LTER III Site Review
July 2003

We would like to express our appreciation in having the opportunity to visit with investigators, students, and staff at the Harvard Forest LTER review July 16th and 17th in such an open manner, in such delightful surroundings, provided with unaccustomed, but greatly appreciated, amenities.
In our review we consider the extent that the Harvard Forest LTER program has met or is prepared to meet NSF's goal "that the science is multidisciplinary, multidimensional, scalable, information-driven, predictive and model-based, education-oriented, and increasingly virtual and global". We also will evaluate the extent that social scientists have become involved in the program "to increase understanding of interrelationships and reciprocal impacts of natural ecosystems and human systems to inform environmental policy"(from NSF report on 20 year review of the LTER program).
Our report will document in some detail that the Harvard Forest LTER:

- has outstanding leadership that fosters collaborative science and synthesis.
- illustrates the need to acquire historic information to interpret present and future ecosystem responses.
- justifies the effort to acquire long-term, high quality, biophysical measurements.
- confirms the value of field experiments to enhance our understanding of underlying processes necessary to develop robust predictive models.
- has established an educational program that encourages integrative science.
- made advances in information management that improve exchange of data among
- LTER sites and to the broader community of scientists.

In addition, we will offer comments on current experiments and future plans that involve Harvard Forest and other LTER sites in New England.

Leadership in scientific collaboration and synthesis
Almost from its start in 1907, Harvard Forest has been a Mecca to forest scientists, and shortly thereafter, to the public with the opening of the museum showing the historical dioramas. The founders of the LTER site continued the tradition by bringing a historical appreciation and openness to all who might share common interests. As a result, the number of scientists involved has continued to increase, supplementing research beyond NSF's investment by more than 8-fold. The cadre of disciplines has expanded as well and now includes social scientists from the fields of anthropology, economics, and forest policy. We give great credit to all of the PIs for their leadership contributions. In particular, we recognize David Foster, the site director, for creating such a "fermenting" environment for the exchange of ideas that we believe will continue to foster innovative, integrative research. We also appreciate David's contribution in bringing a historical and paleoecological perspective to ecosystem studies along with his ability to communicate with enthusiasm and elegance to any audience. The examples of synthesis of ecological

research in a series of Harvard Forest publications and books that David and others have authored are outstanding and warrant sharing with other LTER sites.

Suggestion:
None, although eventual replacement of the present leadership with equally capable people will be a challenge.

Value of a historic perspective
History matters, and evidence continues to accumulate with additional insights provided through a reconstruction of land-use from the time of colonization in New England, and before, when native Americans combined hunting and fishing with an innovative agriculture. Paleobotanical studies confirm land-use changes and extend the time line to before human activities. The reconstruction of changes in wildlife abundance across Massachusetts is particularly instructive as it demonstrates the consequences of policy decisions, intentional or unintentional, that create the mosaic we view today. The recognition of historical legacies provides a natural intellectual meeting ground for multiple disciplines and strengthens attempts to envision and predict how the landscapes of New England might change in the future.

Suggestion:
There is an opportunity and challenge to develop models that couple historic, current, and future patterns of human land use with the structure, function, and trajectories of New England landscapes. Before executing large-scale analyses, we recommend that a framework be developed that couples conceptual and quantitative models of human behavior to biological and physical processes operating at a variety of scales. The framework should articulate explicitly how time and space scales differ and interact with possible changes in climate and atmospheric conditions (CO2, ozone, N deposition).
Following the definition of testable hypotheses and experimental designs regarding the role of exotic species on the landscape, native and exotic herbaceous species should be sampled on different soil types, reflecting quantitative measurements of functional differences in chemistry, water availability, and compaction. There is a potential role for experimental manipulations in deriving coupling functions between time and space that would involve merging models that predict land use patterns with those that consider plant distribution, including invasion and local extinction. Experiments should be designed to define dispersal and other environmental limitations quantitatively.
Harvard Forest has a remarkable set of historical records of land use on the property that was John Sanderson's farm, and scientists are utilizing paleoecological records from small lakes and ponds throughout the region, as well as within the Forest itself. We recommend that these sets of data be stratified by land use and physiography (geology, geomorphology, soils and hydrology), so that the impact of land use can be evaluated unambiguously.
Pollen records from sediment cores generally provide a history of regional land use, but seeds could be used to reconstruct local land use. Seeds also have the added advantage over pollen of being identifiable to species. Biogeochemical analyses of

sediment cores for nitrogen, sulfur and carbon isotopes could provide information on the source of the nutrients. Because of complexities in the cycling of nitrogen, cores should be collected from wetlands, which also contain well preserved pollen and seeds. These extensions of the paleoecological records might not be achievable immediately, because the field and laboratory work is labor intensive and the stable isotope analyses expensive, but we recommend that seed and biogeochemical analyses be included in future research.

We also recommend that the stream studies, which are designed to show the effect of different land uses, be extended to include paleoecological studies. The paleoecological records of diatoms, (chironomids which are being quantified), insects and biogeochemistry are extremely useful for separating the effects of local land use from more regional shifts in climate or atmospheric inputs. As a result of wider spatial sampling, paleoecological records should be valuable in concert with archeological studies for developing models to predict rates of aquatic eutrophication across New England.

Value of long-term biophysical measurements

The HR LTER monitoring of carbon dioxide and water vapor exchange from hardwood forests started in 1992 and now represents the longest continuous eddy-flux data set available. Concurrent measurements of carefully calibrated meteorological variables, including wind direction and velocity, have provided a basis for quantifying methane, nitrogen oxide radical, and ozone exchange rates between forests and atmosphere. In addition, long-term measurements of variation in soil moisture and soil $CO2$ efflux, along with canopy light interception, leaf conductance and photosynthesis, provide the foundation for testing a variety of ecosystem process models at different time scales. These exemplary data sets, available online, are the most widely cited to date. We agree with the investigators that these complementary sets of measurements should be continued as significant variation in ecosystem responses not previously recorded could be expected following storm damage, insect outbreaks, or chronic ozone/nitrogen interactions.

Suggestion:

There is a suite of ecosystem process models available that treat the system with various degrees of refinement. These models also incorporate different assumptions on linkages between plant nutrition, photosynthetic capacity, respiration, carbon allocation, and decomposition. It would be valuable to compare the validity of these models to measured fluxes at monthly and decadal time steps. Because these ecosystem models also provide reasonable estimates of NPP, they could serve to set limits on growth simulated for multi-storied plant communities by conventional gap models.

At Harvard Forest and throughout New England there are a large number of permanent plots on which vegetation surveys are conducted periodically, including sites now supporting hemlock. We recommend that supplemental allometric data be collected so that variation in leaf display can be expressed as vertical layers of leaf area index, or the fraction of light intercepted. In this way, variation in species

abundance and cover can be incorporated into ecosystem models and predictions evaluated via lidar remote sensing.
Although the current measurements of increments in standing biomass and transfer to the forest floor are indeed valuable, the key unknown, demonstrated from girdling experiments, is the fraction of gross carbon uptake that goes seasonally below ground to support root growth, mycorrhizal activity, and the production of exudates that stimulate heterotrophic microorganisms. A temporary cold-block on phloem transport, developed under laboratory conditions with carbon-11 (Goeschl et al. 1984. Plant,Cell Environ. 7: 607-613) has recently been transferred to the field using refrigeration (Kurt Johnsen, USFS Durham; Sune Linder, Uppsala, Sweden). It would be worthwhile following the results of these experiments and considering installing similar treatments at Harvard Forest.

Contributions of experiments at Harvard Forest
In addition to the widespread silvicultural activities on Harvard Forest, a series of long-term experiments have been laid out. These experiments, for the most part, were funded from sources other than the LTER grant but are clearly core components of long term research at Harvard Forest. They provide tests of underlying assumptions for a wide variety of ecological models. Many surprises have emerged from these experiments that have brought about a reevaluation of basic assumptions. These include an increased appreciation of how much nitrogen can be immobilized in the soil, that excess N affects photosynthetic capacity adversely, that interactions between carbon and nitrogen availability affect decomposition, and that sprouting vegetation dampens the impact of hurricanes on ecosystem function. The committee recognizes that small plots allow for statistical replication whereas large plots generally do not. On the other hand, large plots provide a basis for studying system interactions and can be registered and interpreted on satellite imagery.

Suggestion:
Small, well-replicated studies are highly desirable as pilot studies for they define the minimum time and intensity of manipulations required to record significant responses. From such pilot studies larger, unreplicated plot studies can be justified to incorporate longer term, more comprehensive sets of observations. This approach mirrors that followed in the soil heating experiment and should apply to a host of possible manipulations in studies on invasive species and land use legacies.
In regard to the soil heating experiment, relatively little work has been done to examine treatment effects on soil microbial functional group as they affect gross rates of N-cycling processes. Previous work on the soil warming plots showed an increase in soil N availability. Is this a result of an increase in gross N mineralization or a decline in N immobilization by microbes? The answer to this question would explain how C-cycling has been modified, and provides information on the mechanisms for N retention in ecosystems modified by global change.
We suggest continued use of the high-N saturation red pine plot for testing additional directed hypotheses. This plot provides a unique experimental unit for examining specific hypotheses related to the mechanisms for N-retention and

inhibition of decomposition, the decline in NPP, the differential abilities of pine and hardwoods to establish on highly N-enriched sites, and perhaps an opportunity to record and interpret premature conversion of sapwood to heartwood.
The DIRT plots are well designed, and are especially interesting because groups at other US and international sites are setting up similar experimental designs. The persistent moss cover on the litter-free plots needs to be eliminated, however, because the C-inputs by mosses may be substantial. Pilot tests are required to demonstrate feasibility. It would also be useful to measure surface litter moisture content throughout summer months to assess whether some of the differences recorded in CO_2 efflux among treatments could be attributed to this previously unmeasured variable.

An educational program that fosters integration
The review committee very much enjoyed the opportunity to meet with students and learn of their experiences at Harvard Forest. The refurbished housing facilities enhance opportunities for comradeship and encourage interchange among those who are in residence all summer and well as with those who visit the forest irregularly. The formal summer educational program, consisting of seminars and workshops, has proven valuable in broadening the experience of students, and in providing them an opportunity to learn about scientific writing. In addition, the "switch day" and student symposiums offer each participant insights to other fields of science.

Suggestion:
Additional opportunities to broaden contacts across disciplines, so critical to the future advancement of integrative ecosystem studies, might include a journalistic exercise to translate, in colorful images, the work of classmates and to post these essays for all to share on a web page. A class project devoted to developing an outline for an integrative study plan might also be considered.
Opportunities to acquire NASA support and reach a wider audience of students might be attained through participation in NASA's "GLOBE" program. This program seeks ways of confirming satellite-inferred classifications of land use and rates of change by involving school children, their teachers, and other professionals.

Advances in information management
Active participation by the site Information Manager (IM) in LTER Network level activities, including ClimDB, Personnel database, and committees and workshops, has contributed to the decision making process that guides the direction of information management within the LTER network.
Financial investments by the site administration, together with annual NSF supplements, have enabled the IM group at Harvard Forest to make critical upgrades to computer and network infrastructure in recent years. As a result, the capabilities have been greatly enhanced to support ongoing research through improved networking, data archiving, and online access to data. Additional opportunities for web development and interactive capabilities are now possible with the web server on site.

Harvard Forest online metadata includes a subset structured in Ecological Metadata Language (EML), which marks a goal set by all LTER sites to facilitate machine queries, intersite collaboration, and synthesis activities. This speaks highly of the recent efforts of the information management team to supplement existing metadata and covert it to the new EML standard in such a timely fashion. More than 100 data sets have been formatted in EML and are now online from the Harvard Forest web site. Most of these data sets are available as ASCII files, making them useable on all platforms. Those data not yet available for release to a broader scientific audience are flagged and justified, e.g., a manuscript in preparation or a new project of less than 2 years.

To achieve a high level of network security Information Managers maintain both antivirus and software patch updates to servers and all linked workstations. There is strict access control, enforced through password protection and user rights. To further protect data, computer servers are backed up with well-structured, standardized protocols using incremental backup daily, full weekly backups, and retention of files for the previous 3 months. Yearly CD backups are made of the web server where online data are maintained.

The Harvard Forest IM group has defined short- and long-term goals that will, we believe, add significantly to the long-term integrity, accessibility, and usability of the data.

Short-Term Goals:

1. Formalize the procedure for updating data and metadata update by having IM make direct requests annually to all investigators with active data sets.
2. Import selected offsite datasets currently maintained online at other institutions to ensure consistency in structure and metadata, increase flexibility in utilization of XML and EML-based tools, and provide site-consistent security and archival procedures.
3. Create cross-index catalogs to document all available archived data sets and LTER related publications.

Long-Term Goals:

1. Develop a management strategy for accessing data for special query and synthesis. This might involve shifting from EML and flat files to relational databases.
2. Develop dynamic capability (e.g., web services) to facilitate accessing online data and metadata locally, off-site, and cross-site.
3. Extend wireless network to field sites to allow real-time or near real-time data availability and checks on instrumentation and data quality.

Suggestions:

At Harvard forest an increasing amount of remotely sensed data is accumulating. We suggest that these digital images be fully registered into a GIS format and referenced with IMS to increase opportunities for synthesis and expanded use through web interfaces by investigators.

Harvard Forest LTER's goal to expand regional cross-site interactions will bring additional problems because other LTER sites have data stored in a variety of forms, in different units, and operate in dissimilar modes. Although EML can accommodate some of these incompatibilities, we believe that additional resources will be needed to develop the full suite of tools to establish a modular, flexible, generic system that can be utilized on multiple platforms by different Information Management Systems.

Current and New thrusts of LTER research

Examining the role of historic land-use patterns in regulating ecosystem structure and function is the primary emphasis of the most recent LTER III proposal. Researchers at Harvard Forest have done a great job in documenting past land-use patterns, both locally and regionally, and are now poised to take the next step of linking these patterns, using a more quantitative and predictive framework that should lend itself to hypothesis testing. Carefully designed experiments will likely be required to define these linkages. Development of a coherent framework for making advances is the most significant challenge facing Harvard Forest during LTER III, but success at this venture could represent the most important contribution to advancing the science.

We were introduced to three other major projects on which considerable resources have, or are likely soon to be committed. These include aquatic studies at Bigelow Brook, the impact of hemlock wooly adelgid on New England ecosystems, and studies of invasive plants.

Suggestions

We believe that specific hypotheses are required before large data sets are accumulated. In some cases, integrated models are available, as is the case for predicting water flow through basins. In other cases, such as the outbreak of hemlock wooly adelgid, a historical perspective might be added. One might hypothesize that the susceptibility of hemlock forests in the eastern US is greater than elsewhere because of chronic atmospheric additions of N coupled with climatic warming. Hemlock generally grows on N-deficient sites and thus rarely exhibits high levels of free amino acids in their phloem sap stream, from which adelgids attain their nourishment. Julian Hadley also showed us that summer temperatures are well above optimum for hemlock photosynthesis at Harvard Forest. Based on such a hypothesis, hemlock growing on north slopes and calcium-rich substrates, away from the heavy atmospheric N deposition, might be highly resistant to adelgids whereas the opposite situation would be high susceptible to the insects. Opportunities for long-term experiments would also be possible, in line with the heritage of Harvard Forest. Geographic variation (e.g., comparisons along the entire Appalachian chain) in hemlock response to adelgids may provide additional opportunities for testing such hypotheses. In this regard, we encourage and support collaborative efforts (such as with Coweeta) already underway.

Summary

The Harvard Forest LTER researchers have done an excellent job of identifying cutting edge topics related to carbon and nitrogen cycling. These include the long-term patterns of ecosystem C fluxes, the impacts of disturbances such as atmospheric N-deposition and global warming, and more recently, the importance of historic land-use patterns on biogeochemical cycling. Continuing to collect and refine the eddy flux data should be a very high priority. The emphasis should also be maintained on developing modeling approaches for scaling up physiological measurements from individual plants to the ecosystem level. The manipulative experiments utilizing stand-level plots are a strength of HF-LTER. The DIRT, soil warming, hurricane blowdown and N-saturation studies examine extremely important issues related to the effects of disturbance on ecosystem structure and processes, such as N retention and release, feedbacks between C-inputs and N-availability, and nutrient regulation of NPP. In future work, a focus should be placed on appropriate process level measurements, specifically those designed to elucidate mechanisms for ecosystem-level responses to disturbances, rather than simply documenting ecosystem responses. Involvement of paleobotanist, anthropologist, forest policy experts, remote sensors, and technical advances in data management should expand the cadre of students involved in ecosystem research and increase opportunities to contribute to policy decision at the regional, national, and global level. To this end, the vision to expand LTER linkages to other sites in New England is most appropriate. The committee feels that the HF LTER program has met or exceeded most of the objectives set forth by NSF. We hope that our comments will be taken constructively, as they are offered in the spirit to perpetuate the fine tradition that Harvard Forest has established in expanding our understanding and application of ecosystem p rinciples.

Respectfully,

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Norm Christensen; Duke University
John Stark; Utah State University
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