WILDLANDS AND WOODLANDS SCIENCE

LONG-TERM FOREST MEASUREMENTS FOR ECOLOGICAL AND CONSERVATION INSIGHTS

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Highstead

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The *Wildlands and Woodlands* (W&W) vision calls for the permanent protection of 70% of New England in forest to provide natural infrastructure for society in the face of a rapidly changing environment (Foster et al. 2005, 2010). Within this expansive forest area, two broad management categories are proposed. ***Woodlands***, which would predominate, are actively managed for diverse resources and values including wood products, energy, water, wildlife habitat, biodiversity, recreation, carbon sequestration, and aesthetics. ***Wildlands*** would comprise approximately 10% of the forest area in large blocks free from direct human manipulation and allowed to develop in response to prevailing environmental conditions, including disturbances such as wind, ice, drought, pest and pathogen attack, and herbivory (see Box 1, *the Wildlands and Woodlands* vision). While Wildlands may encompass patches of remaining old growth forest and other unusual natural features, their primary purpose is to allow large expanses of locally or regionally common forest types to develop without direct human interference.

Over 95% of New England's forested landscape has been cut one or more times for timber, agriculture, and development, leaving our current forests typically young (i.e., <100 years old), structurally simple, and carbon-poor (O'Keefe and Foster 1998, Hall et al. 2002). Consequently, many of the areas initially designated as Wildland reserves or managed Woodlands would be fairly similar and dominated by maturing second-growth forests. Through time, however, and as a consequence of their varied management, Wildlands and Woodlands would diverge in age, structure, composition, ecological processes, and habitat qualities (Foster 1999, 2001).

Given these anticipated changes, a number of questions arise: How will we document and understand the progressive changes in Wildlands and Woodlands? How will we evaluate the effectiveness and sustainability of our management and harvesting of Woodlands? What lessons regarding natural processes and environmental change will emerge for large forest reserves free from direct human impacts? Such questions have been posed by leading conservationists and ecologists like Henry Thoreau, Robert Marshall, and Aldo Leopold for over 150 years. These visionary thinkers stressed the need for careful comparisons of actively managed and wild areas as a critical part of successful land management. Yet, despite this insight few forests are or have been managed based on such a comparative approach.

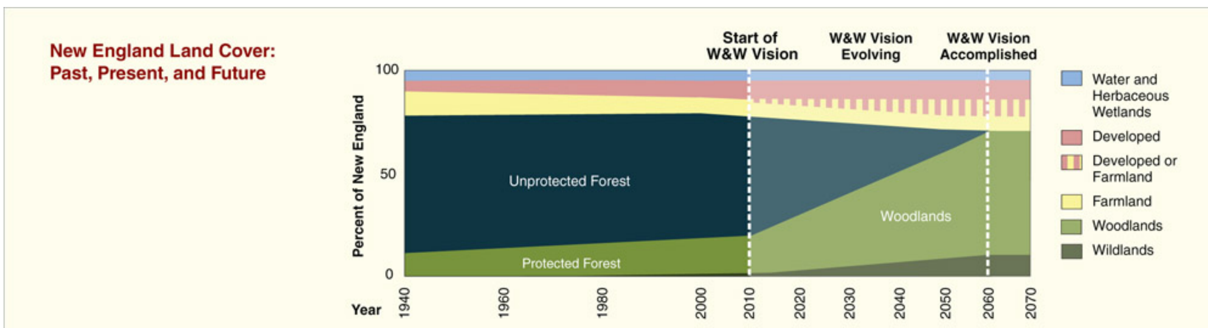
Many reasons account for the sporadic use of comparative studies of Wildlands and Woodlands including cost, lack of long-term commitment and loss of long-term data, lack of interest by scientists, and the perceived lack of technical expertise among landowners (Holck 2008, Lindenmayer and Likens 2010). W&W Stewardship Science seeks to address these issues and seize a great opportunity to learn from nature and active management by creating a program of forest measurement that is simple, flexible, broadly applicable and yet scientifically rigorous. The W&W Stewardship Science program acknowledges and draws from the strengths of several existing forest monitoring programs (e.g., the USDA Forest Service, the National Park Service, Naturserve, Maine Natural Areas Program, and the state of Massachusetts). Yet W&W Stewardship Science also aims to be suitable and available for landowners of any type and technical expertise – from scientist and amateur naturalist to wilderness organization and timber products company – who seek to understand how forests are changing and manage their land in an informed way. If widely adopted, the cumulative result will be more comprehensive understanding and more thoughtful management of forests at a regional scale. This is the ultimate goal of the W&W Stewardship Science Program.

Box 1. **The Wildlands and Woodlands Vision at a Glance**

The *Wildlands and Woodlands* vision (Foster et al. 2010) calls for a 50-year conservation effort to retain at least 70 percent of New England in forestland, permanently free from development. This vision would conserve 30 million acres of New England's existing 33 million acres of trees, waters, and wetlands for current and future generations

- 90% of forests would be "Woodlands," conserved by willing landowners and sustainably managed for multiple uses, from recreation to wood products.
- 10% of forests would be "Wildland" reserves, identified by local communities and shaped only by the natural environment.

Together with farms and preserved open space, the natural infrastructure conserved by Wildlands and Woodlands would support thriving and sustainable communities with a balance of well-managed forests and protected special places.



Data from Foster et al. (2010).

The Opportunity for Ecological and Conservation Science

Forest dynamics from natural disturbance, climate change, and human activity have characterized the New England landscape for millennia (Foster et al. 2004); however, recent human activity has initiated unprecedented rates and magnitude of change. Hence, there is a compelling need to evaluate long-term shifts in the growth and composition of our forests resulting from the interplay of natural processes and human activity (Mladenoff et al. 1993, Foster et al. 1996, 1997, Orwig et al. 2002, Ollinger et al. 2004). The study of Wildlands and Woodlands will yield at least two major benefits to ecological science, conservation and natural resource management: (1) an evaluation of changes generated through active management and (2) an improved understanding of natural processes and dynamics in our forests,

Evaluating and Interpreting Changes from Active Management

Comparative studies of Wildlands and Woodlands create good opportunities for evaluating conservation and forest management that seek to (1) promote specific species, assemblages or structural features; (2) enhance ecosystem services such as carbon sequestration and water production; (3) yield biomass, quality timber, or other products; (4) confer resistance and resiliency against contemporary environmental disturbances and stressors such as elevated CO_2 levels; increased frequency of storm events; shifts in wildlife populations; and the introduction of plants, pests, and pathogens (cf. Aber et al. 2000). Basic questions can be addressed. Did different treatments yield different results? Did the applied treatment yield the desired result? What would have been the result if no treatment was applied? Such information is critical for adaptive management.

Wildland reserves serve as an important reference for assessing the consequences and effectiveness of management (Seymour and Hunter 1992, Peterken 1996, Aber et al. 2000, Foreman and Daly 2000, Anonymous 2003, Pennsylvania DCR 2003). For example, in 1925, when Robert Marshall, future founder of the Wilderness Society and then a Forest Service employee, was tasked with developing a management proposal for the Selway-Bitterroot Forest in Montana he recommended "one thousand acres [be] set aside as a reserve and control against which we can measure the effects of activities on all of the surrounding area." A comparison of the structure and composition of managed forests versus reserves can provide a clear assessment of the impact of diverse management practices.

The Study of Natural Processes and Indirect Consequences of Human Activity

In New England and across the eastern U.S., there is an intriguing opportunity to evaluate how forests recover from centuries of intensive land use (Motzkin and Foster 2004, Motzkin et al. 2004). New England has reforested over the past 150 years as agriculture declined and farmland was abandoned, providing a remarkable natural laboratory to study processes that are fundamental to ecology and conservation: the movement and arrival of species, the continual reshaping of natural communities, and the dynamic interplay between novel processes and old conditions (Foster et al. 1998, Aber et al. 2000). The study of these processes is best undertaken in Wildland reserves that are free from recent human land use.

Some major questions include:

- How persistent are the historical legacies of past land use (e.g., deforestation, grazing, plowing, burning, logging, planting) and natural disturbances such as the 1938 hurricane, ice storms, pest and pathogen outbreaks?[1]
- How do natural forest processes recover after centuries of intensive human impact? How long do forests mature towards a "steady state" condition? (Box 2).
- As forests age, what changes occur in population processes (e.g., recruitment, regeneration, growth, migration, local extinction), community properties (e.g., diversity, composition, structure, and succession) and ecosystem processes (e.g., nutrient cycling, productivity, water and energy flow). How are these various processes linked and how do they vary across different sites, forests, and landscapes with different histories?

[1] Studies demonstrate strong persistent effects from this history that may linger for centuries or longer. Nonetheless, despite the ubiquity of these legacies in forests across the globe, there is essentially no rigorous information concerning the duration of these historical legacies and no studies that carefully document their changing importance over time (cf. Foster et al. 1998).

Box 2. **“Steady State” Forests and Climate Change**

Understanding the pace and ways that forests approach a “steady state” condition lie at the heart of many classic studies by Odum (1969), Vitousek and Reiners (1975), and Bormann and Likens (1979) and have great relevance to modern concerns of global change, carbon sequestration and forest management. Remarkably, many questions remain unanswered (cf. Wofsy 2004; Aber et al. 2001). Across most of eastern North America forests are, on the whole, growing faster than they are being harvested; consequently many stands and the region are accumulating biomass and storing carbon (Keeton et al. 2011). At a sub-continental scale this process is large enough to significantly offset the atmospheric rise in carbon dioxide, a major greenhouse gas (Munger et al. 2004). The future of this process and its ability to mitigate climate change will depend on a few factors: whether forests are protected from development; the way they are managed; and their recovery from past and future impacts (Wofsy et al. 2001). Thus, there is great value in documenting the dynamics in maturing forests and understanding how long this will continue in forests on different sites with different histories (Foster and Aber 2004).

A Surprising Dearth of Long-term Studies of Reserves and Managed Forests

Despite agreement over the need for assessment of management and the value of Wildland reserves as controls and natural experiments, comparative studies of Wildlands and Woodlands are notably erratic and spotty for most forest and conservation management activities, including restoration, habitat improvement, invasive species removal, and biodiversity stewardship. There are many reasons for the lack of rigorous science in management and conservation:

- **Misperception of the required expertise**. There is a misconception among landowning organizations and individuals that measuring change in forest ecosystems requires highly trained personnel and a sophisticated and complex protocol. Yet, a rigorous long-term study can be accomplished through simple methods applied by individuals with modest training as long as a consistent protocol and relatively simple methods are used (Holck 2008).

- **Lack of sustained funding**. Sustained long-term studies can be expensive (cf. Caughlan and Oakley 2001). Ecologically meaningful studies should continue for decades or longer, which is a challenge for public and private groups. It is often easier to apply resources to conserving new forests or administering and managing existing reserves.

- **Lack of commitment to science**. The personal or institutional commitment to science on reserves is often limited even by groups described as "science-based." Where scientific commitment does exist, it is generally applied to the design of conservation plans, the development and application of management activities, or the evaluation of policy rather than rigorous evaluation of whether such plans, management or policies yield desired results over time (Sutherland and Hill 1995).

- **Lack of scientific interest.** Monitoring, separate from well-conceived and hypothesis-driven experimental design, is not a high priority for most scientists. Little public funding is available to maintain the repeated measurements that are necessary for long-term, research-based analyses. Scientific funding for such efforts necessarily needs to address compelling basic research questions and must usually be supported through a series of typically short-term (three to five years) research grants. Fortunately, research programs such as the Long-Term Research in Environmental Biology (LTREB) and Long-Term Ecological Research (LTER) programs sponsored by the National Science Foundation offer limited support for such efforts once they are established.

A Simple and Effective Protocol for Long-term Measurements of Change in Forest Structure, Composition, and Environment

A research framework to study important long-term changes in Wildlands and Woodlands need not be complex. Many answers to the questions posed above and critical insights into the effectiveness of management activities can emerge from a simple suite of repeated measurements from permanently marked forest plots in reserves and/or actively managed areas. In a short time (e.g., five to ten years) even a small number of plots can yield rich data and insights into an intriguing array of issues including tree and forest growth rates, changes in canopy and subcanopy tree abundance, and the arrival of invasive species. A suite of permanent forest plots also provides a platform for additional studies on a wide range of organisms, processes, and questions.

The first step in a successful monitoring program is to develop well-defined objectives (Silsbee and Peterson 1993; Stout 1993; Olsen et al. 1999; Vos et al. 2001, Sutherland and Hill 1995). Clearly articulated goals help focus the work (Vos et al. 2001); identify the appropriate sampling design, intensity, and frequency (see below); and allow the success or outcome of monitoring to be evaluated at a later date. Although no sampling protocol can meet all of the potential objectives that different landowners, resource managers, and researchers may wish to address in their forests, we propose a general sampling approach for documenting long-term changes based on the following goals.

1. To yield an initial understanding of forest composition and structure that will allow comparisons among Wildlands and Woodlands in the landscape and through time.

2. To facilitate the detection and analysis of long-term changes in Wildlands and Woodlands.

3. To use methods that are readily adoptable by anyone knowledgeable of the local flora.

4. To offer a platform for additional studies of organisms, processes or the environment that may easily be adapted to address site-specific concerns and objectives.

5. To encourage and promote the sharing of data, insights, and comparisons across sites, forest types and regions.

Sampling strategy

Since the *Wildlands and Woodlands* vision is forest-based, we focus primarily on the monitoring of vegetation composition and structure in forested sites. We encourage the development of comparative studies between Wildland reserves and managed Woodlands whenever feasible in order to take advantage of the scientific and adaptive management benefits of studying both management types (see *Evaluating and Interpreting Changes from Active Management* above). Questions that pertain to fundamental ecological processes and the recovery of forests from past land use can be addressed by the study of Wildland reserves (see *The Study of Natural Processes and Indirect Consequences of Human Activity* above). In order to be most useful, the proposed methods and system must be: (1) simple, so that diverse researchers and land managers can apply the protocols in a consistent manner over time; (2) applied consistently over time; (3) relatively inexpensive, so that there is a strong likelihood of continued study; (4) permanent and accessible, so that measurements can be continued easily in the future, even if the plots are abandoned for some period of time (Silsbee and Peterson 1993; Scott 1998; Caughlan and Oakley 2001); and (5) robust yet flexible to accommodate other monitoring efforts, detailed studies and unforeseen questions in the future.

Number, size and location of plots

The appropriate sample size will depend on (1) the specific objectives of the monitoring effort, (2) available time and budget, and (3) the size and variation of the study parcel. In general, the greater the number of plots sampled and the less variation in the data, the greater the ability to detect vegetation differences across a landscape and over time (Gotelli and Ellison 2004). A minimum of two plots should be established in each management category for adequate scientific replication and comparison, although a minimum of five to ten plots in each will provide greater statistical power (Gotelli and Ellison 2004). Plot size should be based on the ecological scale of study and be large enough to characterize and be relevant to the attributes being studied (Scott 1998); however, for the W&W Stewardship Science project we use a standard size of 20 x 20 m (400 m^2).

Comparative plots should be randomly selected either using a stratified or systematic sampling design. For a stratified approach, plots are randomly located with regards to one or more key factors such as forest type, forest age, land-use history, soils or geologic substrate within each management type (Scott 1998; Vos et al. 2000; Eberhardt et al. 2003, DeGasperis and Motzkin 2007). Systematic sampling design in which plots are located at consistent, established intervals along line transects (e.g., one plot every 100 meters) can also be established in each management category or in a study of reserves. Once sample size and plot locations have been determined, permanent plots can be located in the field with a GPS unit. Plots should be marked with iron or PVC pipe at a minimum of three corners with labeled caps (or labeled rebar). Plot sampling frequency should be determined by the original study objectives, the expected rate of change in attributes of interest, and the available funding (Scott 1998). Five-to ten-year intervals are generally adequate for monitoring forest structure and composition in the eastern United States. [For more details on sampling procedures see the *Wildlands and Woodlands Stewardship Science Manual for Long-Term Forest Monitoring*].

Sampling attributes

Within each plot, a set of simple measurements should be recorded to characterize the vegetation composition and structure. Descriptions of site conditions should also be recorded at the time of each sampling, including the management treatment, physical features (e.g., slope, landscape position, aspect), canopy coverage, and signs of human or natural disturbance (pests or pathogens, uprooted or snapped trees, pit/mound topography, stone walls, mammal browsing etc.). In addition, permanent photographic points (i.e., from the same plot corner at each sampling period) are recommended for long-term documentation of stand conditions and change.

We propose a relatively simple system for describing and monitoring forest vegetation over time that combines standard forest measurements with methods widely used throughout the U.S. by state Natural Heritage programs, United States Forest Service crews, the National Park Service, The Nature Conservancy, and NatureServe ecologists to document natural communities (Cutko 2009, Tierney et al. 2009, Forest Inventory and Analysis 2011). At each sampling period we propose the following minimum set of measurements in 20 x 20m plots:

- measure and identify all standing tree and shrub stems (alive and dead) ≥ 2.5 cm diameter at breast height (dbh- 1.37m), by species and dbh, and record tree condition in one of two condition classes (alive or dead)

Depending on the goals of the monitoring project, additional, but optional, measurements can be included:

- **tree seedlings/saplings:** tally and identify all tree seedlings (30 cm to 1.36 m tall) and saplings (≥1.37 m tall and <2.5 cm DBH) within two 5 x 5 meter subplots in two corners of the plot.
- **vascular plant species (shrubs, herbs, dwarf shrubs):** list all species that occur in the 20 x 20 m plot and estimates the abundance of each species in broad percent cover classes (Mueller-Dombois and Ellenberg 1974). Graminoids (grasses, sedges, and rushes) are lumped into one group.
- **cut stumps:** measure the diameter and identify (if possible) all cut stumps in the plot
- **coarse woody debris:** measure pieces of downed wood that are greater than 1.5 m long and greater than 10 cm in diameter within the plot. Measure piece length and the diameters of both ends.

We outline more detailed sampling procedures for sampling trees and other attributes in the *Wildlands and Woodlands Stewardship Science Manual for Long-Term Forest Monitoring*. Landowners may wish to supplement basic vegetation measurements with other monitoring efforts depending on study questions and management goals (see Box 4).

Box 4**. Additional variables that can be measured in established forest plots**

Tree height/Tree age (Wenger 1984)

Soil properties: (cf., Robertson et al. 1999)

- pH
- carbon and nitrogen content
- organic matter content
- additional anion and cation analyses (e.g., calcium content)
- horizon depth
- bulk density
- texture

Large mammals (Kuijper et al. 2009, Silvy 2012)
browsing
pellet counts
track plots
remote camera surveys

Small vertebrates
Amphibians (cf., Mathewson 2009)
Small Mammals (Jenkins et al. 2005)

Invertebrates
Insects (Ellison et al. 2007, Eiseman and Charney 2010)
Earthworms http://greatlakeswormwatch.org/research/methods_worms.html

Bryophytes
mosses, liverworts, hornworts (cf., Cooper-Ellis 1998)

Fungi, lichens, mycorrhizae (cf. Rossman et al 1998)

Data management and quality control

The costs associated with data collection are commonly the most expensive component of long-term monitoring programs (Vos et al. 2001; Caughlan and Oakley 2001). This includes salaries, training, equipment and supplies, travel, and overhead. However, often overlooked are plans and funding for data management needs required for successful long-term efforts (Stafford 1993; Caughlan and Oakley 2001; Vos et al. 2000). The W&W Stewardship Science program offers an online database with analysis techniques for participating landowners interested in sharing their data and accessing other datasets in New England. Hence, costs associated with data management can be reduced for those who submit their datasets to the program.

Wildlands and Woodlands (W&W) Stewardship Science –New England Examples

We highlight five examples (from eight initial locations) where monitoring efforts are being developed to illustrate the range of opportunities for research and the flexibility of the research approach presented here (Fig.1). The areas highlighted range from suburban Connecticut to rural portions of northern New England, from private to public lands, from single ownership to partnerships, and from small-to moderate-sized Wildlands. They also vary in overall objectives and in the status of their long-term measurement activity from those that are well established, to those that are planned or currently under development.

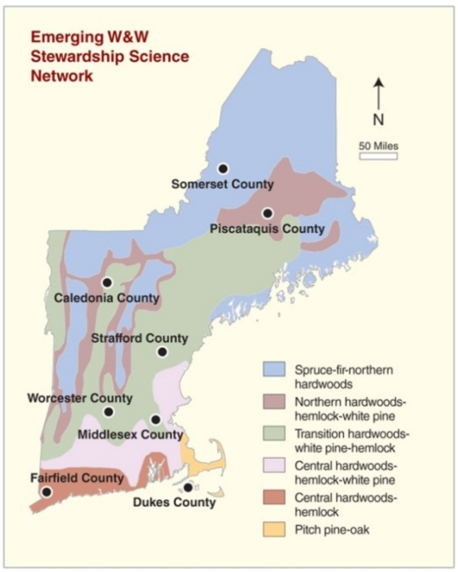


Figure 1. Locations where private landowners and conservation organizations have initiated Wildlands and Woodlands Stewardship Science monitoring programs.

Highstead Fairfield County, CT

In a suburban forest landscape within commuting distance of New York City, Highstead, a small private conservation organization, has initiated a long-term sampling effort based on local and regional collaboration. On about 100+ acres of land, Highstead's holdings and management approach include a small forest reserve (15 acres), 135 acres of protected woodlands, meadows, and a pond embedded in a larger conservation landscape owned by diverse entities: the Redding Land Trust, town of Redding, The Nature Conservancy, State of Connecticut, and private individuals whose property is protected with conservation restrictions (see Fig. 2).

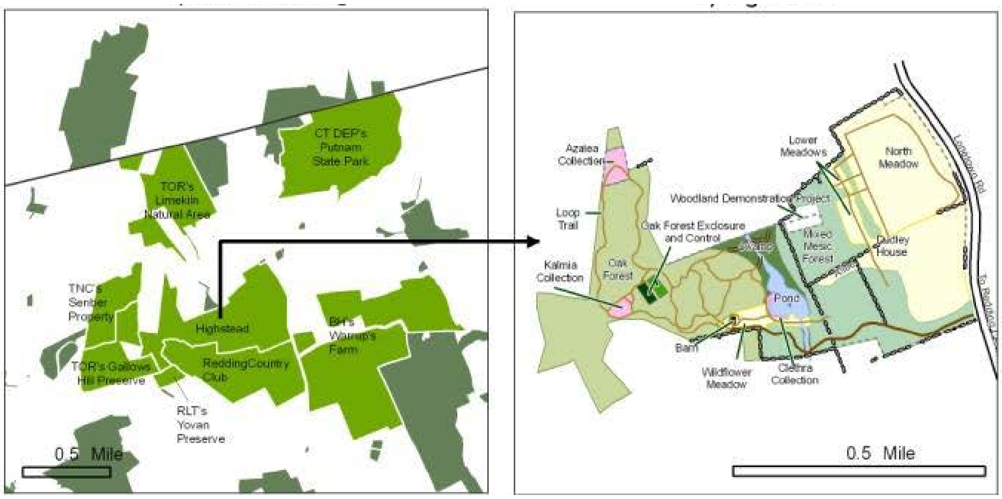


Figure 2. Highstead and its location within a broader conservation landscape in Redding, CT.

The research opportunities seized by Highstead take advantage of a fortuitous conservation history: despite extraordinary land prices and intense development pressure in the greater New York region, more than 30% of the land in the town of Redding is protected from development and buffered by considerable conservation land in adjoining towns. The network of protected land resulted largely from the actions of numerous groups: vision and leadership in early land planning and protection by the Redding Land Trust beginning in the 1960s; development of a far reaching and adaptable Open Space Map and Plan by the town of Redding; establishment of large conservation properties for recreation, water production and species and habitat protection by the State of Connecticut (Putnam State Park, 1887 and Huntington State Park 1930s), Aquarion Water Company/Bridgeport Hydraulic Company (Saugatuck and neighboring Aspetuck Reservoir Lands), and The Nature Conservancy (Devil's Den Preserve); and expansive financial support by the town, State of Connecticut, and many private individuals. This effort received a great boost in the 1990s when The Nature Conservancy, the State of Connecticut, and Aquarion forged a remarkable deal that protected nearly 15,000 acres of land.

Objectives

A Wildlands and Woodlands forest sampling scheme was initiated by Highstead in 2004. The sampling framework was designed to address basic objectives that suited Highstead's role as an emerging ecological and conservation organization seeking to answer regionally important questions and engage a diverse regional community:

- Establish baseline sampling and long-term studies of natural plant communities that would provide a framework to support and attract other researchers and studies of plants, insects, wildlife and ecological processes.
- Evaluate modern vegetation variation and future dynamics with regards to the past history of land use and environmental conditions, especially the highly varied physiography and soils.
- Measure the intensity and impact of deer browsing in relation to variation in vegetation type and hunting pressure.

- Assess the current state and monitor future changes in populations of invasive exotic plant species.
- Capture these data in a way to best highlight the striking landscape patterns in vegetation, physiography, and land use.
- Expand beyond the limited land base of Highstead by sampling adjoining properties in order to capture regional variation in forest vegetation and environments.

Approach

The selected sampling design broadly follows the plot-based protocol suggested in this paper and is arrayed to cover the diversity of forested habitats. However, in order to provide a compelling representation of the vegetation patterns that emerge from the property's contrasting physiography of drumlins and bedrock hills, Highstead ecologists chose to array their plots in a systematic grid covering all forest areas. The original grid was professionally surveyed and was then extended by Highstead staff across adjoining and more distant ownerships using a Geographic Information System and Geographical Positioning System. A total of 100 plots have now been established and permanently marked with metal pipe across 90 acres at Highstead, and an additional 110 plots have been established across 180 km^2 on 12 other ownerships. The plan is to resample these plots every five-to ten-years.

The sampling effort is funded by Highstead and coordinated by its staff with fieldwork undertaken largely by undergraduates as part of an annual internship program. Data management, analyses, and publications are undertaken by Highstead with all data and results freely available to all participants. Data will also be made accessible to the broader community in a timely fashion on the Highstead webpage and the W&W online database. Long-term studies on other properties are conducted through formal agreement with the respective landowners. Although there is active communication and collaboration among groups, there is no active coordination of management and the different landowners have contrasting objectives, approaches and policies regarding harvesting, hunting, and public access and use.

Early Results

The Highstead plots were resampled for the first time in 2009 after five years and reveal the rate of change that can take place in suburban forests exposed to a suite of human disturbances and development in the surrounding landscape. The most striking early results are related to the expansion of invasive exotic plants. Japanese stilt grass (*Microstegium vimineum*) – an aggressive invader from the south that can tolerate low light levels and form monocultures on the forest floor (Baiser et al. 2008) – was absent in Highstead's woodland in 2004, but invaded many plots by 2009 (Fig. 3). Another invasive species, oriental bittersweet (*Celastrus orbiculatus*) was already well established in Highstead's woodland in 2004, but had spread to nine new plots in 2004. Garlic mustard (*Alliaria petiolata*) was also common in the 2004 sample, but had only spread to four new plots in 2009. Bittersweet and garlic mustard generally invaded plots close to foot paths and along Highstead's border near residential development. These changes demonstrate the dynamics common in suburban forests and the potential pitfalls of creating trails for visitor access. Trails can act as conduits for human dispersal of seeds and provide the soil disturbance necessary for invasive plants to colonize new areas. Highstead has subsequently retired one of its trails and is evaluating the necessity of a few others.

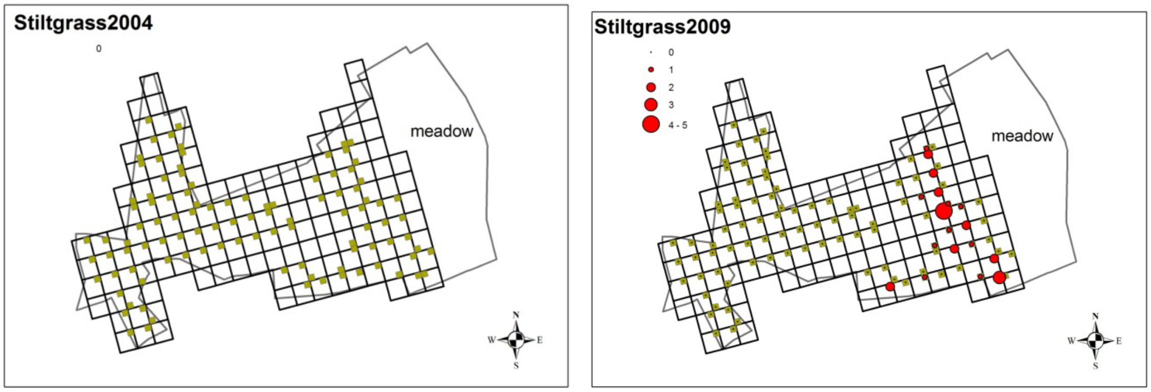


Figure 3. Comparison of the invasive Japanese stilt grass (*Microstegium vimineum*) abundance in 2004 and 2009 at Highstead in southwestern CT. Stilt grass was absent in 2004 and invaded many sample plots by 2009. Size of red circle is proportional to stilt grass abundance in each plot. Numbers next to red circles are cover classes that correspond with estimates of the percentage of each plot covered by this species.

Blue Hills Foundation Strafford County, NH

Situated in rural southern New Hampshire in a heavily forested landscape that is coming under increasing pressure for housing development, Blue Hills Foundation (BHF) presents an intriguing model of Wildlands and Woodlands thinking based largely on a single ownership. The Foundation was established in the 1970s to continue a land protection and stewardship effort initiated in the 1930s by a Boston-based family with strong ties to the forest and farmscape of southern New Hampshire. Its land holdings now total nearly 7,000 acres, largely protected from development with conservation restrictions held by the New England Forestry Foundation and Society for the Protection of New Hampshire Forests. The area is dominated by diverse hardwood and softwood forests that have been under long-term management that includes regular timber stand improvement and harvesting activity. Ecologically, the land is intriguing due to its large size and single ownership, diverse array of forest types that range from white pine and hemlock to spruce, fir and oak to northern hardwoods, large agricultural fields, extensive streams, ponds, and wetlands, and a large extent of native red pine forest. BHF is uniquely poised to contrast the long-term changes between high-quality silviculture and unmanaged reserves across diverse forest types.

Perhaps the most unusual and valuable asset of the BHF property is the extraordinarily detailed and comprehensive database on the land’s cultural history, including ownership, tax valuations, land use, artifacts, and vegetation history. Given its size and the fact that it encompasses numerous abandoned farmsteads, small industrial sites, cemeteries, etc., the land provides an extraordinary opportunity to examine the influence of land use history on forest development and dynamics, as well as a compelling landscape on which to teach and demonstrate these relationships to a broad audience.

Objectives

As Blue Hills Foundation looks to the future it has three main objectives: (1) to increase the conservation value of its land protection efforts by acquiring additional lands and by forging landscape linkages with other conserved land in the surrounding region; (2) to continue diversified long-term stewardship for timber, biodiversity, and human values under a management plan that identifies managed woodlands, Wildland reserves, and supporting natural areas; and (3) to expand the opportunities for research, education and passive human enjoyment of the lands.

To further these objectives BHF is finalizing the mapping of management areas across this property (managed Woodlands, habitat management areas, agricultural fields, protected wetlands, pond shores and riparian areas, and Wildland reserves) and is implementing a research plan focused on the measurement of long-term changes under contrasting management regimes. The primary motivations for the monitoring program are to:

- Document the variation in vegetation associated with the diverse land use history and habitat variation across the landscape.
- Provide a broad base of spatially explicit information that may be used by other researchers.
- Evaluate long-term vegetation development under contrasting management regimes, especially Woodlands subjected to timber and wildlife habitat management versus Wildland reserves.
- Review the effectiveness of silvicultural techniques in achieving specific forest characteristics
- Assess long-term trends in reserves as the forests recover from past land use and experience changes in the environment, especially climate change and shifts in wildlife species including moose, bear and beaver.

Approach

The Blue Hills Foundation project motivated the development of this Wildlands & Woodlands sampling protocol, and consequently BHF is committed to implementing this approach. Sampling will be stratified to capture major variation in forest type, environmental and edaphic factors, historical land use, and future land management. Although sampling may be extended to surrounding or outlying lands in the future, the central focus will be on BHF property. Field studies and subsequent analyses will be undertaken by graduate and undergraduate students, supervised by Harvard Forest and other institutions. An initial set of 71 stratified random plots were set up among or within broad vegetation categories proportional to the land area in each category (Fig. 4). Subsequent analyses of these plots (along with expert opinion) were used to inform the decision of where to establish reserves and managed areas.

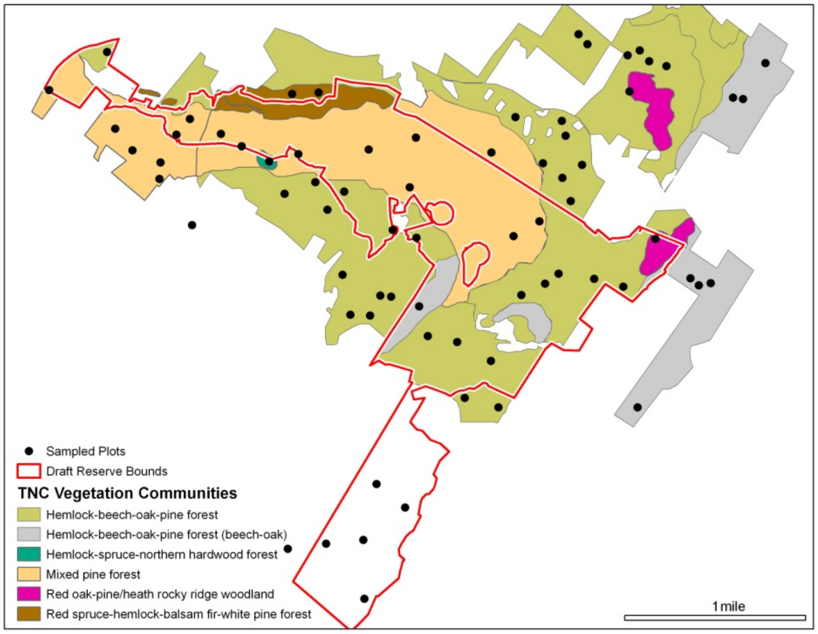


Figure 4. Study plots, forest types, and proposed reserve designation at the Blue Hills Foundation, southern New Hampshire

South Petersham Conservation Partnership Worcester County, MA

This project, initiated and conducted by Harvard Forest scientists, is a continuation of a long-term collaboration in central Massachusetts between Harvard University and two major conservation organizations: The Trustees of Reservations (TTOR) and Massachusetts Audubon Society (MAS).

As it enters its second century as Harvard University's field center for ecology and conservation, Harvard Forest has finalized a new long-term management plan for its 3,500-acre field laboratory and classroom. In identifying four major land use zones of increasing levels of human influence, the plan takes into consideration the history of research activities, the current array of long-term experiments, measurements, and prospective research and educational needs. The plan also seeks to buffer intensive research sites with protected land and to coordinate Harvard Forest management with that on adjoining lands owned by conservation organizations, the Town of Petersham, Commonwealth of Massachusetts, and private individuals who have protected their lands with conservation restrictions. Numerous characteristics of the landscape history and conservation setting lend themselves to this emphasis on coordinated research and conservation:

- Since its founding in 1907 Harvard Forest studies have operated from site to regional scales and have involved considerable research across ownerships in Petersham and north central Massachusetts.
- Nearly 71% of Petersham is protected from development by more than 13 groups, three State agencies, the town, and more than 21 private landowners.

- The Swift River Trust, formed by Harvard Forest, TTOR and MAS, was established in 1967 to coordinate objectives among these complementary groups in their management of Connors Pond, an impounded portion of the Swift River tributary to the Quabbin Reservoir.
- Protected land in Petersham and surrounding towns offer a diverse array of habitats for research in ecology, conservation, and forestry as well as providing land for nature and outdoor recreation.

Objectives

To capitalize on the educational and research opportunities in Petersham and the broader landscape and to provide feedback on its conservation management, Harvard Forest is expanding its considerable array of long-term measurements by establishing a monitoring system that incorporates reserves and managed landscapes. Major research objectives aim to:

- Document the long-term re-wilding of the landscape - i.e., the gradual decline and loss of legacies of past human activity and the concomitant increased expression of natural processes and condition.
- Measure changes associated with major environmental changes and ecological processes, especially invasive pests, pathogens and plants, expanding moose populations, and climate change and parallel changes in ecosystem characteristics such as nutrient cycling or carbon dynamics.
- Evaluate long-term changes in vegetation associated with forest management including the conversion of tree plantations to native stands and selective harvesting of maturing forests create a network of sites and information to be augmented by other population or ecosystem studies.

Approach

The protocol presented in this report complements the methods utilized in many Harvard Forest studies across New England (e.g., Foster et al. 1998; Motzkin et al. 2002; Bellemare et al. 2005). It will be applied in a stratified fashion to sample major variation in vegetation, land use history, soils, and future management across an extensive area in southern Petersham. The area is characterized by large blocks of protected land owned by Harvard Forest, TTOR, and MAS. All three groups have expressed common interest in having no or minimal management on connected portions of their lands and would like to allow natural processes to dominate, thus providing an opportunity to form a reserve exceeding 4,000 acres. The strengths of these three groups are complementary and may lend themselves to interesting local and regional opportunities. In addition, this area might be expanded through agreement with other abutters such as the Massachusetts Department of Conservation and Recreation on its Quabbin Watershed lands. Meanwhile, the sampling opportunities could extend beyond the reserve onto a wide array of managed state, town, and private lands that are nearby. The scientific studies and undergraduate educational activities pursued by the Harvard Forest could be nicely conveyed and augmented by the development of outreach programs across these lands by the larger conservation organizations and the state in ways that would be mutually beneficial and would advance the goals of the town of Petersham’s Master Plan.

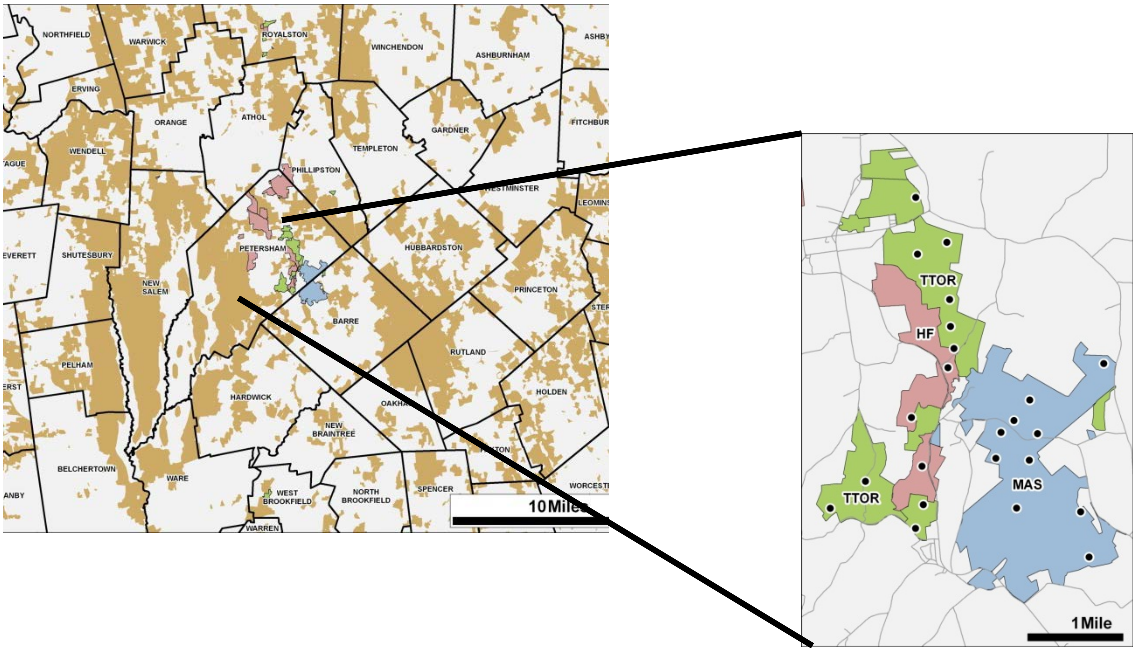


Figure 5. South Petersham Conservation Partnership- embedded in landscape of protected land with various owners. Potential plot locations among the three land ownerships.

Vermont Land Trust Caledonia County, VT

Since its founding in 1977, the Vermont Land Trust has permanently protected more than 500,000 acres of farmland and forestland from future development. In 2003 VLT worked with a family to protect more than 600 acres of forest that lie between two properties owned by the state of Vermont: Groton State Forest (GSF; 26,000+ acres) and Levi Pond Wildlife Management Area (LPWMA; 262 acres) in what is known as the Northeast Kingdom of the state. While much of GSF is actively managed for timber products, habitat, and recreation, Levi Pond is a pristine and completely undeveloped headwater pond fringed with a narrow band of conifers and wetlands and supporting on its banks one of the state's largest and most northern populations of Great Rhododendron (*Rhododendron maximum*), a state listed species that that has a range centered on the southern Appalachians. Due to the ecological importance of this area the state management plan for LPWMA indicates that the area has been

> "…set aside as a no-timber harvest area. With time these forests will develop into an example, albeit relatively small, of old-growth hardwood forests that will add to the unique experience of those who visit Levi Pond to fish its quiet waters and/or observe its large natural stand of great laurel (*Rhododendron maximum*).
>
> State of Vermont Levi Pond WMA Management Plan 2008

The state property covers just one-half of the watershed of the pond as well as the pond itself. Accordingly, the family that owns the other half of the watershed has decided to cooperate with the state and VLT and set its portion of the watershed aside from active timber harvesting. The Wildland reserve that emerges from this collaboration covers just 303 acres but provides a nice complement to adjoining private and state land that is open or accessible to harvesting.

Objectives

Over the past decade the Harvard Forest has undertaken a range of paleoecological studies across New England, and Levi Pond has served as one of the premier sites representing a long-term history of minimal disturbance by natural processes or humans. To complement this work and to take advantage of the designation of the watershed as a reserve, the Forest is working collaboratively with the state, VLT, and the private landowner to develop a system of permanent plots to monitor future changes in both the reserve and adjoining managed areas. The data collected will be used to contrast the dynamics of harvested and unharvested areas and evaluate the long-term development of the mixed northern hardwood-conifer forests after a century of moderate intensity harvesting. The data collected will address conservation and management questions for the state in addition to the broad ecological questions posed by the Harvard Forest.

Approach

Plots were randomly located and stratified in a manner similar to the plots in South Petersham area and at Blue Hills Foundation.

State of Massachusetts Reserves and Managed Forest System

While the W&W vision argued for the establishment of large reserves across nearly 50% of state lands, the Commonwealth has made meaningful strides in this direction by establishing a new system of large and small reserves that, in combination with its managed forests, will be monitored through an established long-term monitoring program. Approximately 10% of Massachusetts (500,000+ acres) is managed by the state Executive Office of Energy and Environmental Affairs (EEA) as state parks, forests, and wildlife management areas. As part of the Forest Stewardship Council (FSC) green certification process for its land, the State is required to set aside lands from active harvesting to provide unique habitat for native plant and animal species. Working with The Nature Conservancy and other scientists, state managers identified approximately 40,000 acres in eight large forest reserves (so-called “matrix forests”) to be managed predominantly for biodiversity protection and low-impact recreation such as hiking, camping, biking, hunting and fishing (see Table 1). Recently the State completed Landscape designations for DCR Parks and Forests. Through this designation, the State committed to setting aside approximately 111,227 total acres as Reserves to protect the least fragmented forested areas. The overall goal is to place approximately 60% of state-owned land in reserves and parklands that are managed for biodiversity and low-impact recreation and to support a range of animals, plants, and natural communities. EEA also seeks to work cooperatively with non-profit, municipal, and private landowners adjacent to these state lands to enhance the size of these reserves.

Objectives

The Commonwealth has committed to including reserves as an essential part of its long-term and comprehensive forest management plan. It has recommended management that allows ecological processes to determine the long-term structure, composition, function, and dynamics and has identified a number of objectives for its system of large and small areas:

- Serve as research and reference sites to track changes in forest conditions over time and make comparisons with conditions on non-reserve state lands or on private lands. Using Continuous Forest Inventory (CFI) data for state lands and USFS Forest Inventory and Analysis (FIA) data for private lands these trend comparisons will be conducted at a regional level and will involve comparing the suite of reserves to managed forests to assess changes in species, natural communities, and ecological processes.
- Help restore natural structural characteristics such as coarse woody debris, nurse logs, standing dead snags, thick soil organic layers, old trees, and unique assemblages of species in the forest understory.
- Provide peaceful outdoor settings and ensure continued enjoyment of a wide range of recreational activities, from hiking and cross-country skiing to hunting and fishing.

Approach

The state agencies have proposed a long-term ecological monitoring program for the large reserves based primarily on the existing CFI permanent measurement plots (de la Cretaz et al. 2007). Established on nearly all Massachusetts State Forests and Water Supply Protection Areas beginning in 1958, CFI plots were initially designed to assess the timber harvesting program (Rivers 1998). The sampling design for CFI uses 0.20-acre (810-m^2) permanently marked, circular plots located on a 0.5-mile (805-m) square grid to produce a sampling intensity of one plot per 160 acres (64 ha). Approximately 220 plots are distributed across the eight reserves and the sampling plan proposes to identify a similar or a larger number of plots on managed State Forest lands to be used for comparisons. Measurements in the CFI plots are made approximately every 10 years, depending on the allocation of funds by the legislature and availability of staff. In 2000, measurements were expanded beyond the previous timber-oriented variables, to include additional ecological data. Although details differ, these additional measurements make the CFI methods broadly comparable to those employed on the other sites discussed in the paper.

Early Results

Data from the 2000 CFI measurements of plots were used to establish a baseline for forest structural characteristics for the eight initially designated reserves (132 plots) located in Western Massachusetts compared to the managed state forests (561 plots) in that region. These two groups of forests were not expected to differ in this inventory, because data from 2000 were collected before any differences in management had occurred. However, structural differences would occur if the reserve selection criteria led to the establishment of reserves in areas with greater proportions of stands with older forest structure, as designed. Most structural variables of live and dead tree biomass, volume, and diameter were similar between reserves and state forests, but mean snag diameter and total CWD volume had significantly higher levels in the reserves than in the state forests.

Future Directions

The size and value of the new state reserves have been recognized by many scientists, and a number of additional long-term studies have been proposed for these areas. One activity that will be undertaken through a collaboration between The Nature Conservancy and the Harvard Forest will involve supplementing the existing CFI plots with a large number of 20x20 meter plots that will be sampled according to the protocols laid out previously in this paper. These plots will be located using a stratified random approach where vegetation characteristics, land use history, geology and soils, and physiography will be considered. Plots will be located both on the reserves and on adjoining or comparable areas that lie within forest zones slated for active management in the future.

Table 1. Largest designated state reserves in Massachusetts

Site Name	**Location**	**Approximate area (acres)**
Beartown State Forest	Monterey	10,214
Manuel F. Correllus State Forest	Martha’s Vineyard	5,158
Mohawk Trail/Monroe/Savoy State Forest	Charlemont/Monroe	11,593
Mount Greylock State Reservation	North Adams, Adams, Williamstown, Lanesborough, Cheshire, New Ashford	11,400
Mount Washington/Everett/Jug End	Egremont/Mt. Washington	6,912
Myles Standish State Forest	South Carver	9,044
October Mountain State Forest	Lee	3,967
Tolland State Forest	East Otis	4,076
Wendell State Forest	Wendell	4,191

Suburban Ecology Project Weston, MA – Eastern Massachusetts

The Suburban Ecology Project (SEP) is a joint partnership between the Environmental Studies Department at Brandeis University and Land’s Sake, a non-profit community farm and environmental education organization in Weston, MA. The SEP connects researchers, students, and community members and addresses research questions about the suburban Boston forest. Land’s Sake in Weston emerged as a strong community partner for research and forest management based on their farming, forestry, and stewardship activities in Weston. They have a rotational forest harvest plan that reflects the sustainably managed woodland philosophy of Wildlands and Woodlands.

The majority of the SEP's research is conducted on Weston conservation land. The town holds over 1,700 acres of land in fee, however, research is occurring on approximately 1,000 acres of this forested land (see map). This land had undergone a complete transformation since the peak of agriculture in 1850 when only 10% of Weston was forested. Each forested stand in Weston has a different cultural history, which has influenced the re-growth pattern of the forest.

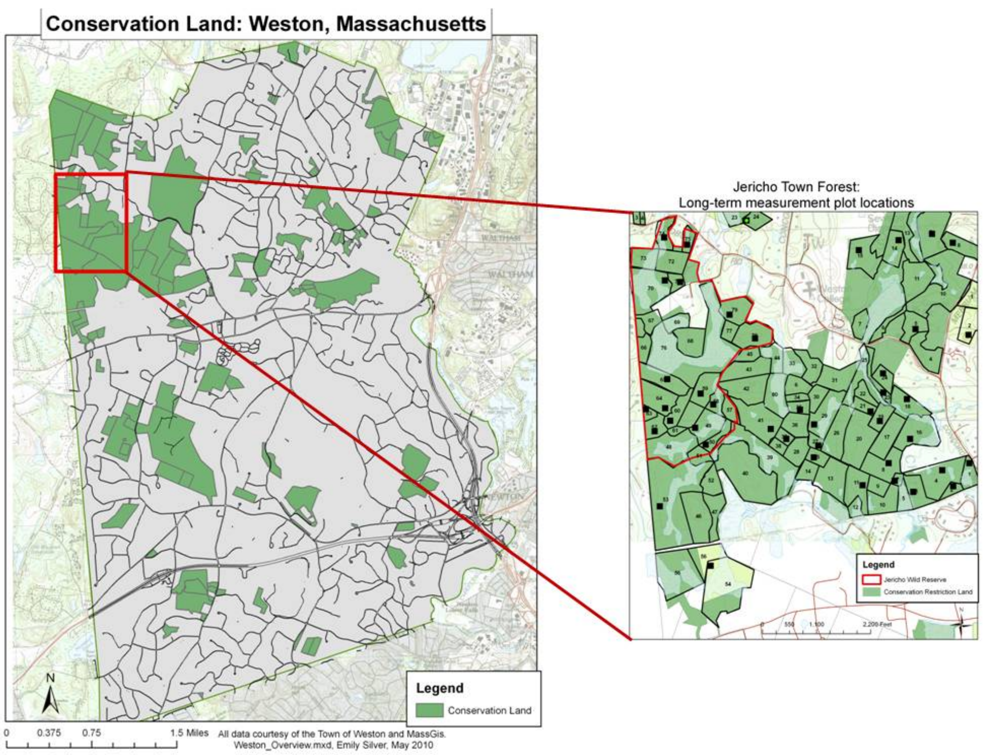


Figure 6. Weston Conservation land highlighting the wild reserve set aside by the town and subsequent long-term measurement plots.

Objectives

A Wildlands and Woodland forest sampling design was initiated by the Suburban Ecology Project in 2009. Weston emerged as the ideal community for this work due to the variety of ecosystems, accessible conservation land, and commitment to forest management. All of the study area is owned by the town of Weston and is managed in accordance with Land's Sake's forest management plan. In addition, one portion of the town forest has been set aside as a wild forest reserve. The sampling framework was designed to address some basic questions as well as establish plots that address specific forest studies for the town of Weston:

- Measure the changing dynamics of managed woodland based on Land Sake's forest harvest plan versus the dynamics in the town's designated wild forest reserve

- Evaluate the impact of a pesticide used to prevent Hemlock Wooly Adelgid infestation and subsequent health and survival rates of *Tsuga canadensis*
- Understand the increasing prevalence of *Fagus grandifolia* across the landscape.
- Compare the dispersion and recruitment success of *Acer platanoides* with *Acer saccharum*
- Map and provide spatial data to the broad community
- Connect data and land-use history for conservation land in Weston

Approach

The sampling design selected broadly follows the plot-based protocol suggested in this paper. Prior to utilizing stratified random sampling, SEP completed an inventory of Weston's forest resources. Plotless transects were run throughout the entire study area to determine species composition and basal area as well as general land form and vegetation type. Based on this inventory, each forest block was divided into stands based on historic land-use and forest ecosystem type. Concurrently, plots were installed that represent all identified forest stand types. Over 100 plots were established and permanently marked with PVC pipe in two corners. Depending on the questions the plot addresses, re-sampling will occur between every two and ten years.

The sampling effort is being supervised by Professor Brian Donahue of Brandeis University and managed by Emily Silver and staff member of the SEP. Interns from Brandeis have assisted with collection and will continue to participate in future re-sampling efforts. Additionally, students from Weston High School are adopting approximately ten plots which they will sample and re-sample in the future. Data management, analyses and publications are undertaken by the Suburban Ecology Project. Data will also be made accessible to the broader community on the Suburban Ecology Project webpage.

Conclusion

The *Wildlands and Woodlands* vision calls for the designation of large reserves in common forest types embedded within expansive forests that are actively managed for diverse values. Long-term studies of forest dynamics on adjoining Wildlands and Woodlands yield important information on a range of management practices. Moreover, such longitudinal studies yield invaluable insights into two critical ecological processes: the way in which heavily humanized landscapes "rewild" themselves and recover from a history of land clearance and harvesting, and the ways in which our natural landscapes are shaped over long periods of time by active management and a changing environment.

Although we have long recognized the importance of measuring ecological changes on actively managed and naturally-shaped landscapes, the ecological and conservation professions have few examples of such studies. Here we propose and illustrate a relatively simple approach for undertaking such measurements. Employed already by a diverse collection of organizations, institutions, state agencies, and private individuals, this approach can be applied, at relatively little cost, by anyone with the basic capacity for identifying the common trees, shrubs, and herbs in New England forests. Through a website where the resulting plot-based data can be entered, stored, and analyzed, we also provide an opportunity for sharing and permanently archiving the results from around the region, further reducing data management costs for participating landowners.

Though simple in concept and initial execution, meaningful measurement of long-term ecological changes requires a commitment of energy, care, and financial resources. Data are only as good as the quality of the sampling effort and are only useful if archived and documented carefully. Long-term changes can best be identified by re-measuring baseline data plots. This will require both initial care in securely identifying sampling locations and persistence in following up with subsequent sampling in an identical manner. Once established and documented, these long-term study sites can be relocated and resampled by others at whatever intervals or for whatever duration is required. Invaluable data sets that arise from both the initial effort and subsequent monitoring will inform conservation organizations, educational institutions, land managers, and the forestry community for decades to come.

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