ecology that employs the NEON platform is critical to NEON achieving its potential. The proposed reduction in data products during construction seems rational, given that lower-level data products should be rigorously evaluated prior to development of higher-level data products. However, the commitment to delivering higher-level data products must remain firm. These higher-level data products will be the basis for much of the high-impact research envisioned for NEON; the vast majority of prospective NEON users are not familiar with many or most of the lower level data products nor are they prepared for (or interested in) creating higher-level data products; and most of NEON's education and outreach activities appear to be based on higher-level data products. While it is not in this Subcommittee's scope to evaluate or make specific recommendations about NEON's cyberinfrastructure planning, in the course of investigating the proposed data product descoping, the criticality of ensuring that robust higher-level data products emerge from NEON could not have been more clear. The proposed movement of this activity to post-construction places a great responsibility on the Observatory to produce these useable data products in the earliest possible stages of operations.

Perhaps the best way to examine the impact of the totality of the cuts is to re-examine NEON's ability to answer the five grand challenge questions that framed the Observatory's initial design. In the view of this Subcommittee, NEON after the scope changes is still capable of delivering important data to advance each of the five questions. The ability to study land use is perhaps the most clearly impacted by the loss of urban sites, but sufficient data should remain from NEON and other sources to make significant impact in this area.

Delays and adjustments are to be expected when embarking on a project of this size and novelty. The great progress that NEON has made in building a unique infrastructure for ecological research is apparent, testimony to the hard work, creativity, and dedication of a large number of NEON staff, as well as scientists from the community who have largely volunteered their time and energy over more than a decade. In short, given robust NSF commitment to NEON operations and data production, future investigator-led research on the NEON platform, and sufficient investment in education of the scientific community, NEON's potential to enable transformative research will remain strong.