National Park Service
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Natural Resource Stewardship and Science

Northeast Temperate Network Long-term Forest Monitoring Protocol

2017 Revision

Natural Resource Report NPS/NETN/NRR—2017/1563

ON THE COVER
Camilla Seirup and Mary Short sampling a forest plot in Acadia National Park
Photograph by: Kate Miller, NPS

Northeast Temperate Network
Long-term Forest Monitoring Protocol

2017 Revision

Natural Resource Report NPS/NETN/NRR—2017/1563

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Revision History

Version numbers will be incremented by a whole number (e.g., Version 1.30 to 2.00) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g., Version 1.06 to Version 1.07) when there are minor modifications that do not affect requirements or procedures included in the protocol. Add rows as needed for each change or set of changes tied to an updated version number.

Revision History Log

Version #	Date	Revised by	Changes	Justification
1.01	November 2007	Geri Tierney Brian Mitchell	Added to Existing Monitoring Programs; minor editorial changes; revised discussion of connected design to document decision to not use this design.	Changes were based on suggestion from external review.
1.02	May 2008	Brian Mitchell	Reorganized table of contents.	Changed order of SOPs, added new SOPs (LAR), added appendices (field notes and "on-the-road" procedures), and deleted the appendix for the slope conversion table.
1.03	December 2008	Kate Miller Geri Tierney	Minor editorial changes. Changed number of forest plots in Acadia NP to 176. Added Safety Precautions SOP.	–
1.04	April 2009	Kate Miller	Minor editorial changes.	Based on external review.
1.05	June 2009	Sarah Lupis Kozlowski	Editorial changes, formatting.	Conform to NPS standards.
1.06	December 2009	Kate Miller Andrew Vincello Brian Mitchell	Minor editorial changes Removed USFS Pest Alert Appendix and added online links to these documents to EquipPrep SOP.	–
1.07	October 2010	Kate Miller	Minor editorial changes	–
1.08	March 2013	Kate Miller	Altered target for detectable level of change to refer to 12 years instead of 10.	To match 4-year survey cycle.
1.09	December 2013	Kate Miller	Changed Type I error rate from 20% to 10% and revised power justification.	To match goals and results from power analysis conducted in 2013. Minor editorial changes

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Executive Summary

The Inventory and Monitoring (I&M) Program's Northeast Temperate Network (NETN) has identified forest vegetation, and several associated vital signs, as high priority for long-term monitoring. The NETN long-term forest monitoring protocol was adapted from methods developed by the U.S. Forest Service Forest Inventory and Analysis program and was developed in collaboration with other eastern forest I&M networks. The NETN forest monitoring protocol assesses the status and trends in structure, function, and composition of forested ecosystems, along with the impacts of stressors such as white-tailed deer, invasive exotic plants, exotic pests and pathogens, and effects of acid deposition on forest soils. A set of Standard Operating Procedures are shared with the Mid-Atlantic Network's forest vegetation monitoring protocol.

The current protocol has been designed to sample 350 plots in forested areas of NETN parks. Plot locations are randomly chosen using a spatially balanced design (generalized random-tessellation stratified). Each plot consists of a 20 x 20 m square (15 x 15 m square in Acadia National Park) where all trees with a diameter at breast height (dbh) ≥10 cm are identified, measured, tagged, marked, mapped, and their condition assessed. Trees with a dbh ≥1 cm are identified and measured in each of three microplots. Number of tree seedlings by height class and percent cover of shrubs ≥30 cm tall are also recorded in each of three microplots. Percent cover of all vascular plant species is estimated by species in eight 1 m^2 quadrats. Coarse woody debris is measured along three 15 m transects. Data collected by the NETN forest monitoring protocol are used to inform management decisions affecting forested systems in NETN parks.

Background and Introduction

This protocol has been developed for long-term monitoring of forest vegetation within the National Park Service (NPS) Northeast Temperate Network (NETN) as part of the Inventory and Monitoring Program (IM). The protocol includes methods for assessing and reporting the ecological integrity of forested ecosystems.

The 11 parks of NETN have been grouped together as a NPS Vital Sign network due to their common temperate forest systems. Northeast Temperate Network forests range from the central oak-hardwood forests of southern New England to the northern hardwoods and spruce-fir forests of northern New England, and include the pine woodlands of Acadia NP as well as the plantations and successional habitats found in several of the national historic parks. These forested systems are described in detail within the Conceptual Ecological Model Appendix of the NETN Vital Signs Monitoring Plan:

https://irma.nps.gov/App/Reference/DownloadDigitalFile?code=434103&file=NETN_MonitoringPlan_VitalSign.pdf

An extensive scoping process that included NPS staff from both the network and parks, academic researchers, and other stakeholders has identified key stressors to NETN systems. Within forested systems, key stressors include land use change and habitat fragmentation surrounding the parks (particularly fragmentation by roads), invasive exotic species, atmospheric deposition and ozone pollution, climate change, increased browsing pressure by white-tailed deer (*Odocoileus virginianus*), land management within the parks, and visitor impacts. Both the scoping process and these stressors are described within the NETN Vital Signs Monitoring Plan (Mitchell et al. 2006).

Justification

In May 2004, NETN convened a workshop of park staff and managers, academic and government scientists, and other stakeholders to identify key "Vital Signs" or indicators of ecological condition for long-term monitoring in NETN parks. The terrestrial breakout group at this workshop identified Forest Vegetation as one of 23 high-priority Vital Signs for NETN. The group recognized that forest vegetation is a primary component of most NETN parks, and that the structure, composition and condition of forest vegetation determines habitat for a wide variety of organisms. This workshop is summarized in an Appendix to the NETN Vital Signs Monitoring Plan (Mitchell et al. 2006).

Goals and Objectives

Our overall goal is to monitor status and trends in the structure, function and condition of NETN forested ecosystems in order to inform management decisions affecting those systems. To do so, NETN will interpret and report the ecological integrity of NETN forested systems from monitoring data. The "ecological integrity" of an ecosystem is a measure of the structure, composition, and function of an ecosystem as compared to pristine or benchmark ecosystems operating within the bounds of natural or historic disturbance regimes (Karr and Dudley 1981, Parrish et al. 2003). Ecological integrity can be assessed by comparing key elements or attributes of an ecosystem to a reference area or to historical measurements or modeling efforts. In this way, NETN hopes to provide

reliable data to inform management decisions relevant to NETN forested systems, including NPS land management and forest harvest plans, exotic species control, deer population management, NPS internal development, and national pollution control legislation.

Monitoring objectives for each component of the NETN forest protocol are listed in Table 1. This protocol primarily addresses the NETN Forest Vegetation Vital Sign. However, some measures also address related Vital Signs selected by NETN as high priority. These include Acidic Deposition & Stress, White-tailed Deer Herbivory, Exotic Plants—Early Detection, Exotic Animals—Early Detection, Landcover and Landuse. Relationships between NETN Vital Signs and specific components of this Forest Protocol are also shown in Table 1.

Table 1. Northeast Temperate Network Forest Protocol monitoring objectives.

Category	Metric	Monitoring Objectives	Vital Sign(s)
Landscape Structure Metrics	Forest patch size	Determine status and trend in forest patch size.	Forest Vegetation, Landcover, Landuse
	Anthropogenic landuse	Determine proportion of surrounding area in natural cover and in anthropogenic landuse.	Forest Vegetation, Landcover, Landuse
Stand Structure Metrics	Stand structural class	Determine status and trend in the distribution of structural classes across each park, and compare to that expected under natural disturbance regimes.	Forest Vegetation
	Snag abundance	Estimate status and trend in snag abundance and size class distribution.	Forest Vegetation
	Coarse woody debris (CWD)	Determine status and trend in coarse woody debris volume.	Forest Vegetation
	Canopy closure	Determine status and trend in canopy closure in mature stands. Examine correlation between canopy closure and climatic stress, storms, pest and pathogen outbreaks and other disturbances. To be developed.	Forest Vegetation
	Photopoint	Provide visual reference of plots for long-term comparison.	Forest Vegetation
Tree Metrics	Tree condition	Semi-quantitatively assess condition of trees by species.	Forest Vegetation, Exotic Animals-Early Detection
	Tree growth and mortality rates	Determine growth and mortality rates of canopy tree species. Examine correlation between these rates and air pollution, pest or pathogen outbreaks, climatic stress or other known stressors.	Forest Vegetation, Acidic Deposition & Stress, Ozone
	Tree regeneration	Determine status and trend in quantity and composition of tree seedling establishment in forest understory.	Forest Vegetation, White-tailed Deer Herbivory

Table 1 (continued). Northeast Temperate Network Forest Protocol monitoring objectives.

Category	Metric	Monitoring Objectives	Vital Sign(s)
Understory Metrics	Indicator species	Determine status and trend in exotic plant species cover. Determine change in cover or extent of species indicative of deer browse pressure and other stress.	Forest Vegetation, White-tailed Deer Herbivory, Acidic Deposition & Stress, Ozone
	Biotic homogenization	Determine status and trend in biotic homogenization.	Forest Vegetation
Soil Metrics	Forest floor condition	Qualitatively assess forest floor condition and estimate trends in spatial extent of earthworms and trampling impacts.	Forest Vegetation, Visitor Usage, Exotic Animals-Early Detection
	Soil chemistry	Determine status and trend in soil Ca:Al and C:N ratios to assess the extent of base cation depletion, increased aluminum availability and/or nitrogen saturation impacting NETN forest soils.	Forest Vegetation, Acidic Deposition & Stress

Existing Monitoring Programs

The U.S. Forest Service (USFS) Forest Inventory and Analysis Program (FIA) has been monitoring forest resources on a regional basis across the U.S. since the 1930s. Beginning in the 1990s, a Forest Health Monitoring (FHM) component was developed by the USFS and the Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program, and later incorporated into the FIA program. Forest Inventory and Analysis protocols have undergone extensive development by the USFS with academic and other government agency partners (USFS 2005, http://fia.fs.fed.us/library/field-guides-methods-proc/), and have been used to develop a substantial and ongoing database revealing regional trends in forest resource capacity and health across the region and the country (http://fia.fs.fed.us/tools-data/). For these reasons, NETN has chosen to use FIA protocols as a starting point for the NETN forest monitoring protocol; however, NETN has tailored FIA protocols to fit NETN parks and objectives, and to be cost-effective in this context.

At least two states in the region have undertaken monitoring programs for state-owned forests. In New York, permanent plots were established and monitored in forests on state lands during 2000 - 2002 (Manion et al. 2003). In Maine, a long-term monitoring program is being established in state ecological reserves, including those near Acadia NP (Cutko 2005). Both of these programs used modified versions of FIA protocols. The Vermont Monitoring Cooperative, a partnership between the University of Vermont, USFS, and the Vermont Agency of Natural Resources has been coordinating long-term natural resource monitoring efforts and research in federal and state lands since 1990.

Smaller-scale forest or silvicultural monitoring programs exist within two NETN parks. A forest monitoring program was established at Marsh-Billings-Rockefeller NHP (MABI) in 2001 (Keeton 2004). These plots were revisited in both 2002 and 2003 to establish initial conditions, and will likely be revisited on a multi-year interval in the future. Likewise, a forest health monitoring program was established at Saint-Gaudens NHS (SAGA) by USFS scientists in 1995 (Cook 1999). These plots

were reassessed in 1999 and 2003. In addition, a forest plantation inventory is planned for the Home of Franklin D. Roosevelt National Historic Site (HOFR), part of the Roosevelt-Vanderbilt National Historic Sites (ROVA). David Hayes, ROVA natural resource manager, plans to inventory a variety of stand, tree, and silvicultural properties of the historic plantations at HOFR.

Specific threats to forested systems are currently monitored in several NETN parks. Air quality data are collected at ACAD and are collected regionally throughout the northeast. White-tailed deer population size is monitored at two NETN parks—Morristown NHP (MORR) and Saratoga NHP (SARA)—where impacts of increased deer browsing pressure on forest composition and regeneration have been documented. Monitoring of some invasive exotic plant species and monitoring of visitor impacts are both ongoing at ACAD.

NETN's forest monitoring program will complement these ongoing programs by monitoring Vital Signs on a regular basis within a subset of these existing plots or by adding additional plots in under-represented areas. Ongoing monitoring efforts by individual parks can continue to provide more detailed information as desired. NETN has and should continue to collaborate with existing and new park-based forest monitoring programs on methods, sampling design and, in some cases, co-location of sampling points.

Sampling Design

Approach

The NETN Forest Protocol is designed to monitor forest ecosystem integrity in a standardized and cost-efficient manner across NETN parks. This protocol must allow statistical inference of status and trends within and across parks with sufficient statistical power. The use of permanent plots will increase power to detect trends over time by eliminating spatial variation. The protocol will also facilitate comparison of NETN data with other NPS networks and regional data such as that from the USFS FIA program.

This protocol is designed to assess stand structure; tree condition, regeneration, and growth and mortality rates; snag abundance; coarse woody debris volume; understory plant composition; forest floor condition; and soil chemistry—all at an extensive network of permanent plots within NETN forested parks. Data describing stand structure will allow comparison of the current distribution of stand structural classes in NETN forested stands with expected distributions under natural disturbance regimes**.** Tree condition will be semi-quantitatively assessed to provide information on tree health problems. Tree growth can serve as an early-warning indicator of decline in canopy trees of a particular species or region, which may be followed by elevated mortality rates. Tree regeneration data provide an early warning indicator of overstory composition change, and are indicative of browsing pressure. Monitoring understory plant species composition and abundance will help determine the impacts of multiple stressors upon native plant communities, and will provide information on the abundance of invasive exotic species. Snags and coarse woody debris are key structural features providing habitat for wildlife and fungi, and are impacted by park hazard tree removal and silvicultural policies. Forest floor condition will be monitored for trampling impacts, as well as for the presence of earthworms. Soil chemistry will be monitored to determine Ca:Al and C:N ratios which are indicative of atmospheric deposition stress and nitrogen saturation. Finally, photographs will document the appearance of plots to provide long-term visual reference. Additional detail justifying the selection of these measures is included in SOP 17 - Analyzing and Reporting Ecological Integrity.

Stand canopy closure (or its inverse—canopy openness) is suggested as a discrete quantitative measurement that is directly applicable to understory light regimes and could serve as a useful indicator of stand-level disturbance as human activity increasingly alters forest disturbance regimes and thus canopy structure. NETN is not yet ready to implement this metric, but will continue to explore its development.

In addition, digital orthophoto quarter quads (DOQQs) or the U.S. Geological Survey (USGS) National Land Cover Database (NLCD) will be used to monitor change in the landscape context of forest plots over time. Calculation of the forest patch size is a useful measure of the habitat available to fauna requiring interior forest patch habitat. Likewise, calculation of the proportion of forest cover, natural non-forest cover and anthropogenic landuse within the immediate area surrounding plots provide additional measures of fragmentation and anthropogenic stress. In the future, NETN may incorporate additional remote sensing measures into this protocol—using hyperspectral remote

sensing to assess canopy condition within the entire area of NETN parks. New hyperspectral sensors show promise for assessing the degree and spatial extent of stress experienced by canopy vegetation. Current research seeks to develop relationships between remotely sensed spectral signatures (e.g., red reflectance indices) and canopy vegetation stress for a variety of vegetation cover types (Sampson et al. 2000, Zarco-Tejada et al. 2002, Miles et al. 2003). NETN may incorporate this measure in the future, as reliable relationships for NETN vegetation cover types are developed, and the cost of newer hyperspectral imagery, such as Hyperion, becomes more affordable.

Sampling Frame

NETN plans to monitor forest resources within eight NETN parks (Table 2) which vary in size, forested ecosystem cover, and management. Acadia NP on the Maine coast is the only designated National Park in the northeastern U.S. The other seven parks are national historical parks (NHP) or smaller national historic sites (NHS), and are managed for historic and cultural values. Each of these historic parks also has forest resources. These parks are Morristown NHP (MORR) in northern New Jersey, Saratoga NHP (SARA) and Roosevelt-Vanderbilt NHS (ROVA) in eastern New York, Weir Farm NHS (WEFA) in western Connecticut, Minute Man NHP (MIMA) in eastern Massachusetts, Marsh-Billings-Rockefeller NHP (MABI) in central Vermont, and Saint-Gaudens NHS (SAGA) in central New Hampshire.

Table 2. Hectares of forested ecological systems within NETN parks.

Ecological System Group	Northeast Temperate Network Parks								TOTAL[1]
	ACAD	SARA	MORR	ROVA	MABI	MIMA	SAGA	WEFA	
Spruce-fir forest	7,952	–	–	–	–	–	–	–	7,952
Northern hardwoods forest	1,234	705	44	160	130	20	32	1	2,327
Central hardwoods forest	–	–	229	3	1	112	–	20	364
Pine forest	731	–	–	–	–	–	–	–	731
Conifer woodland	2,959	–	–	–	–	–	–	–	2,959
Plantation	–	4	–	14	63	-	11	–	92
Old-field successional	–	162	193	15	3	62	–	–	435
Total forested area (hectares)	12,876	871	465	345[1]	197	194	43	21	14,668

[1] Total reflects additional area from new acquisition that has not yet been mapped by ecosystem.

Several NETN parks are comprised of more than one unit. Acadia NP is comprised of two non-contiguous main units (Mt. Desert Island and the Schoodic Peninsula) and numerous islands, the largest of which is Isle au Haut. NETN's forest sampling frame will include both main units at ACAD and Isle au Haut, but will exclude the many smaller islands due to the logistical difficulty and

cost of accessing them by boat. Three park units comprise Roosevelt-Vanderbilt NHS: Home of Franklin D. Roosevelt NHS (HOFR), Eleanor Roosevelt NHS (ELRO), and Vanderbilt Mansion NHS (VAMA)—all of which will be sampled. Minute Man NHP and MORR each consist of two discontinuous but nearby units; at these parks both units will be sampled.

Three NETN parks will not participate in this forest monitoring. Saugus Iron Works NHS (SAIR) does not contain significant forested resources. Boston Harbor Islands National Recreation Area (BOHA) was not selected for forest monitoring because BOHA vegetation is largely exotic, and because the logistical difficulties in transport to the many islands that comprise BOHA preclude cost-efficient sampling. NETN also coordinates monitoring activities with the Appalachian NST (APPA), which has extensive forest resources. A monitoring plan for this complex resource is under development and will not be addressed herein.

Spatial Allocation

In order to achieve balanced spatial coverage across forested ecosystems within NETN parks, plots will be spatially allocated using generalized random tessellation stratified sampling (GRTS) (McDonald 2004). This design employs random plot selection, allowing for statistical inference while also providing balanced spatial coverage and flexibility for post-stratification of plots based on ecological system, association, or other criteria as needed over the long-term. Further, GRTS sampling allows for sample size to be adjusted as needed after sampling has begun without sacrificing spatial balance.

Sample size will vary by park in order to ensure a minimum sample size in the smallest NETN parks, while allocating sufficient resources to ACAD, NETN's largest park. Sample size allocation is shown in Table 3. In addition, NETN will intensify the sampling grid with 40 additional plots within rare woodland and forest communities found at ACAD. Ten plots will be established within each of these rare communities: 1) Pitch Pine/Broom Crowberry Woodland (globally rare), 2) Pitch Pine/Black Chokeberry/Wavy Hairgrass-Little Bluestem Woodland (state-ranked rare), 3) Jack Pine/Sheep Laurel - Blueberry species Woodland (state-ranked rare), and 4) Eastern White Pine - Red Pine/Canadian Bunchberry Forest (state-ranked rare).

Table 3. Forest sampling plot allocation in Northeast Temperate Network parks.

						ROVA				
Allocation	**ACAD**	**SARA**	**MORR**	**MABI**	**MIMA**	**ELRO/ HOFR**	**VAMA**	**SAGA**	**WEFA**	**TOTAL**
Plots	176	32	28	24	20	24	16	20	10	350
Sampling Intensity (ha forest/plot)	73	27	17	8	10	13	3	2	2	–

Temporal Allocation

Our allocation of sampling effort seeks to balance statistical power for trend detection with broad spatial coverage. NETN plans a rotating revisitation schedule for permanent plots (Table 4). All plots will be revisited at 4-year intervals, with annual sampling at ACAD (four sampling panels) and alternate year sampling at NETN's historical parks and sites (two sampling panels). Thus, 25% of the plots will be sampled annually at ACAD, while 50% of the plots will be sampled biennially at the other forested parks. Annual sampling at ACAD will ensure annual events (such as a drought or a pest outbreak) are not missed, while alternate-year sampling at the historical parks will optimize allocation of sampling effort by reducing travel costs compared to annual sampling. Plots will be assigned to panels in a spatially balanced fashion using GRTS.

Table 4. Northeast Temperate Network forest monitoring panel design.

	Year								
Panel	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	X	–	–	–	X	–	–	–	X
2	–	X	–	–	–	X	–	–	–
3	–	–	X	–	–	–	X	–	–
4	–	–	–	X	–	–	–	X	–

ACAD is sampled annually.

SARA, MIMA, MABI, and SAGA are sampled in panels 1 and 3.

MORR, ROVA, and WEFA sampled in panels 2 and 4.

NETN considered increasing the power to detect trends by employing a connected sampling design at ACAD during the early years of monitoring (Table 5). In such a design, each panel at ACAD would be subdivided into three subpanels of equal size. One subpanel would be resampled each year to provide connectivity between panels. This connectivity would allow increased power to detect trends using fixed or mixed effects linear models (Urquhart et al. 1998, McDonald 2003). However, this design would have incurred increased cost and would have exposed plots to additional sampling impacts from trampling by the field crew. The additional trampling could be particularly problematic in plots with delicate moss-dominated ground flora. In 2007, NETN decided not to use the connected design because a high proportion (approximately 20%) of plots established in 2006 still showed signs of trampling almost one year after establishment and initial measurement.

Pre-existing data were insufficient to allow for adequate power analysis to determine appropriate sample size for a protocol consisting of so many components. However, GRTS sampling will allow adjustment of sample size and allocation of plots among parks after data collection provides sufficient data for this purpose. Statistical power to ascertain status and detect trends will vary by measure, reflecting the specific objectives of each measure as well as the variability inherent within each measure. A general goal for statistical power would be to detect a trend of 40% effect size over 12 years (3 sampling cycles), controlling type I error at 0.10, and type II error at 20%. These error

rates are within the range typically used in ecological studies, and they are weighted such that the chance of falsely detecting a trend when it does not exist is approximately half the chance of failing to detect a trend when it does exist (Di Stefano 2003, Legg and Nagy 2006). In other words, we feel that falsely reporting a trend (and recommending unnecessary management action) is more of a problem than failing to report a trend that does exist (and potentially delaying management action).

Table 5. Alternate connected panel design for Acadia National Park, not selected for implementation.

	Year											
Panel[1]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1a	X	X	–	–	X	–	–	–	X	–	–	–
1b	X	–	–	–	X	X	–	–	X	–	–	–
1c	X	–	–	–	X		–	–	X	X	–	–
2a	–	X	X	–	–	X	–	–	–	X	–	–
2b	–	X	–	–	–	X	X	–	–	X	–	–
2c	–	X	–	–	–	X		–	–	X	X	–
3a	–	–	X	X	–	–	X	–	–	–	X	–
3b	–	–	X	–	–	–	X	X	–	–	X	–
3c	–	–	X	–	–	–	X	–	–	–	X	X
4a	–	–	–	X	X	–	–	X		–	–	X
4b	–	–	–	X	–	–	–	X	X	–	–	X
4c	X	–	–	X	–	–	–	X	–	–	–	X

[1] Each panel has three subpanels. One subpanel resampled each year provides connectivity

Methods

Forests are highly valued ecosystems for the many economic, ecological and recreational benefits they provide. For this reason, methods for sampling forest vegetation are numerous and well developed. Wherever practicable, NETN has chosen to adopt or adapt existing protocols into this Forest Protocol rather than "reinvent the wheel" by creating new protocols that duplicate existing efforts. Particularly since the addition of protocols for monitoring forest condition in the 1990s, the FIA program provides well researched and documented protocols for monitoring forest resources (see Existing Monitoring Programs on page 2). In addition, adoption of FIA conventions will allow NETN to compare conditions at the relatively small NETN parks to larger regional trends using FIA data. For these reasons, NETN has chosen to use FIA protocols as a starting point for the NETN Forest Monitoring Protocol; however, NETN has tailored FIA protocols to fit NETN parks and objectives and to be cost-effective in this context.

NETN has also collaborated with several other NPS Vital Signs Networks in the eastern U.S. to collaborate on standards and protocols where applicable.

The standard operating procedures (SOPs) which follow this narrative provide detailed, step-by-step instructions for data collection and analysis. These SOPs include instructions on preparation, site selection and establishment, and data management and analysis in addition to data collection. It is essential for successful long-term monitoring that established methods such as these be carefully followed.

Plot Layout

NETN will monitor an extensive network of permanent plots for a suite of site, stand, tree, understory, and soil measures (Figure 1). Tree and stand measurements will be made within fixed-area, square plots (15 x 15 m^2 at ACAD; 20 x 20 m^2 at NHPs). Tree regeneration will be measured within three, 2-m radius circular microplots embedded within each plot. Coarse woody debris will be assessed using line intersect sampling along three, 15-m transects originating at the plot center. Understory diversity will be monitored within eight, 1-m^2 quadrats, and soil samples will be obtained from a location adjacent to the plot.

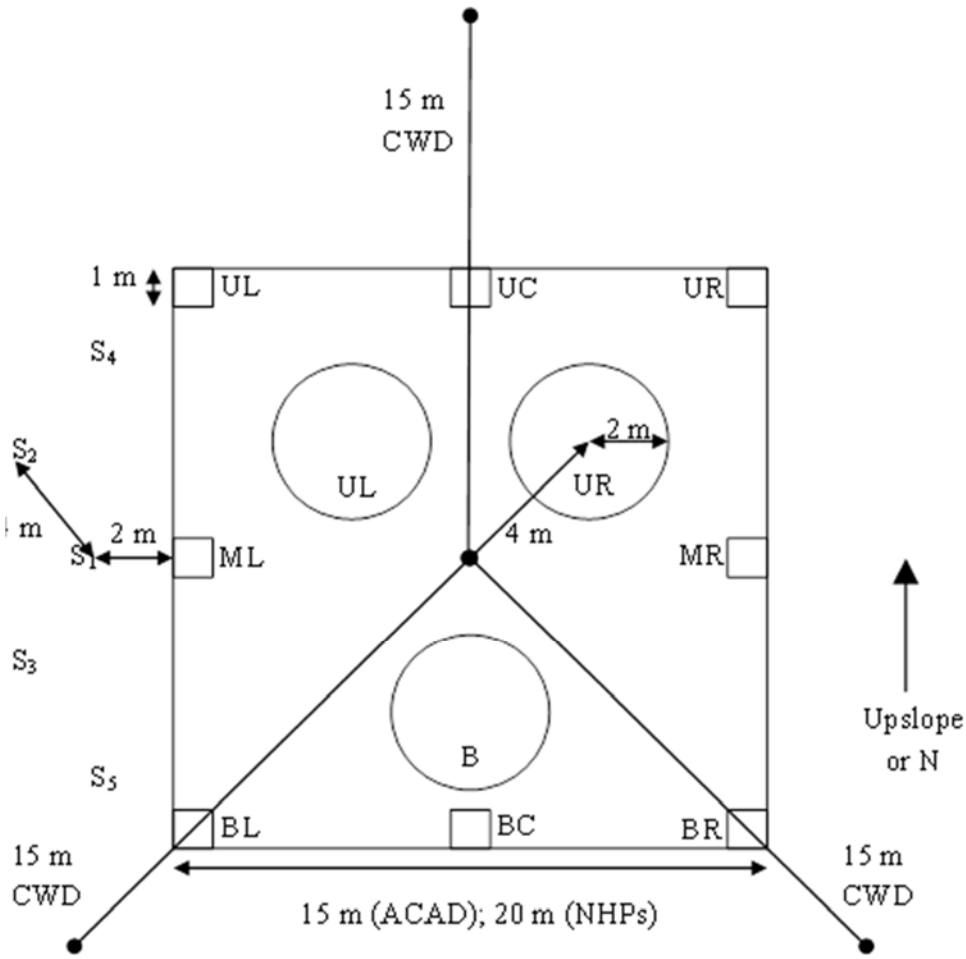

Figure 1. Northeast Temperate Network plot layout showing square tree plot with three nested 2-m radius regeneration microplots; eight,1-m2 vegetation quadrats; and three, 15-m coarse woody debris transects. Locations of the five soil samples are indicated with "Sx".

Forest Measurements

Within each plot, basic information describing the site (e.g., slope, aspect, and terrain position) will be collected to allow proper interpretation of other data collected. Photographs will be taken of the plot and understory to document change in appearance over time. Stand structure and disturbance will be qualitatively assessed from visual inspection. Each tree ≥10 cm diameter-at-breast-height (DBH) will be tagged and measured for status (live/dead), size (DBH) and condition. These data will yield information on tree growth, mortality and condition, and stand structure and composition. Tree seedlings will be quantified by species and size class within microplots in order to assess advance regeneration and the effects of deer browsing. Understory composition and abundance within 1-m^2 quadrats will be recorded to yield information describing species composition, including presence of exotic species. These data will also be examined for correlation between the frequency of specific indicator species and key stressors such as deer browsing. Coarse woody debris will be quantified along line intersect transects originating at plot center. Forest floor condition will be assessed by

visual inspection for microtopography,[1] trampling and evidence of earthworm presence. A composite soil sample will be collected adjacent to the plot and analyzed to provide information on the effects of atmospheric deposition and the ability of these soils to support forested ecosystems.

A three-person crew can install and measure a plot following this protocol in about 2.5 hours, in addition to travel time. A two-person crew can install and measure a plot following this protocol in about 3.5 hours, in addition to travel time.

Wherever possible, these protocols follow FIA conventions (USFS 2005) including definitions and size thresholds of items to be measured (e.g., trees and coarse woody debris). However, NETN protocols are adapted to specifically fit NETN objectives, and thus are not identical to FIA protocols. Significant departures are described here.

- NETN uses metric rather than English measuring units, for better compatibility with the scientific community.
- Both NETN and FIA employ fixed area plots; however, NETN will use single, square plots that differ in size, shape and arrangement from FIA, which uses a cluster of four, 7.3-m radius circular subplots. NETN's sampling frame is far smaller and more discrete than the FIA's, so clustered subplots were not needed. In addition, NETN will tag trees, making a square plot quicker and easier to setup and reassess than a circular plot.
- NETN will monitor all trees ≥10 cm DBH on these plots, rather than ≥12.7 cm (5 in) DBH as does FIA, to better calculate ecological stand structure indices (e.g., Peet et al. 1998, Tyrrell et al. 1998).
- NETN will use simpler rules for measuring DBH of forked trees than FIA, because FIA rules were found by NETN to be too difficult to use by crew members of average or shorter height.
- NETN will use a larger size cutoff for CWD (≥10 cm diameter) than FIA (≥7.5 cm). The FIA size cutoff corresponds to a 100-hour fuel burning threshold which is less relevant to ecological monitoring in the northeastern U.S. The 10 cm threshold is preferred because it is consistent with our size cutoff for trees, more straightforward to measure in-situ, and often used by ecological studies in the northeastern U.S. (Harmon and Sexton 1986, Pyle and Brown 1998).

Some components of FIA have not been adopted by NETN because they are not relevant to NETN objectives. NETN will not monitor lichen communities as an indicator of atmospheric deposition; rather, NETN will monitor atmospheric deposition directly within the Acidic Deposition & Stress Vital Sign, and indirectly as it impacts soil chemistry and forest ecological integrity. NETN will not

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[1] Microtopography indicates site history. Lack of microtopography indicates the site has been plowed prior to establishment of second-growth forest.

monitor fine woody debris. This is a time consuming protocol used as an indicator of fuel loading and fire occurrence, which is not an objective of NETN. Finally, the FIA methods that have been adapted into NETN protocols have been streamlined to fit NETN's monitoring objectives and schedule.

In addition, NETN will record some data not collected by FIA. Some measures of forest floor condition—microtopography and earthworm presence—are not monitored by FIA but will provide NETN with useful information on the integrity of this critical soil layer.

Landscape Context

NETN will calculate two landscape context metrics indicative of fragmentation and the influence of adjacent landuse and stressors on the ecological condition of the plot. These metrics are forest patch size, and neighborhood anthropogenic landuse. Change over time will be monitored using Digital Orthophoto Quarter-Quadrangles (DOQQs) or the USGS NLCD database. This landscape context analysis will be undertaken in conjunction with the Landuse and Landcover Vital Sign.

QA/QC

NETN will resample approximately 5% of sampled plots annually to determine reliability of data collection. Additional methods for quality control and quality assurance are specified within SOP 5 - Data Management & Quality Assurance/Quality Control.

Data Management and Analysis

Data will be stored in an MS Access database designed by the NETN data manager. When possible, data will be entered directly into the database as it is collected using a field computer. When the field computer is not used, data will be collected using NETN datasheets designed for accurate and complete data collection.

Data Analysis

Forest metrics will be calculated from raw data as shown in SOP 17 - Analyzing and Reporting Ecological Integrity.

NETN plans to estimate both status and trend over time of specific measures within forested systems in each sampled park, and also within specific ecological system groups in ACAD. Analyses will be based on a general linear model which partitions spatial and temporal variability to allow assessment of change over time, as is done by the FIA program (Woodall and Williams 2005). This model, as shown in Equation 1, is:

$$y_{ij} = b_0 + b_1 (t_j - t_0) + \eta_i + \varepsilon_{ij}$$

where:

y_{ij} = the value of a measure on plot i at time j
b_0 = the estimated mean value of all plots at year 0
b_1 = estimated change in y over time
t_j = time of measurement j
t_0 = time of initial measurement
η_i = spatial (between-plot) variability
ε_{ij} = temporal (within-plot) variability
and measurement error is assumed to be normally distributed with mean 0 and variance σ^2.

NETN also plans to collect and analyze covariate data (such as climate variables and air pollution concentration and deposition rates) in order to better account for the relationship between certain response variables (such as tree growth or mortality rate) and key ecosystem drivers and stressors. When a covariate is related to a response variable, incorporating the covariate into Equation 1 will allow more precise estimation of change and an estimate of the strength of the relationship as shown in Equation 2:

$$Y_{(i+n),j} = b_0 + b_1 (t_{(i+n),j} - t_{ij}) + b_2 (x_{(i+n),j} - x_{jj}) + b_3 (t_{(i+n),j} - t_{ij})(x_{(i+n),j} - x_{ij}) + \eta_{ij} + \varepsilon_{ij}$$

where:

n = the interval between measurements
$Y_{(i+n),j}$ = the value of Y at measurement $i+n$ for plot j
b_0 = the initial value of Y
b_1 = the change in Y over time

b_2 = the change in Y per change in unit x
b_3 = the interaction between change in x and Y
$t_{(i+n),j}$ = the time of measurement $i+n$ on plot j
t_{ij} = the time of measurement i on plot j
$x_{(i+n),j}$ = the value of a covariate at measurement $i+n$ on plot j
x_{ij} = the value of a covariate at measurement i on plot j
η_{ij} = spatial (between-plot) variability
ε_{ij} = temporal (within-plot) variability

This covariate model is also used by the FIA program (Woodall and Williams 2005).

Reporting

Assessing and reporting the ecological integrity of park resources is a major goal of both NETN and the larger I&M program. Ultimately, a vital sign is useful only if it provides information which guides management decisions or quantifies the success of past decisions. Ecological integrity must be assessed from data and presented in a format that can be clearly understood by managers, scientists, policy makers, and the public. Powerful communication tools will be needed to accomplish this goal—NETN will use an Ecological Integrity Scorecard as a primary communication tool.

Assessing Ecological Integrity

NETN will use the concept of "ecological integrity" to inform management decisions affecting park ecosystems. The "ecological integrity" of an ecosystem is a measure of the structure, composition, and function of an ecosystem as compared to pristine or benchmark ecosystems operating within the bounds of natural or historic disturbance regimes (Karr and Dudley 1981, Parrish et al. 2003). Assessment of ecological integrity is a challenging undertaking (NAS 2000). Useful attributes for assessment of ecological integrity change predictably in response to stressors, discriminate between anthropogenic and natural variability, and are easy to measure and interpret (Karr and Chu 1999). Determination of ecological integrity must consider the natural or historic range of variability inherent in natural systems (Landres et al. 1999), and variation in ecosystem attributes among successional stages. As global change alters background environmental conditions beyond historical levels, interpretation of ecological integrity in this fashion will be more challenging still.

In order to identify key aspects of forest composition, structure and function most relevant to the assessment of ecological integrity, NETN developed a conceptual ecological model for terrestrial systems within NETN parks. This model highlighted linkages between NETN terrestrial ecosystems, known stressors and agents of change acting within NETN parks, and key attributes and ecological processes of these systems. This model is presented within the Conceptual Ecological Model Appendix of the NETN Monitoring Plan, as noted above. This conceptual model identifies a suite of metrics with which we can assess the ecological integrity of NETN forests (Table 1). Justification for each metric is included within SOP 17 - Analyzing and Reporting Ecological Integrity.

To assess ecological integrity using these metrics, we have used data, models and expert opinion from the scientific literature to establish assessment points that distinguish expected or acceptable conditions from undesired ones that warrant concern, further evaluation, or management action (Bennetts et al. 2007). Assessment points for rating ecological integrity are based upon natural or historic variability. Estimates of historical or natural variation in ecosystem attributes provide a reference for gauging the effects of current anthropogenic stressors, while at the same time recognize the inherent natural variation in ecosystems across space, time, and stages of ecological succession (Landres 1999). Documentation of metric and rating development is presented within SOP 17 - Analyzing and Reporting Ecological Integrity. The interpretation of ecological integrity is a useful but developing conservation application, and ratings will be reviewed and updated as new information becomes available.

Scorecard

NETN will use a scorecard format to clearly and concisely report ecological integrity to a wide audience. A successful ecological scorecard should transparently convey status and trend in key ecological parameters in a way that is meaningful to the public, managers and other stake-holders (Harwell et al. 1999).

We have developed a scorecard reporting framework to visually convey status and trends in each metric of forest integrity using the NPS stoplight symbology. This symbology uses color to convey integrity rating—Good, Caution and Significant Concern are conveyed respectively as green, yellow or red circles—and uses an embedded arrow to convey the direction of trend observed across sampling intervals (increasing, stable or decreasing). For transparency, actual data values will be noted on the scorecard in addition to ratings. An example Forest Integrity Scorecard based on pilot data collected in 2005 is shown in Appendix D.

These data can be aggregated into higher levels of the NPS Ecological Monitoring Framework for reporting at the national level.

Reporting Schedule

Results of NETN Forest Monitoring will be reported in three types of reports (Table 6). An annual implementation report will report on the annual implementation and summarize data from each season. The Forest Integrity Scorecard, as described above, will complement these annual implementation reports. An annual Scorecard will be prepared for ACAD to match the annual sampling schedule at that park; a biennial Scorecard will be prepared for other NETN parks to match the biennial sampling schedules at those parks. Finally, NETN Forest Monitoring data will be synthesized and integrated with other Vital Sign and regional data every four or five years within Integration and Synthesis Reports prepared by NETN staff and relevant collaborators.

Table 6. Northeast Temperate Network forest protocol reporting schedule.

Report	Purpose	Audience	Frequency
Implementation Report	Summarize information from annual implementation of Forest Protocol	Parks, Network	Annual
Forest Integrity Scorecard	Report Forest Ecological Integrity	Parks, Network, Public	Annual for ACAD, Biennial for other parks
Integration and Synthesis Report	Report trends in forest vegetation. Integrate NETN forest data with other Vital Signs and regional data.	Parks, Network, Cooperators, External scientists	Every four or five years

Operational Requirements

Personnel Requirements and Training

This forest monitoring protocol can be staffed by any of several configurations of forest crew leader and crew, as outlined in SOP 2 - Preparation and Equipment List. The forest crew leader should have good northeastern plant identification skills and exposure to forest sampling methods. The crew should have good northeastern woody plant identification skills. A contract botanist(s), well trained in local flora at each park sampled, may also be needed to accompany the crew or provide support by identifying unknown plant specimens. The protocol will also require some GIS mapping in ArcGIS or ArcView, and support by NETN personnel including the data manager.

To secure field personnel, NETN may wish to advertise locally at northeastern universities, as well as nationally on environmental job websites such as the Society for Conservation Biology job database (http://www.conbio.org/jobs) or listserves such as the Ecological Society of America's ecolog listserve (ecolog-l@listserv.umd.edu). NETN may also find it useful to network with regional environmental professors and professionals to identify skilled seasonal staff.

NETN must ensure that all field personnel fully understand this protocol by conducting in-situ training sessions as described in SOP 2 - Preparation and Equipment List.

Facility and Equipment Needs

A list of necessary equipment is included in SOP 2 - Preparation and Equipment List. NETN does not currently have soil analysis capabilities, and will need to arrange for analysis at a regional soil chemistry lab as described in SOP 2 - Preparation and Equipment List and SOP 12 - Soil Measurements and Sampling.

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