Ecological Patterns and Consequences of Catastrophic Mortality of a Foundation Species due to Abrupt Climatic and Biotic Stresses

An Update on Harvard Forest Research – March 2010

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The Harvard Forest LTER is an integrated program investigating forest response to natural and human disturbance and environmental change over broad temporal and spatial scales. LTER IV extends intensive studies of primary physical drivers of forest change at a single site or landscape to a comprehensive analysis of primary and secondary forces and responses operating across the entire New England region. This larger focus requires a greater emphasis on the biological components of landscape change such as invasive species and pathogens and the contributions of individual taxa to ecosystem processes. In this proposal we request funds to conduct a rapid response study of massive oak decline on the southern New England coast. This work will be integrated with ongoing studies of hemlock and beech decline across New England and will address the scientific and management challenges associated with loss of a foundation species.

Project Summary. Arguably one of the most pressing tasks facing scientists, policymakers and land managers is to develop the ecological understanding and management tools to address species declines in response to the multiple stresses presented by climate change interacting with increasing human and natural disturbance, including pest and pathogen outbreaks. The Harvard Forest LTER program, with many academic partners and policy-relevant NGOs and agencies, has developed a theoretical, experimental, observational and modeling framework to address these science and management challenges[5]. This integrated effort is focused on historic and modern dynamics of three foundation tree taxa in the eastern U.S – hemlock, oak, and beech– and involves coordinated paleoecological and regional studies, large experimental manipulations, and long-term measurements of microbial, population, community, and ecosystem processes[6, 12, 15].

The catastrophic 2008-09 and ongoing mortality of oak canopies across coastal New England following severe drought and multiple insect defoliations requires immediate attention. We seek to integrate this massive episode of oak decline into our existing LTER research and management framework by advancing four pressing and time-sensitive activities: (1) measurement of environmental, ecosystem, and biotic responses in disturbed and control plots; (2) dendrochronological studies of dead and dying trees to assess age structure, trajectories of the recent decline, and past disturbance; (3) remote sensing and collection of dispersed entomological, commercial, and environmental records to reconstruct and interpret the spatio-temporal patterns and controls of the outbreaks, defoliations, and tree declines and mortalities; and (4) extensive ongoing engagement with relevant managers, policy makers and the public. The effort will: capitalize on and advance NSF-funded activities including Ecosystem, LTER and Site

REU grants; leverage major resources and personnel from partner agencies and organizations; utilize the extraordinary conservation and management entities on the coast as well as great media and public interest in oak mortality to disseminate science and management information, and; become an integral part of the HFR LTER program.

Intellectual Merit. Experimental, observational and theoretical studies indicate that (i) disturbance generally involves complex interactions among multiple agents and (ii) climate change often triggers rapid responses through extreme events that interact with other stressors[6,12,15]. Consequently, it is likely that future changes in biological systems under a changing climate will not occur gradually. Species and ecosystems will respond abruptly and episodically as stressed organisms and systems are disturbed by human activity, unusual climatic events, and multiple biotic factors including pests and pathogens[1, 14]. Paleoecological studies corroborate this interpretation (Fig. 1). Although the broad post-glacial pattern is one of ongoing change, high resolution records reveal episodic population collapse and reorganization of biotic assemblages associated with moisture or temperature extremes [13, 17, 18]. In the most widely recognized event, the mid-Holocene hemlock decline, it appears that climatic stress was reinforced by defoliating insects and extreme droughts[1].

Forest and partner scientists have advanced a conceptual and research framework for understanding the cause and consequences of declines in foundation taxa that disproportionately control forest ecosystem pattern and process (Table 1)[6]. This work capitalizes on parallels between Holocene and recent histories of two dominant taxa: hemlock (replaced by birch, maple, pine), and oak (replaced by beech and other species)[2,3,8].

Time-critical Research Need and Response. Beginning in 2005, successive annual outbreaks of native and introduced insects (fall cankerworm and winter moth; gypsy moth, eastern tent caterpillar, and forest tent caterpillar) defoliated oaks across New England's southeastern coast. The 2008 defoliation was followed by an extended drought that led to widespread oak mortality across Martha's Vineyard and adjoining Cape Cod. Ground surveys and aerial flights each summer documented the broad pattern of defoliation and, in June 2009, confirmed the broad mortality of forest canopies across multiple hundred-hectare blocks (Fig. 2). There is an urgent need for immediate studies to: document the early phases of environmental and ecosystem response; archive samples of soils, wood, tree chronologies; capture data from transient organic materials, especially tree stems; collect observations and records from contractors, scientists and pest-control specialists and arborists; and obtain high resolution aerial photographs to complement remote sensing interpretations of defoliation and mortality. To initiate this research effort, in June 2009 PI Foster, collaborators, and two REU students: obtained more than 300 rectified aerial images; coordinated more than ten collaborating organizations and agencies; acquired all necessary permissions for long-term studies; and sampled the soils and vegetation across the area of heaviest canopy loss in twenty 400 m^2 plots (Fig. 3).

Proposed Studies. To investigate this time-sensitive natural experiment and initiate a long-term study that fits our research structure on hemlock and oak we propose a series of immediate activities. (i) *Ecological and Environmental Sampling to Assess Species, Community, and Ecosystem Responses*. Based on available and proposed aerial imagery, remote sensing, field studies, and documentary information, five 400 m^2 plots will be established in each of the following: 90-100% canopy mortality; 25-75% mortality; oak controls with no mortality and beech controls with no mortality. In each plot the following will be undertaken: complete vegetation census of vascular species using standard HF protocols; organic and mineral soils sampled in two locations; soil nitrogen availability (NO_3^- and NH_4^+) assessed with incubated resin bags; environmental measurements taken using I-button data loggers; monitoring of populations of defoliating insects and keystone soil invertebrates (ants and beetles). (ii) *Dendrochronological Analyses of Individual and Community Histories*. Tree ages and growth chronologies will be determined from ten randomly selected trees in each plot. Cores will be dried, mounted, aged, and measured using a Velmex tree-ring measuring system to develop ages for individual trees, age structures for plots and radial growth histories of prior disturbance and the current decline. (iii) *Remote Sensing, Regional Data Assembly and Spatial Analyses*. To characterize and interpret the distinctive pathways of forest change initiated by these multiple disturbances that reshaped the coastal landscape, we will conduct a trajectory-based change detection analysis of spectral reflectance at 30-m resolution using a dense temporal stack of Landsat Thematic Mapper imagery[21] from 1994 (ten years before the first outbreak) to 2009. Each forested pixel will be classified according to the best-fit model describing key aspects of the disturbance history including timing and intensity of defoliations, year of death and pattern of recovery. Satellite imagery will be supported by ground surveys, extensive historical aerial imagery and new aerial imagery rectified to GIS. Emerging patterns will be interpreted in relation to spatial layers of biophysical factors and information on each historical outbreak, collected from collaborating scientists, NGOs, public agencies, and contractors (insect control, arboriculture, landscaping firms). (iv) *Integrated Analysis*. The patterns of mortality, response and reassembly will be interpreted at site, landscape, and regional levels and integrated into the emerging understanding of the drivers and consequences of foundation species loss under a changing environment. Through collaboration with partner groups and landowners the permanent plots will be maintained to provide ongoing insights and expanded as necessary to assess new episodes of change.

Broader Impacts. The Harvard Forest group has an extensive history of collaborative work on the coast[2,3,4,10,16]. This new effort is closely designed with local to national research and management partners from public and private realms (e.g., municipalities, regional land commission; state agencies, pest control and extension; coastal, state-wide and national conservation organizations) to ensure that it will directly inform immediate and long-term management and policy concerns. To further disseminate information one partner organization has agreed to host a one-day regional conference and workshop on the decline that will integrate historical and scientific perspectives; conservation and health issues; management options; and future perspectives. Local and regional news media that have shown great interest in this episode and our work will be invited and summaries of each session will be made available through Harvard Forest and partner web sites and publications. The effort will integrate training of undergraduates, graduate students, and staff of partner groups and will reach out extensively to landowners.

Table 1. The integrated approach developed by Harvard Forest researchers and collaborators to study the pattern and consequences of the decline of foundation species in northeastern forests due to the interacting effects of climate change, disturbance and environmental stressors. The requested NSF Rapid Funds would complete this research template (shaded box) by supporting intensive, long-term study of the recent catastrophic mortality of oak forests across the southeastern coast of New England.

Approach	**Oak Species**	**Eastern Hemlock**
Paleoecological Studies	**Oak Decline: Beech Increase 5-3000 yrs B.P** Climate Change X Severe Droughts X ??? Cape Cod and Coastal Islands NSF Ecosystems	**Hemlock Decline: Birch/Pine Increase 5-3000 yrs B.P.** Climate Change X Severe Drought X Insects Eastern North America (Hemlock Range) NSF Ecosystems
Site to Regional Long-term Studies	**Oak Decline: Beech Increase 2005 –** Multiple Insects X Drought Martha's Vineyard - Cape Cod ***NSF - THIS PROPOSAL***; NSF REU Site	**Hemlock Decline: Black Birch Increase 1985 –** Hemlock Woolly Adelgid Southern New England – S Appalachians NSF Ecosystems & LTER (HFR, CWT); USDA
Large Experimental Manipulations	**Oak Removal 2007 –** Girdling Black Rock Forest – Cornwall, NY BRF Consortium	**Hemlock Removal and Harvest 2004 –** Girdling or Commercial Harvest Harvard Forest - Petersham, MA NSF LTER and REU Site; Harvard Forest

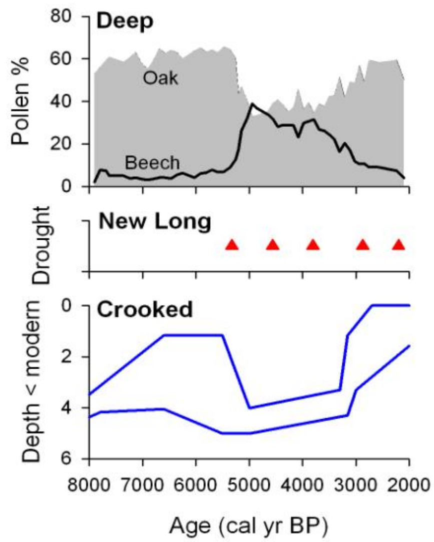

Figure 1. Paleoecological record of the collapse of oak populations and replacement by beech 5-3000 yrs B.P. in Falmouth, MA approximately 30 km from the area of heaviest oak mortality in 2008. Evidence from Crooked Lake and New Long Lake, MA indicates

Figure 2. Following four years of defoliation and mortality to oak forests an extended mid-summer drought initiated widespread mortality of forest canopies across the southeastern coast, with a concentration on Martha's Vineyard (top, oblique aerial photograph) and adjoining Cape Cod. Mortality was concentrated in oak species, with some apparent variation in susceptibility by size and species (lower photo along the border of the natural areas of the Polly Hill Arboretum and Newhall Woods Preserve (TNC). Where present beech survived in the canopy and understory and will apparently dominate the forest locally. Photos June 2009 – D.R. Foster.

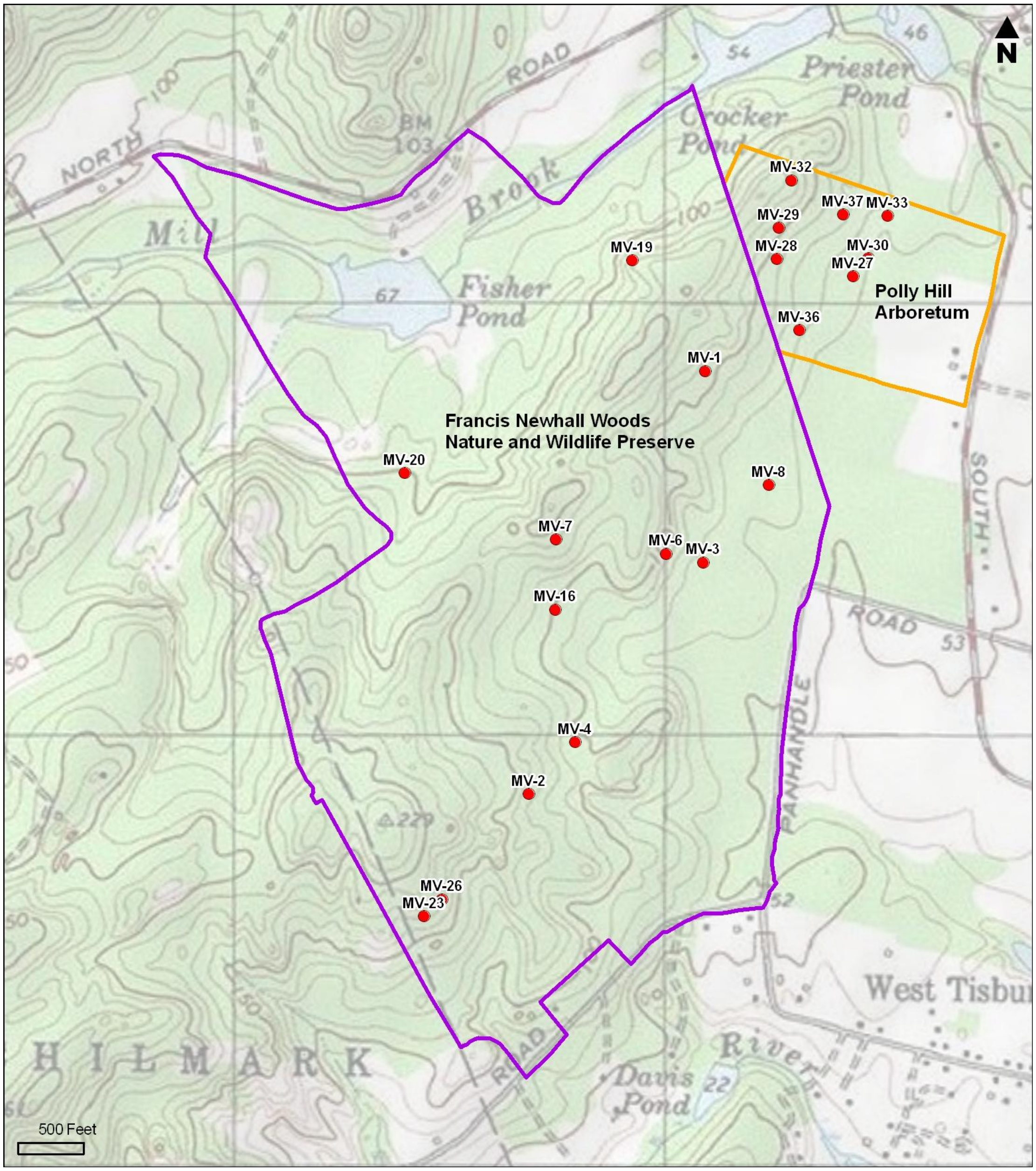

Figure 3. Vegetation sampling plots on the Francis Newhall Woods Nature and Wildlife Preserve (purple outline) and adjacent Polly Hill Arboretum (orange outline) set up by Harvard Forest researchers in the summer of 2009. Each plot measures 20 meters square and is marked in each corner with a 1.5 inch-diameter pipe protruding 12-18 inches above the ground.

For more information please contact David Foster or Brian Hall at the Harvard Forest (978-724-3302).